Intelligent Interference Management for Dense Femtocellular Networks

By

Kazi Nawshad Azam

A thesis submitted in partial fulfillment of the requirements for the degree of M.Sc. Engineering in the Department of Electrical and Electronic Engineering

Department of Electrical and Electronic Engineering (EEE)
Khulna University of Engineering & Technology (KUET)
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Dedicated to my beloved mother, father, wife, and daughter.

Declaration

This is to certify that the thesis work entitled "*Intelligent Interference Management for Dense Femtocellular Networks*" has been carried out by ***Kazi Nawshad Azam*** in the Department of *Electrical and Electronic Engineering*, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

Signature of supervisor

Signature of candidate

Approval

This is to certify that the thesis work submitted by ***Kazi Nawshad Azam*** entitled "*Intelligent Interference Management for Dense Femtocellular Networks*" has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of *M.Sc. Engineering* in the Department of *Electrical and Electronic Engineering*, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh in June 2014.

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Abstract

Intelligent Interference Management for Dense Femtocellular Networks

To meet the future demand of high data rates in wireless communication with improved indoor coverage we need a promising new technology. In searching such a new technology, femtocellular technology is one of the promising alternatives, having a low power small cellular base station termed as the femto-access-point (FAP). This new technology has some unique features such as it provides good signal quality for the indoor users for supporting high data-rate communication with improved coverage, network capacity, and quality of service. The extreme goal of the femtocellular technology is highly dense femtocellular deployments, which will require significant degree of self-organization with some intelligent configuration to mitigate interference effects, random unwanted handover, and high level of outage probability. The conventional FAP transmits small power continuously but femto-user does not stay all the time at home or office. So, continuous transmission of this FAP power cause high interference effect when femtocells are deployed densely. To gain control over this continuous power transmission of femtocell this thesis proposes two operational power modes for FAPs which is a new idea of on-demand service connectivity (ODSC) in femtocell termed as low-power femto-idle-mode (FIM) and high-power femto-active-mode (FIM) system. When femto-users are trying to get service from FAP, then FAP automatically changes its mode from low power idle mode to high power active mode otherwise FAP remains in idle mode and transmits beacons only in regular intervals. In this intelligent way, FAP transmits low power in idle mode and give less interference effect. The dense deployment of femtocell with the proposed ODSC scheme can solve the low level of signal-to-noise plus interference ratio (SNIR) and throughput problems in the multistoried building or home environment. The SNIR level, throughput, probability of outage, and probability of activeness of a FAP are analyzed. The simulation results show that the proposed ODSC scheme in femtocell deployment significantly enhances performance of the SNIR level, throughput, probability of outage, and reduces the probability of activeness of a FAP having no user in the multistoried building or home environment.

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Nomenclature

3G	Third generation
3GPP	Third generation partnership project
AWGN	Additive white Gaussian noise
BS	Base station
CAC	Call admission control
CPICH	Carrier pilot channel
CTRL	Complementary TRi-control Loops
DL	Downlink
DSL	Digital subscriber line
FAM	Femto active mode
FAP	Femto-access point
FGW	Femto-gateway
FIM	Femto idle mode
FUE	Femto user equipment
HO	Handover
HSDPA	High speed DL packet access
HSPA+	High speed packet access plus
HSUPA	High speed UL packet access
LTE	Long term evolution
MBS	Macrocellular base station
MS	Mobile station
MUE	Macro user equipment
M_FUE	FUE handed over from MBS
N_FUE	FUE handed over from neighbor FAP
OAM	Operations, administration and maintenance
ODSC	On-demand service connectivity
OFDMA	Orthogonal frequency division multiple access
QoS	Quality of Service
RF	Radio frequency
RRM	Radio resource management
RSSI	Received signal strength indicator
SIR	Signal-to-interference ratio
SNIR	Signal-to-noise plus interference ratio
SON	Self-organizing network

UARFCN	UMTS absolute radio frequency number
UE	User equipment
UL	Uplink
UMTS	Universal mobile telecommunications system
UTRA	UMTS terrestrial radio access
UTRAN	Universal terrestrial radio access network
Wi-Fi	Wireless Fidelity
WiMAX	Wireless interoperability for microwave access
WLAN	Wireless local area network

Chapter 1

Introduction

In recent period femtocellular network system has widened the horizon of new research areas. Femtocell is a low cost, more reliable, less power utilizing network deployment planning for future cellular system with a small coverage area. The growth in wireless capacity is exemplified by this observation from Martin Cooper of Arraycomm: "The wireless capacity has doubled every 30 months over the last 104 years." This translates into an approximately million fold capacity increase since 1957. Breaking down these gains show a 25× improvement from wider spectrum, a 5× improvement by dividing the spectrum into smaller slices, a 5× improvement by designing better modulation schemes, and a whopping 1600× gain through reduced cell sizes and transmit distance. The enormous gains reaped from smaller cell sizes arise from efficient spatial reuse of spectrum or, alternatively, higher area spectral efficiency. The main problem in this continued microization of cellular networks is that the network infrastructure for doing so is expensive. A recent development is femtocells, also called femto-access points (FAPs), which are short-range low-cost low-power base stations (BSs) installed, by the consumer for better indoor voice and data reception. The user-installed device communicates with the cellular network over a broadband connection such as digital subscriber line (DSL), cable modem, or a separate radio frequency (RF) backhaul channel. While conventional approaches require dual-mode handsets to deliver both in-home and mobile services, an in-home femtocell deployment promises fixed mobile convergence with existing handsets. Compared to other techniques for increasing system capacity, such as distributed antenna systems and microcells, the key advantage of femtocells is that there is very little upfront cost to the service provider. Studies on wireless usage show that, more than 50 percent of all voice calls and more than 70 percent of data traffic originate indoors. Voice networks are engineered to tolerate low signal quality, since the required data rate for voice signals is very low, on the order of 10 kb/s or less. Data networks, on the other hand, require much higher signal quality in order to provide the multimegabit per second data rates. For indoor devices, particularly at the higher carrier frequencies likely to be deployed in many wireless broadband systems, attenuation losses will make high signal quality and hence high data rates very difficult to achieve. This raises the obvious question: why not encourage the end user to install a short-range low-power link in these locations? This is the essence of the win-win of the femtocell approach. The subscriber is happy with the higher data rates and reliability; the operator reduces the amount of traffic on their expensive macrocell network, and can focus its resources on truly mobile users. But all the femtocell deployment plan deal with the conventional or reference or single power mode or continuous service connectivity or existing or other or without proposed scheme or typical FAP power transmission rate and which is continuous power transmission. However all the time users are not stays in home or office. During outdoor period of user resource gets wastage due to continuous power transmission of FAP. To avoid this wastage of valuable radio resource on-demand power transmission by FAP is required and which is proposed through FAP on-demand service connectivity (ODSC) scheme having feature of dual power mode FAP service for user to reduce the interference effect in dense deployment of femtocell in overlaid macrocell network.

1.1 Problem statement

Femtocell has a low coverage area placed indoor to improve coverage in home environment in association with existing macrocell network. As femtocell existed in macrocell, there are some technical, regulatory, and business issues to be solved. In the macrocell network equipped with femtocell the technical issues are such as interference mitigation, frequency management between macrocell and femtocells, end-to-end quality of service (QoS) provisioning to the users, handover (HO) and mobility management. Proper frequency allocation, would allow largest utilization of the valuable radio spectrum and the highest level of user's quality of experience (QoE). Specifically, appropriate interference management, implemented with suitable frequency allocation, increases the system capacity, reduces the unwanted HOs and probability of outage, and increases the frequency utilization. Although the interference in a femtocellular network cannot be fully eliminated, it is possible to reduce the interference to within a reasonable range by proper management. Now to manage interference, we should consider the effect of continuous power transmission for both femtocell and macrocell of existing system. Femtocell transmits less power compared to macrocell. But this small power of femtocell may cause severe interference in the system. This is because of accumulation of femtocells typical continuous transmission of power, when femtocells have deployed densely in the overlaid macrocell. If we have control over femtocell continuous transmission of power, then the effect of interference would be negligible caused by the continuous transmission of power of femtocells. Proposed ODSC scheme is based on this important issue. In ODSC scheme, femto-user-equipment (FUE) gets service from FAP when FUE enerate demands for it but FAP response about serving that FUE is also depends on operational power modes of FAP. There are two operational power modes such as femto-idle-mode (FIM) which is the low power operational mode (self/network service providing mode) and femto-active-mode (FAM) which is the high operational power mode (user service providing mode) of FAP in ODSC scheme. The advantage of two operational modes of FAP is much than typical single power mode of FAP. While FIM state of FAP, FAP transmits less power and thus the effect of interference is less possible to occur. This is due to the fact that, in a day FAP is not required to give service all the time. Most of the time in a day, FAP remain in out of service. So, with proposed ODSC scheme more efficient dense deployment of femtocell is possible with less interference effect by keeping more FAPs in FIM. On the other hand, FAP can change its mode from FIM to FAM according to user request. FUE can request for service only at its active mode state. In the active mode of FUE, FUE is switched on and user attempting to make use of it. Besides this active state of FUE, there are two more states of FUE considered in the proposed ODSC scheme. These are idle state (FUE remains only switched on) and detached state (FUE remains switched off). The idle state of FUE does not send any service request to FAP. So FAP does not change its mode having idle FUE in its coverage area. Detached state of FUE also does not affect the mode of FAP. Only active state of FUE makes request of service to FAP and FAP changes its mode from FIM to FAM when FAP is initially in FIM or remains in FAM if FAP is initially in FAM.

1.1.1 Literature review

Before introducing proposed ODSC scheme for femtocell technology there are different existing literatures associating femtocell deployment successfully into existing macrocell infrastructure and among those literatures different strategies used in femtocells are given below:

In [1], a wireless interoperability for microwave access (WiMAX) network deploying both macrocellular base stations (MBSs) and FAPs, where it is assumed that FAPs have wired backhaul such as cable or DSL and operate on the same frequency band as MBSs. Here, significant areal capacity (throughput per unit area) gain can be achieved via intense spatial reuse of the wireless spectrum. In addition, FAPs improves indoor coverage, where the MBS signal may be weak, by the gains in capacity and coverage offered by femtocells.

In [2], various femtocellular network deployment scenarios, and a number of frequency allocation schemes to mitigate the interference and to increase the spectral efficiency of the macrocell and femtocell integrated network is proposed. These schemes include: shared frequency band, dedicated frequency band, sub-frequency band, static frequency-reuse, and dynamic frequency-reuse. An analytical model is derived to analyze in details the users probability of outage, and the performance of the proposed schemes is compared using numerical analysis.

In [3], the technical and business arguments for femtocells are overviewed. Also the technical challenges facing femtocell networks and give some preliminary ideas for how to overcome them is described.

In [4], new application of the femtocell technology is proposed. The femtocells are deployed in the vehicular environment. Short distance between the user and the FAP provides better signal quality. The inside FAPs are connected to the core network through the outside macrocellular networks or the satellite networks with one stronger transceiver is installed at outside the vehicle. This stronger transceiver is connected to FAPs using wired connection and to MBS or the satellite access networks through wireless link. Here, the capacity and the outage probability are analyzed and the proposed mobile femtocell deployment significantly enhances the service quality of mobile users in the vehicular environment.

In [5], an overview of WiMAX femtocell requirements, deployment models, and solutions in the near and long terms is presented.

In [6], different frequency deployment and access strategies for femtocells are explored, and their impact on the performance of both the femtocells and existing macrocellular networks is investigated. Options such as shared, partially shared, and separate carrier deployments with private and public access are discussed. For shared carrier operation, the impact on the coverage, probabilities of blocking, and capacity is investigated based on scenario data from real deployments using the Alcatel-Lucent Ocelot coverage engine, which includes sophisticated models for various wireless technologies including the Universal Mobile Telecommunications System (UMTS) and high speed downlink (DL) packet access (HSDPA). Here, for public access co-channel operation of femtocells and macrocells is feasible without causing coverage problems due to the increased interference is shown. For private access, co-channel operation results in dead zones and reduced coverage probability for proximate mobile terminals with no access to those femtocells. This problem can be resolved by using partially shared carriers with a "clean" macrocell carrier for affected mobile devices, or a separate carrier deployment.

In [7], the major issue of mobility management for the integrated femtocell/macrocell network is presented. A novel algorithm to create a neighbor cell list with a minimum, but appropriate, number of cells for handover is proposed. Also detailed handover procedures and a novel traffic model for the integrated femtocell/macrocell network are proposed. Here, the proposed call admission control (CAC) effectively handles various calls. The importance of the integrated femtocell/macrocell network and the performance improvement of the proposed schemes are shown and for dense femtocells this scheme will be very effective for those in research and industry to implement.

In [8], the performance of two-tier femtocell networks with co-channel femtocell deployment while considering cellular geometry and cross-tier interference in DL is investigated. Here, derivation of the per-tier probability of outage by introducing a simplified mathematical model that provides closely approximate femtocell interference distribution is provided. Based on the probability of outage analysis, also derivation of the transmission capacity that represents the total capacity of the co-channel two-tier networks with outage constraints is given. An accurate characterization of the outage probability and the transmission capacity, accounting for the density of randomly scattered femtocells and femtocell transmission power is also shown.

To quantify near-far effects with universal frequency reuse, [9] derived a fundamental relation providing the largest feasible cellular signal-to-noise plus interference ratio (SNIR), given any set of feasible femtocell SNIRs. Here, provided a link budget analysis which enables simple and accurate performance insights in a two-tier network. A distributed utility based SNIR adaptation at femtocells is proposed in order to alleviate cross-tier interference at the macrocell from co-channel femtocells. The Foschini-Miljanic (FM) algorithm is a special case of the adaptation. Each femtocell maximizes their individual utility consisting of a SNIR based reward less an incurred cost (interference to the macrocell).

In [10], two interference mitigation strategies that adjust the maximum transmit power of femtocell users to suppress the cross-tier interference at a MBS are proposed. The open-loop and the closed-loop control suppress the cross-tier interference less than a fixed threshold and an adaptive threshold based on the noise and interference level at the MBS, respectively. Both schemes effectively compensate the uplink (UL) throughput degradation of the MBS due to the cross-tier interference and that the closed-loop control provides better femtocell throughput than the open-loop control at a minimal cost of macrocell throughput.

In [11], descriptions of the requirements and architecture for the self organizing network (SON) functions within the operations, administration and maintenance (OAM) system are given. SON includes provision of infrastructure for SON, in the OAM system are enabling SON operations, providing SON capabilities (each of which can either be distributed or centralized) within the OAM infrastructure, including their management, accessing to SON relevant attributes, identifying of SON relevant measurements, accessing to and transferring of SON relevant measurements, and transferring of SON relevant alarms.

In [12], a self-optimized coverage coordination scheme for two-tier femtocell networks, in which a femtocell BS adjusts the transmit power based on the statistics of the signal and the measured interference power at a femtocell DL is proposed. Furthermore, an analytic expression is derived for the coverage probability of leakage that a femtocell coverage area leaks into an outdoor macrocell, by which the proposed scheme provides sufficient indoor femtocell coverage and that the femtocell coverage does not leak into an outdoor macrocell.

In [13], interference management techniques for both DL and UL of femtocells operating based on third generation partnership project (3GPP) release 7 standards which are also known as high speed packet access plus (HSPA+). Femtocell carrier selection and femtocell DL transmit power self-calibration are proposed as key interference management methods for DL. For UL interference management, adaptive attenuation at the femtocell and limiting the transmit power of the femtocell users are proposed. Different interference models and their analysis are presented. Here, coverage performance and capacity results are presented to quantify the benefits of femtocells. In addition to coverage enhancements, significant capacity improvements are achieved on both DL and UL when femtocells are deployed in third generation (3G) UMTS/HSPA+ networks is demonstrated.

In [14], deployable various possible femtocell network scenarios are presented. Here, the dynamic frequency re-use scheme to mitigate interference for femtocell deployment is proposed. For highly dense femtocells, the functionalities of SON based femtocell network architecture are also proposed. The probability of outage of a femtocell user is analyzed in details.

In [15], a power control method for pilot and data channels in UMTS networks that ensures a constant coverage femtocell radius is introduced. Each femtocell sets its power to a value that on average is equal to the power received from the closest macrocell at a target femtocell radius.

In [16], the approach towards the RF related issues are described.

In [17], performance of frequency allocation schemes in forthcoming orthogonal frequency division multiple access (OFDMA)-based systems is studied. These systems include WiMAX and 3G long term evolution (LTE). Here, the capacity of the system using a Markov model is calculated and taking into account the inter-cell interference and its impact on the adaptive modulation. By applying the Markov model four frequency allocation schemes, namely reuse 1, reuse 3, and static and dynamic mixes of reuse 1 and 3 are compared. Also a fifth scheme, called partial isolation and proposed for 3G LTE systems, that uses different transmission powers in the different frequency bands, in order to reduce interference at cell edge is presented. The partial isolation scheme outperforms all the others, especially in the DL, as it combines the advantage of the reuse 1 scheme (large overall throughput) with that of the mix of reuses 1 and 3 (good cell-edge performance).

In [18], a dynamic fractional frequency reused cell architecture that simplifies the problem of subcarrier allocation with frequency reuse in multi-cell OFDMA networks is proposed. The architecture divides the cell surface into two overlapping geographical regions and orthogonally allocates subcarriers, which are called super and regular group of subcarriers, to the regions. The proposed architecture allows a frequency reuse factor of 1 with reduced inter-cell interference and increased trunking gain, while satisfying minimum data rate requirements. Also an efficient hierarchical solution is given to realize the proposed architecture. The solution first allocates subcarriers to the groups so that long term performance is maximized and next opportunistically schedules subcarriers to the users. The opportunistic scheduling is performed at the BSs considering the fairness requirements of the users.

In [19], OFDMA interference related issues in femtocell are presented.

In [20], a method for coverage adaptation for UMTS networks that uses information on mobility events of passing and indoor users is presented. Each femtocell sets is power to a value that on average minimizes the total number of attempts of passing users to connect to such femtocell.

In [21], interference management related issues in UMTS femtocell are presented.

In [22], an interference avoidance scheme is proposed for LTE DL that uses dynamic inter-cell coordination facilitated through X2 interface among neighboring evolved universal terrestrial radio access network (UTRAN) Node Bs (LTE BSs). Proposed scheme is evaluated by extensive simulations and compared with a number of reference schemes available in the literature. It has been observed that the proposed scheme attains superior performance in terms of cell-edge and sector throughput compared to those in the reference schemes.

In [23], to mitigate UL interference, a distributed and self-organizing femtocell management architecture is proposed, called the Complementary TRi-control Loops (CTRL), that consists of three control loops to determine (1) maximum transmit power of femtocell users based on the feedback macrocell load margin for protection of the macrocell UL communications; (2) target SNIRs of femtocell users to reach a Nash equilibrium; and (3) instantaneous transmit power of femtocell users to achieve the target SNIRs against bursty interference from other nearby users. CTRL requires neither special hardware nor change to the radio resource management (RRM) of existing macrocells, thus facilitating non-disruptive (hence seamless) penetration of femtocells. Also, CTRL guarantees convergence in the presence of environmental changes and delayed feedback. Here, evaluation is shown CTRL to successfully preserve the macrocell users' service quality under highly dynamic user transmission conditions and be able to make a tradeoff between macrocell and femtocell capacities.

Cellular system operators are identified the critical need for standardization of femtocell devices and their associated interfaces into the operators' core networks as a critical requirement for the success of femtocell products. Driven by this demand, the UMTS/UTRAN standards community is undertaken a large-scale and comprehensive effort to specify such standards for femtocell devices and systems that are based on the UMTS/HSDPA/ high speed UL packet access (HSUPA) family of radio access technologies. In [24], those standardization activities are described and an overview for the femtocell system architecture is provided that has been developed within 3GPP.

In [25], a novel dynamic interference avoidance scheme is presented that makes use of inter-cell coordination in order to prevent excessive inter-cell interference, especially for cell or sector edge users that are most affected by inter-cell interference, with minimal or no impact on the network throughput. The proposed scheme is comprised of a two-level algorithm - one at the BS level and the other at a central controller to which a group of neighboring BSs are connected. Here, the proposed scheme outperforms the reference schemes, in which either coordination is not employed (reuse of 1) or employed in a static manner (reuse of 3 and fractional frequency reuse), in terms of cell edge throughput with a minimal impact on the network throughput and with some increase in complexity.

In [26], a unified foundation for understanding and building any wireless network such as a true systems approach to wireless networking; air interference design and network operation; planning, mobility management, radio resources, power management, and security; and 3G, WLANs, Bluetooth, wireless geo-location, and more are presented.

The above strategies illustrating about interference management, frequency planning, cell edge performance improvement, probability of outage reduction, handover management, power control schemes are not able to eliminate femtocell related problem alone. As a new technology, FAP continuous service scheme transmit high power all the time cause femtocell deployment costly for end users. For this reason more interference effect exists in the femtocell network. The ultimate goal of femtocell deployment is to install femtocell densely with low interference effect. To support the huge amount of wireless user demand of wireless network facilities ODSC scheme is required with proper frequency planning, because radio spectrum is limited and costly so more existing radio resource utilization is cost effective.

1.2 Research objectives

In the present research work the main goal is to propose an intelligent approach for optimizing the performance of existing femtocellular communication system including the enhancement of network capacity, mitigation of interference in the presence of ODSC scheme with FIM and FAM. This thesis paper addresses following research issues:

1.2.1 On-demand issues in femtocellular networks

A standalone femtocell or group of small networks of femtocells may be deployed in existing macrocell network. FAP transmit continuous power all the time in the continuous service connectivity scheme. For this reason more interference effect exists in the femtocell network. The ultimate goal of femtocell deployment is to install femtocell densely with low interference effect. To support the huge amount of wireless user demand of wireless network facilities ODSC scheme of FAP should be preferred, because radio spectrum is limited and costly so more existing radio resource utilization means more system efficiency with low wastage of resource. ODSC is a FAP service technique to femto-users when any particular user is demanding to get served by requested particular FAP.

1.2.2 Intelligently interference mitigation and unwanted HO reduction in femtocellular networks

More interference is likely possible to occur in the existing wireless network due to increased demand of wireless user group, which in turns causes the problem of frequent unwanted HO. These two problems can be reduced intelligently by applying ODSC scheme where femtocell serves its users when demand is created for it. In this ODSC scheme before demand creation FAP stays in low-power FIM and searching for any active femto-user which may request to get served by the FAP. Since low power state of the FAP causes less possibility of interference occurrence, hence proposed ODSC scheme is more efficient for dense femtocell network deployment. Besides this, when demand is created for any FAP by active femto-user, FAP changes its mode from idle to active with more power transmission state to serve that service requesting femto-user. The mode transition of FAP in ODSC scheme depends on users demand and automatic which causes less interference intelligently.

1.2.3 Probability of outage reduction of the femtocell users

QoS degradation of end users originates more when outage occurs. When more interference in the wireless network more outage problem is there for the users of that network. Besides this, frequent unwanted HOs also increase the probability of outage for the users. By applying proposed ODSC scheme probability of outage can be reduced along with interference and unwanted HOs problems.

1.3 Thesis outline

The rest of this thesis paper is organized as follows. Chapter 2 shows the femtocell overview, advantages of femtocell, technical challenges of femtocell, and types of femtocell deployment with macrocell. Interference in femtocell, different scenarios of interference in femtocell, sources of interference, effect of interference in femtocell, different interference mitigation techniques, and interference effect of dense femtocell deployment are discussed in chapter 3. Chapter 4 provides proposed ODSC scheme with pictorial and tabular points of view, basic architecture, and working process of proposed ODSC scheme. Also comparison between ODSC scheme and existing (continuous FAP service) scheme is given in this chapter. Mathematical analysis such as SNIR and capacity analysis for the proposed ODSC scheme is shown in Chapter 5. Besides this probability of outage and probability of activeness of FAP of ODSC scheme are also given here. Chapter 6 provides the SNIR level performance, throughput performance, probability of outage observation and probability of FAP activeness observation through simulation results. Finally, discussion and recommendations; future work are drawn in the concluding Chapter 7.

Chapter 2

Femtocell Overview

Femtocell is a low cost, more reliable, less power utilizing network deployment planning for future cellular system with a small coverage area. The wireless engineering community has been searching for low-cost indoor coverage solutions since the beginning of mobile networks. Femtocellular network technology is one of such solutions. The FAPs enhance the service quality for the indoor mobile users. Fig. 2.1 shows the simple femtocell network integration with macrocell by establishing communication between femto-gateway (FGW) of femtocellular network and core network (CN) of macrocellular network. In the following figure we can see the femtocell network side comprised of FUEs, FAPs, connection medium, such as DSL and internet service provider (ISP), of FAPs to the femto-gateway (FGW) to establish integration with existing macrocell network system. FUEs are getting served through respective FAPs. Here, one FAP is connected with FGW by cable TV/DSL and the other one is connected to FGW through internet/ISP. Again in the macrocell network side of Fig. 2.1, it can be seen that it consists of macro-user-equipments (MUEs), MBSs, radio network controller (RNC), and CN. MUEs are getting their service from respective MBSs through communication between RNC and CN. This CN of existing macrocell network has

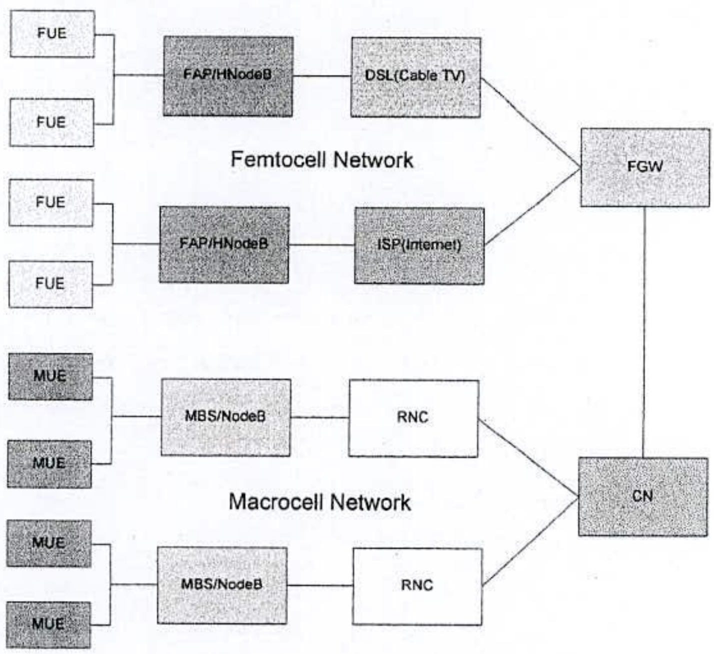


Fig. 2.1. Example of femtocellular network integration with macrocellular network (simplified).

established further communication link with FGW. Thus, in a simple way, the two different wireless network system can co-exists and maintains seamless HOs for their respective users.

2.1 Advantages of femtocell

Femtocells operate in the spectrum which is licensed for cellular service providers thus, it can provide high performance. Here, the key feature of the femtocell technology is that, user do not require any new FUE. Femtocellular technology does not use any dual mode terminal, but wireless local area network (WLAN) uses dual mode terminal. One of the key advantages of the femtocellular technology is that, it uses the similar frequency band which is used by the macrocellular networks. However, the use of the same frequency spectrum can also cause interference if no necessary interference management scheme is introduced into the network design, infrastructure, and the future extension plan. Some advantages of femtocell network deployed in association with macrocell are as follows:

- **Improve coverage:** In home located far from macrocell or in a multistoried building, MBS network causes the connectivity problem to wireless cellular users. To avoid network related problem femtocell deployment in remote or high locations under any macrocell is a promising solution.
- **Enhanced QoS:** Femtocell may be deployed in association with macrocell to enhance quality of service. In the remote place where macrocell cannot support any home users, femtocell through other operator can serve that particular user in home environment.
- **Less battery drain:** In home environment femtocell provides improved signal quality to its users which cause less battery drain for user equipments. If batter draining rate is low more the user equipment will remain alive.
- **Licensed spectrum:** Femtocell can use the same licensed spectrum used by macrocell. This sharing makes femtocell more viable and cost effective for dense deployment of femtocellular network.
- **Reduced cellular network congestion:** Femtocell network deployment in association with macrocell can offload some of the macrocell users. By doing this, femtocell reduces the cellular network congestion.
- **Plug and play:** Femtocell can be used as plug and play as we can use our user equipments. In other words users of femtocell do not require any kinds of training to use and install the femtocell.
- **Simple to deploy:** Femtocell network deployment is simple as like any other home appliances. Femtocell deployment is not planned because of the deployment is controlled by the users.

- **Lower cost:** A group of small networks of femtocell may be deployed in association with macrocell. For small coverage, does not require any special user device, and uses shared spectrum with macrocell, cost for femtocell is small compared to macrocell.
- **No need of dual-mode terminal:** Wi-Fi system requires dual mode terminal. So, compared to Wi-Fi system femtocell does not require any dual-mode terminal.

2.2 Technical challenges of femtocell

There is no such technology which does not face any problem at first deployment. Femtocell technology is not out of this fact. As a new technology femtocell needs to solve the following technical challenges:

- **Network architecture:** A proper standard for femtocell network architecture need to be defined. Recognizing all these benefits mentioned earlier about femtocell, different operators, vendors, and content providers founded the Femto Forum, which is a membership organization to promote femtocell deployments worldwide. Also, recently some cellular operators have launched commercial femtocell products or have been conducting trials with femtocells. In addition to their benefits, femtocells also introduce a set of basic challenges due to the following factors:
    - i. **User installation:** Femtocells are installed by subscribers without special training or knowledge regarding antenna placement and system configuration. Because of this, the femtocell should be capable of self-configuration.
    - ii. **Unplanned deployment:** Unlike a macro network, femtocells are deployed without network planning; no special consideration is given to traffic demand or interference to/from other cells.
    - iii. **Restricted association (or restricted access):** To protect the use of limited resources (femtocell capacity, DSL/modem connection), femtocells may be configured to limit access to only a few authorized subscribers (e.g., family members or hotel guests).
    - iv. **Legacy system support:** Currently available handsets are femto-unaware; femtocells need to support these handsets as well as femto-aware handsets. Moreover, they need to interface with existing access and CNs.
- **End-to-end QoS provisioning:** As femtocell coverage area is low so each femtocell can support very small users. Again femtocell deployment is user controlled so unplanned femtocell deployment causes interference problem in the system. Besides this, end-to-end QoS, need to be provided, for femtocell users.
- **Management of neighbor cell list:** To give priority of neighbor femtocell to place in

neighbor femtocell list, management of neighbor femtocell list is required. This neighbor femtocell list is essential for seamless and controlled HO process.

- **HO management:** Frequent unwanted HO control is another problem in femtocell deployment yet to be solved. More HO causes high probability of outage and less QoE for the users.
- **Interference management:** To give satisfactory network services to femtocell users interference in the system should be low as much as possible. For this reason, interference management is required in femtocell network deployment.
- **Spectrum management:** Spectrum is a valuable resource in wireless system. So, management of radio spectrum in femtocell network deployment is required. It can help dense femtocellular network deployment in a more cost-effective way.
- **Call admission control:** Femtocell network deployment in association with MBS demands controlling over admission of calls between these two networks. This is beneficial for lowering the congestions in both wireless cellular networks.

2.3 Type of femtocell deployment with macrocell

To protect the use of limited resources (femtocell capacity, DSL/modem connection), femtocells may be configured to limit access to only a few authorized subscribers (e.g., family members or hotel guests). Fig. 2.2 shows the different type of femtocell deployment in a simple way. Four different femtocell deployment ways such as standalone femtocell, multi-femtocell, single network of femtocell, and dense network of femtocell are shown in Fig. 2.2 and discussion about these four types of femtocell deployments integrated with macrocell are also presented below:

- **Standalone femtocell deployment:** This type of femtocell is single cell remotely placed outside (FAP# 29) or inside (FAP# 25) macrocell as shown in Fig. 2.2. Stand alone femtocell may not very responsible for high interference effect in the system due to their deployment density is low in a particular area. This type of femtocell deployment is less cost-effective to be deployed.
- **Multi-femtocell deployment:** More than one but less than five standalone femtocells may be called multi-femtocell deployment as presented in Fig. 2.2. Multi-femtocell may be placed near to each other (FAP# 26, FAP# 27, and FAP# 28) and among them possibility of high interference occurrence is more than single stand alone femtocell.
- **Single network of femtocell deployment:** A bunch of six to ten femtocells close enough as shown in Fig. 2.2, to each other to form a network may be integrated with

MBS to support its users. This type of femtocell deployment is responsible for moderate interference effect in the system because each femtocell in the network have more than one neighbor femtocells in a close area and they (FAP# 17 to FAP# 24) are installed in a unplanned way by the femto- users.

- **Dense network of femtocell deployment:** A group of small networks of femtocell as given Fig. 2.2 may be deployed in association with MBS. Dense deployment of femtocell (FAP# 1 to FAP# 16) is more challenging because a lot of consideration about resource allocation, network planning, capital cost, interference effect, unwanted HOs, probability of outage, and regulatory policy are needed.

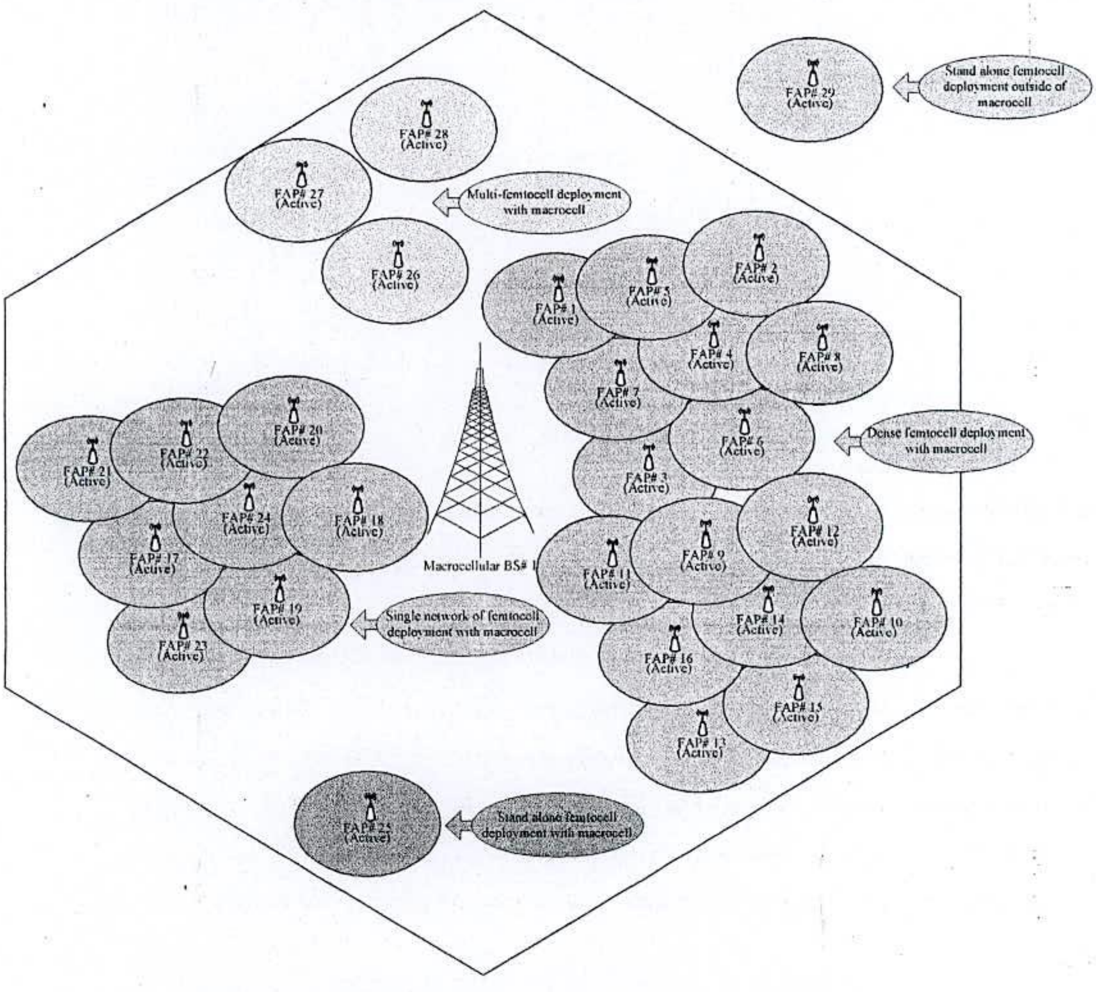


Fig. 2.2. Example of different femtocell deployment scenarios inside and outside of a macrocell.

Chapter 3

Interference in Femtocell

Interference between two or more femtocells is nothing but the unwanted signal reception by the serving femtocell originated from other neighbor femtocells, macrocell, and user equipments. This interference could be managed through proper interference management scheme along with proper frequency allocation scheme. Thus, reduces the unwanted HOs and probability of outage, and increases the frequency utilization.

3.1 Scenario of interference in femtocell

Different sources of interferences are found in the femtocell network deployment due to the co-existence of macrocell and femtocells. Thus, the amount of interference depends on the network architecture, location of femtocells, and density of femtocells. Based on these factors

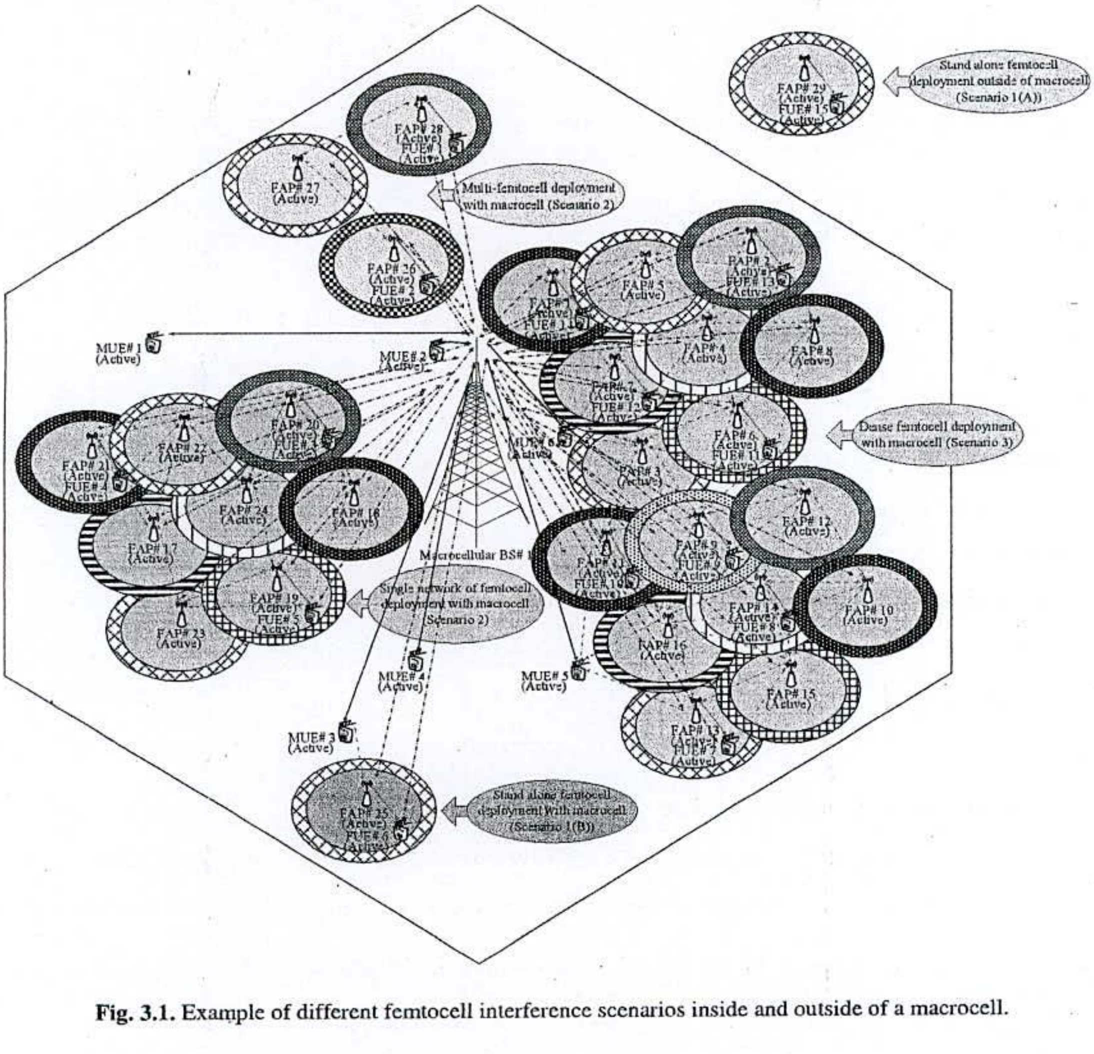


Fig. 3.1. Example of different femtocell interference scenarios inside and outside of a macrocell.

interference scenarios shown in Fig. 3.1 for the femtocell networks deployment with macrocell can be explained as follows:

I. **Single femtocell without overlaid macrocell (scenario 1(A) of Fig. 3.1):** In this case, there is no interference effect from other femtocells. Normally in very remote area, these types of connections are found. For example, FAP# 29 of Fig. 3.1.

II. **Single femtocell with overlaid macrocell (scenario 1(B) of Fig. 3.1):** Only discrete femtocells are overlaid by macrocell. In this scenario, there is no femtocell to femtocell interference. Fig. 3.1 represents this type of interference scenario where the FAP# 25 is discrete one.

III. **Multi-femtocells with overlaid macrocell (scenario 2 of Fig. 3.l):** Discrete femtocells as well as very few interfering overlapping femtocells are overlaid by macrocell. In this situation, the receivers of MBS, MUE, FAP, and FUE are affected. Fig. 3.1 shows that FAP# 17 to FAP# 24 and FAP# 26 to FAP# 28 are causing inter-femtocell interference as well as these femtocells are suffering from femtocell-to-macrocell interference.

IV. **Dense femtocell with overlaid macrocell (scenario 3 of Fig. 3.1):** This is the worst case of interference for ultimate goal of femtocell deployment. Lots of femtocells are deployed in a small area. In this case, the receivers of MBS, MUE, FAP, and FUE are affected. FAP# 1 to FAP# 16 are the examples of showing this type of interference scenario as given in the Fig. 3.1.

3.1.1 Source of interference

Since RF coverage of femtocells is not manually optimized by the cellular operator and deployment is generally ad hoc, RF interference issues may arise unless appropriate mitigation methods are utilized. Furthermore, due to the limited spectrum available to operators, macrocells and femtocells can share at least one frequency in order to increase efficiency of spectrum use. In the following, we outline potential RF interference issues related to femtocell deployments. Fig. 3.2 shows a example of interference source in femtocell deployment.

- **Interference between macrocell and femtocells:** Due to the restricted access requirement, femtocells can cause interference on both the UL and DL. For example, a femtocell installed inside near a window of a residence can cause DL interference to handsets outside the house (i.e., macrocell handsets) that are not served by the femtocell. Home handsets that are served by a certain femtocell can also cause interference to the UL of macrocell handsets.

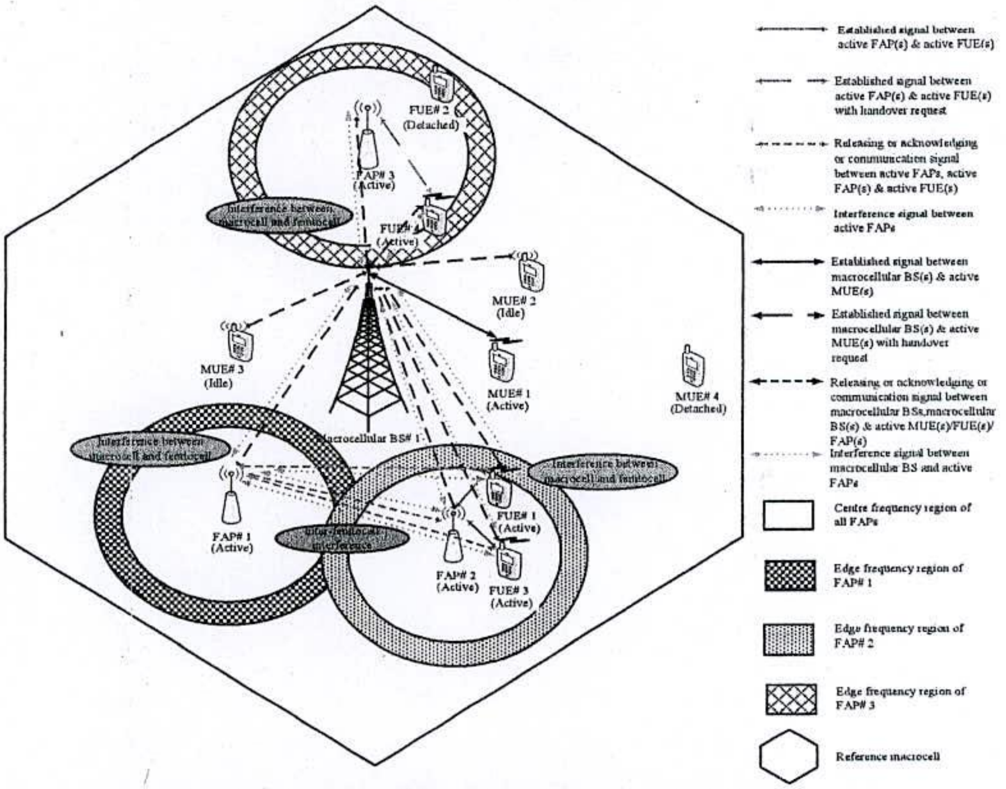


Fig. 3.2. Example of source of interference in femtocell integrated macrocell.

Again from Fig. 3.2, it can be seen that MBS# 1 causes macrocell-to-femtocell interference to FAP# 1, FAP# 2, and FAP# 3.

- **Inter-femtocell interference:** Femtocells can also create interference to each other due to unplanned deployment. For example, in a multi apartment structure femtocells installed near a wall separating two apartment units can cause interference to neighboring apartment units. In such a case, the strongest femtocell for a home handset (in terms of RF signal strength) may not be the serving femtocell due to the restricted access requirement. FAP# 1 and FAP# 2 of Fig. 3.2 show inter-femtocell interference where FAP# 1 is the interference source for FAP# 2, FUE# 1 and FUE# 3

3.2 Effect of interference in femtocell

Effects of interference in femtocell are many such as signal quality degradation, outage problem, less QoS, and low system capacity. From Fig. 3.1 it is obvious that type of aggressors (source of interference) and victims (sufferer from interference) depend on different situations; positions of FAP, MUE, FUE, and MBS. The aggressors are macrocell

DL, macrocell UL, femtocell DL, and femtocell UL. The victims are MUE receiver, MBS receiver, FUE receiver, and FAP receiver.

I. **Macrocell DL:** The entire FUEs receive interference from this macrocell DL. Whenever the location of the femtocell is close to the MBS and FUE is located at the edge of the femtocell, the transmitted power from the MBS causes interference for the FUE receiver. All the FAPs and FUEs of scenarios 1(B), 2, and 3 of Fig. 3.1 suffer interference problem for the macrocell DL.

II. **Macrocell UL:** FAP receiver suffers from this aggressor. Whenever the MUE is close to the femtocell or inside the femtocell coverage area, the transmitted UL signal from the MUE to MBS causes the interference for the FAP receiver. MUE# 3 causes this type of interference problem for FUE# 25 in scenario 1(B) of Fig. 3.1, and MUE# 5; MUE# 6 cause this type of interference problem for FAP# 16; FAP# 3 and FAP# 7 in scenario 3 of Fig. 3.1, respectively.

III. **Femtocell DL:** The femtocell DL causes the interference for the MUE receiver and nearby FUE receiver. Whenever, a macro user is very near, or inside a femtocell coverage area, the MUE feel interference for this femtocell DL (scenarios 2, and 3 of Fig. 3.1). Table 3.1 shows the aggressor-victim relation in details.

Table 3.1. Aggressor- victim relationship of femtocell DL interference scenario of Fig. 3.1

Scenario number	Aggressor	Victim
2	FAP# 17and FAP# 22	FUE# 4
2	FAP# 18	FUE# 3
2	FAP# 18 and FAP# 23	FUE# 5
3	FAP# 8, FAP# 9, and FAP# 12	FUE# 11
3	FAP# 5, and FAP# 8	FUE# 13
3	FAP# 3, FAP# 4, and FAP# 6	FUE# 12
3	FAP# 12, FAP# 14, and FAP# 16	FUE# 9
3	FAP# 10, FAP# 12, FAP# 15, and FAP# 16	FUE# 8
3	FAP# 15	FUE# 7

Also, if two or more femtocells are very close, then the FUE of one femtocell receives interference from the neighbor femtocell DL (shown in details in scenario 2 and 3 of Fig. 3.1).

IV. **Femtocell UL:** Macrocell receiver and nearby FAP receiver suffer from this aggressor. Whenever the femtocell is close to the macrocell, the transmitted UL signal from the FUE to FAP causes the interference for the macrocell receiver (shown in details in scenarios 1(B), 2, and 3 of Fig. 3.1). Also, if two femtocells are close to each other, the femtocell UL causes interference for the neighbor FAP receiver (shown in details in scenarios 2 and 3 of Fig. 3.1).

3.3 Different solutions to mitigate interference effect in femtocell

The choice of the frequency-allocation scheme to minimize the interference and to ensure maximal spectrum utilization should depend on the density of the femtocells and the relationship between the femtocells and the macrocells [2]. The dedicated frequency band allocation [2] is the case where the same frequency band is shared by all the femtocells and a different frequency band is allocated to the macrocells; i.e., in this scheme, femtocells and macrocells use totally separate frequency bands. In the shared frequency band allocation scheme [2], the frequencies from the same spectrum can be allocated for the femtocells and the macrocells. In the sub-frequency band allocation scheme [2], the macrocells use the total system spectrum, while only part of this total frequency band can be used by the femtocells. In the static frequency-reuse scheme [2], the set of all total cellular frequency band frequencies (say, *Bm*) is divided into three equal parts bands (say: *Bm*1,*Bm*2, and *Bm*3) and each one of the three macrocells in a macrocellular cluster uses any one of these three different frequency bands. If a macrocell uses a particular frequency band, then the femtocells within that macrocell use the other two frequency bands. In the dynamic frequency-reuse Scheme [2], the total frequency allocation for the three macrocells in a macrocell cluster and the total frequency allocation for the femtocells in each of these three macrocells is similar to the static frequency-reuse scheme. However, as opposed to the static frequency-reuse where each femtocell uses only one of the two frequency bands which is not assigned to its underlying macrocell, in the dynamic frequency-reuse scheme, each femtocell uses two frequency bands. In each femtocell, one band is used in the center of the femtocell, while another band is used at the edge of the femtocell. The frequency bands used in the center of all the femtocells of the same macrocell are the same. However, the frequency bands used in the edges of the various femtocells are, in general, different, to avoid the interference. The above frequency allocation scheme helps femtocell deployment with less interference effects. Sharing of frequency cannot reduce interference effectively. It is because of continuous power transmission mode of typical FAP. The continuous power transmission of FAP influences the other receivers (such as neighbor FAP, MBS, FUE, and MUE), and try to interfere. However, in proposed ODSC scheme FAP power can be kept low. The low power mode of FAP can reduce more interference effect than only frequency allocation scheme [2]. Therefore, dense deployment of FAP could be implemented through ODSC scheme.

Since femtocells operate in the licensed spectrum owned by wireless operators and share this spectrum with macrocell networks [10], limiting the cross-tier interference from femtocell users at a MBS is an indispensable condition for deploying femtocells in the UL. In addition, since a network operator cannot control the femtocell locations, femtocells need to sense the radio environments around them and carry out self-configuration and self-optimization of radio resources from the moment they are set up in by the consumer. This paper [10] proposes two interference mitigation strategies in which femtocell users adjust the maximum transmit power using an open-loop and a closed-loop technique. With the open-loop control [10], a femtocell user adjusts the maximum transmit power to suppress the cross-tier interference due to the femtocell user, which results in the cross-tier interference less than a fixed interference threshold. The closed-loop control [10] adjusts the maximum transmit power of the femtocell user to satisfy an adaptive interference threshold based on the level of noise and UL interference at the MBS. Both schemes effectively compensate the UL throughput degradation of the existing MBS due to the cross-tier interference. Furthermore, the use of the closed-loop control provides femtocell throughput that is superior to that using open-loop control at a very low macrocell throughput cost [10]. The open loop and close loop power control technique depends on threshold limit of maximum transmission power. The threshold maximum power alone cannot reduce the interference effect properly because of FAP continuous power transmission mode. Here, continuous power transmission of FAP is responsible for wastage of power along with interference. In proposed ODSC scheme FAP uses two operational power modes, one mode is low power mode FIM and other one is high power mode FAM. During FIM, FAP uses low power than FAM and helps FAP operation with less interference. On the other hand FAP serves its users with FAM state but the duration of FAP service to femto-users is small in a day. Since proposed ODSC scheme serves to FUE with user request, so with proposed ODSC scheme very low interference effect is causing to both networks by FAP deployment.

To achieve the desired performance, the following interference and mobility management methods need to be employed as part of the femtocell design [13]:

a. Calibrations of femtocell DL transmit power to limit interference to the macro network while providing good coverage for the femtocell user.
b. Adaptive UL attenuation at the femtocell to mitigate interference caused by a nearby interfering macro and/or femto user not controlled by the femtocell.
c. Carrier selection for femtocells combined with inter-frequency HO for macrocell users to avoid inter-femto and femto-to-macro interference.
d. Limiting a femtocell user's UL transmit power to minimize the interference caused to the UL of the macro network.

- **Basic interference models:** The Femto Forum recently published a report that evaluates extreme cases of macro-femto interference based on both co-channel and adjacent channel deployment [13]. The DL and UL interference is also studied using a "simple" model. For this model, two scenarios are considered: cell edge and cell site. This simple model captures the DL interference from FAP to nearby MUE and the UL interference from the MUE to FAP. The assumption is that the femto and macro are on the same carrier frequency.

- **Dense urban system simulation model:** For system-level simulations, [13] consider a dense urban deployment scenario corresponding to densely populated areas. Here simulation with multiple cells in the macrocell network and drop multiple apartment buildings in the macro network where each building has multiple floors with 10 apartment units per floor. Each apartment unit is 10 m × 10 m and has a 1-m-wide balcony. The probability that FUE is on the balcony is assumed to be 10 percent. Here considering drop of 2000 apartment units in each cell; 96 of them have FAPs installed, and 12 FAPs are simultaneously active. If an FAP is active, it will transmit at full power on DL; otherwise, it will transmit only the pilot (CPICH) and overhead channels. MUE is also dropped randomly into the macro cell such that 30 percent of the MUE is indoors.

DL interference management for FAPs [13]: Due to restricted association, unplanned deployment and low isolation, FAPs can cause DL interference to the macro network and neighboring FAPs. The following key interference management techniques are used to limit the DL interference of FAPs to the macro network and other FAPs while providing good coverage for the FAP users. As part of these methods the FAP needs to have a "sniffing" function that enables the FAP to perform RF measurements such as received signal strength indicator (RSSI), which is the total received power spectral density (also called Io), and CPICH Ec/Io, which is the ratio of the received pilot energy to the total received power spectral density at the user equipment (UE) on the macro and femto DL channels.

- **FAP autonomous carrier selection and inter-frequency HO for macrocell users:** Each FAP needs to be configured for a certain carrier frequency or UMTS terrestrial radio access (UTRA) absolute radio frequency number (UARFCN) for operation [13]. Such a carrier selection mechanism depends on the particular deployment configuration. Analysis with the dense urban model described above shows that single carrier allocation to FAPs would be sufficient for most cases. However, for very dense deployments there could be certain amounts of inter-FAP RF interference. One solution for addressing the inter-femto interference issue would be to use multiple carriers for FAPs. For example, FAPs in neighboring apartments can be assigned to different frequency carriers to mitigate the potential interference problems. To achieve this goal, one carrier can be assigned as the "preferred" carrier for femtocells, and during self-calibration the FAP can pick this particular carrier unless there is significant interference detected on this carrier. Otherwise, FAP can choose to operate on the "secondary" carrier designated for FAPs. When a macrocell network operates on the same carrier as FAPs, FAP-macrocell interference can result in a certain amount of outage and performance degradation for MUE. One solution for mitigating the FAP-macro interference would be to make sure the carrier(s) used by FAPs are not used by the macrocell network. Although this method reduces FAP-macro interference noticeably, it is not efficient in terms of spectrum utilization, especially if FAP deployment density is not high. For most operators with limited carriers (e.g., two or three carriers), sharing the carriers between FAPs and macrocell network would be preferable. In this case, FAPs can be deployed on the least used macrocell carrier(s), and if a mobile MUE still experiences significant interference from an FAP, the macrocell network can perform inter-frequency HO of that MUE to another macrocell carrier frequency. Coverage and capacity results in [13] focus on the case where one carrier is shared by femtocells and macrocells. Other available carriers are used by macrocells only.

- **FAP DL transmit power self-calibration:** To limit the impact of femtocells on existing macrocell networks [13], it is desired to minimize the amount of interference created by the FAP. On the other hand, if the FAP transmit power level is too small, proper femto coverage cannot be maintained inside the home. For example, when a femtocell is close to a MBS, larger transmit power levels would be required to provide adequate femto coverage. Thus, it is desirable to have a method to adaptively adjust the FAP Tx power level depending on macrocell signal levels.

UL interference management for FAPs [13]: Due to restricted association, unplanned deployment and low isolation, FAPs can experience significant UL interference from nearby uncontrolled UE (MUE or FUE). In addition, FUE can cause UL interference to the macro network and neighboring FAPs. The following key interference management techniques are needed to mitigate the UL interference at the FAP and to limit the UL interference caused by FUE to the macro network and other FAPs.

- **Adaptive UL attenuation:** Since the minimum coupling loss between FUE and a FAP can be as low as 30–40 dB [13], FUE can cause very high signal levels at the FAP, from both FUE that cannot be power controlled down due to minimum UE transmit power limitation and out-of-cell (restricted) FUE and MUE. One solution for this would be to use a large noise figure value (or attenuation) at the FAP frontend to bring the signal to the appropriate level for further processing. However, as a result of the high noise figure, FUE transmit power values will increase even when there is no interfering MUE, and this will result in unnecessary UL interference to MBSs. This is particularly important if the FAP happens to be close to a macrocell. Thus, instead of simply increasing the noise figure to a constant level, it is more desirable to adjust FAP UL attenuation adaptively only when needed. Another scenario is when FUE is near a neighbor's wall and causes significant interference to the neighbor's FAP. In this case, applying fixed attenuation at both FAPs will not noise level. This allows the FUE to be power controlled up to overcome the interference. In addition, fluctuations of the received signal levels must also be considered. For example, if an MUE with bursty UL traffic is in the vicinity of FAP, it can create large variations in the UL signal-to-interference ratio (SIR) of FUE connected to the same FAP. The usual power control loops are not designed for this situation, and unstable system operation can result. Here considering decaying the attenuation slowly when the jammer/interference source disappears. This slow decay provides robustness against bursty interferers in the sense that the attenuation is mostly maintained when the next burst arrives and the served FUE already transmits with sufficient power. Alternatively, the attenuation can be reduced when the interference disappears while the FUE power control loop still temporarily maintains the power levels of the served FUE.

- **Limiting FUE transmit power:** As a safety mechanism and to limit the UL interference [13] caused by FUE to the macro network (or neighbor FAPs), the FAP can estimate the path loss to the nearest MBS (and/or FAP) and use this estimate to limit the maximum transmit power of the FUE. The path loss to the nearest MBS (and/or FAP) can be estimated by the FAP by measuring the other cell's DL signals.

The above discussion shows the strategy for interference reduction in femtocell network where FAP transmits power continuously. Proposed ODSC scheme has power switching mechanism from high power mode (FAM: FAP service mode for FUE) to low power mode (FIM: FAP self service mode) and vice-versa. This switching depends on femto-user three different states such as active (FUE switched-on and attempting a call), idle (FUE switched-on only), and detached (FUE switched-off). Only active state of FUE demands for getting service from active FAP (FAP in FAM). Other two states cannot affect the mode switching of FAP in ODSC scheme. So, FAP service period is small in proposed ODSC scheme, because FUE does not stays the entire day time in home environment in each day. During short service period of FAP in proposed ODSC scheme, it is more efficient scheme for dense deployment of femtocell with less interference effect.

3.4 Interference effect of dense femtocell deployment in macrocell

The dense deployment is the main issue for the proper and effective deployment of femtocell network because dense deployment of femtocell will serve more femto-users in

MBS thus, the entire wireless system interference may enhance. Since femtocell may be deployed without macrocell area and under macrocell area, proper frequency planning for both the networks is essential term to be considered for proper integration of these two networks. However, the proper integration of femtocell with macrocell networks depends on further considerations about interference management, proper network planning, and HOs control between femtocell-to-femtocell, femtocell-to-macrocell, and macrocell-to-femtocell. Frequency of these HOs increases with increase of femtocells. More the HOs occur more the probability of outage happens. More outage along with HOs between the two networks and inter-femtocell network may cause more interference effect, which leads to degrade the signal quality of wireless network service to the end users. Some time the femtocell having stronger signal strength may not be the serving femtocell due to the restricted access and this is also a reason to increase the interference in the dense femtocell network. For both networks UL and DL interference occurs as mentioned in earlier section 3.2. Here to mitigate the more interference effect in dense deployment of femtocellular network integrated with macrocell network, this thesis proposes ODSC scheme. Where, FAP has two operational power modes as low-power FIM (FAP having enough power for doing measuring parameters, sniffing for active users purposes) and high-power FAM (FAP having enough power to serve the user). Dense femtocell deployment demands for intelligent self-organizing network (SON) features such as the main functionalities of the SON architecture are: self-configuration, self-optimization, and self-healing. The self-configuration feature allows intelligent frequency allocation among neighboring FAPs, maintenance of the neighboring cell list, and support for mobility. The self-optimization feature optimizes the settings of transmission powers of neighboring FAPs, as well as other operational parameters, such as the size of the neighbor list. The self-healing feature supports automatic detection and resolution of major failures. A sniffing function is required for effective integration of femtocells into a macrocellular network, so that a FAP can scan the air interface and detect available frequencies and other network resources. Communication among neighboring FAPs, as well as between FAPs and the respective MBS, is required to configure spectral resources and transmission powers [??].

Chapter 4

On-Demand Service Connectivity (ODSC) Scheme

ODSC scheme is triggered by demand creation caused by active users under any active femtocell. When a femto user requests to use the idle FAP or a HO request comes to an idle FAP then demand is created. After demand creation, a FAP become active. It is advantageous to keep a FAP in active and idle modes and one of the advantages is if we can keep lower number of active FAPs then interference effect becomes low. Since FAP activeness depends on demand creation so that power consumption by a FAP can be reduced in proposed ODSC scheme.

4.1 Pictorial representation of FAP continuous service scheme

Depending on three states of any FUE, Fig. 4.1 shows three scenarios of a femtocell network deployment with continuous service scheme or without ODSC scheme in integrated macrocell/femtocell networks. In the first scenario, there is no femto user in FAP# 1, but FAP# 1 is active. There are two idle femto users (FUE# 1 and FUE# 3) in FAP# 2 but FAP# 2 is active in the second scenario. FAP# 3 is also active with a detached femto user (FUE# 2) in the third scenario of Fig. 4.1(a). From these three scenarios it is obvious that, in any condition FAPs are active. Besides this, in proposed ODSC scheme a FAP is in FAM when there is a demand for it. As FAP activeness is depending on demand creation so that, proposed ODSC scheme is called on-demand. Fig. 4.1(a) to Fig. 4.1(f) show a common scenario that MBS# 1 is the reference MBS and FAP#1, FAP#2, and FAP# 3 remains within MBS# 1. FAP# 1 and FAP# 2 are neighbor to each other and FAP#3 is stand alone FAP. All three FAPs are active all the time irrespective of activeness of femto-users. Both macrocell and femtocell contains MUEs and FUEs, respectively. However, the states of the MUEs and FUEs are changeable depending on their movement, network coverage, user's willingness of using the mobile station (MS) in different states etc., and MUEs/FUEs change of states affects in mode selection of a FAP. Different scenarios can be explained from Fig. 4.1(a) to Fig. 4.1(f). Firstly, FAP# 1 does not contain any femto user within its coverage area. FAP# 2 contains two idle FUEs (FUE# 1 and FUE# 3) and FAP# 3 contains one detached FUE (FUE# 2). MUE# 1, MUE# 2 are in active state; MUE# 3, MUE# 4 are in idle state; MUE# 5 is in detached state, under MBS# 1. Active MUE# 2 is moving to active FAP# 3 [Fig. 4.1(a)]. Secondly, active MUE# 2 moves to the centre region of FAP# 3 service area (inner region) [4] and active MUE# 2 is treated as active FUE# 4 by active FAP# 3. Idle FUE# 1 and idle

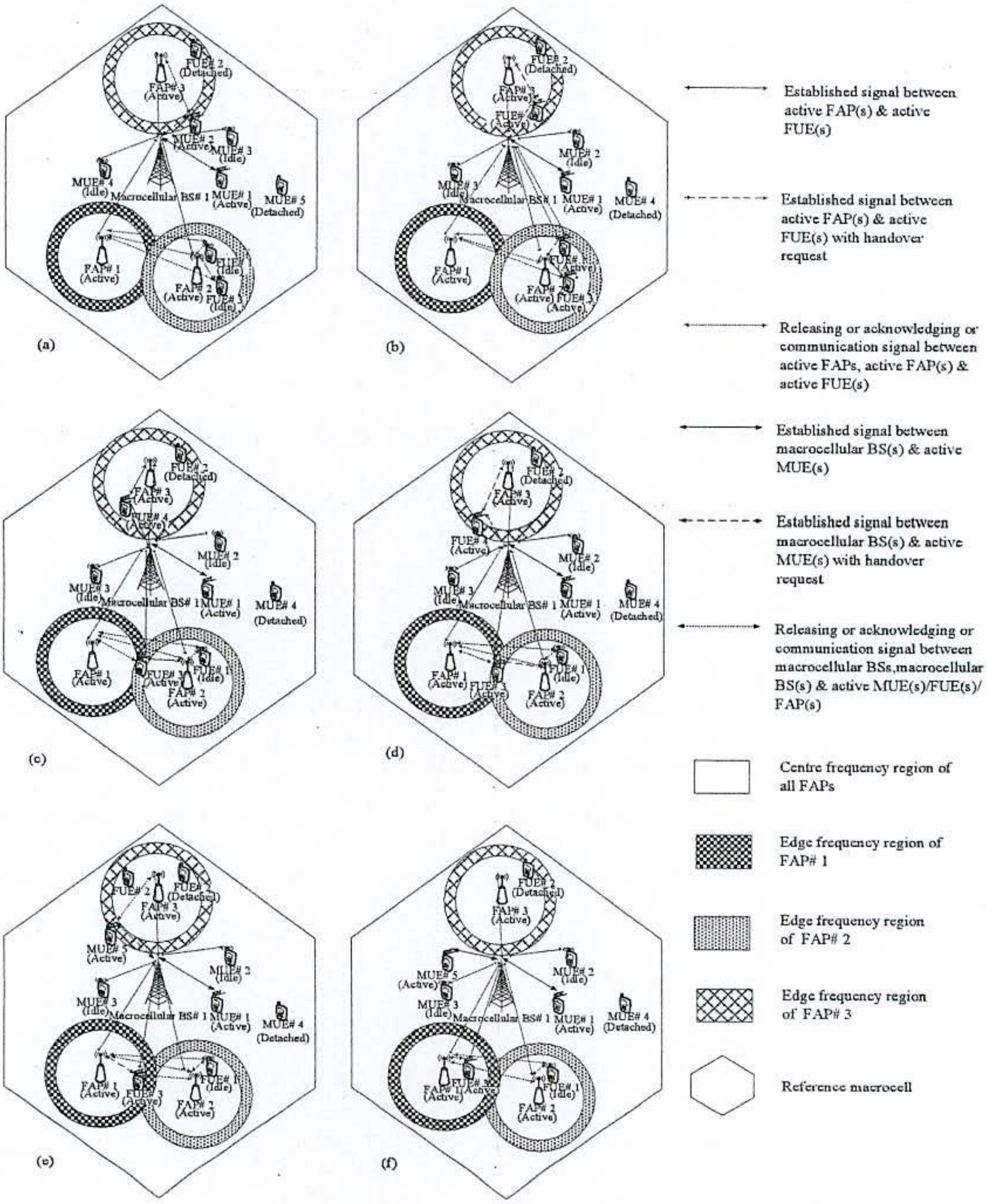


Fig. 4.1. Example of the existing FAP power mode scenario.

FUE# 3 become active in FAP# 2 coverage area. Idle MUE# 3, idle MUE# 4, and detached MUE# 5 can be designated as idle MUE# 2, idle MUE# 3, and detached MUE# 4, respectively under MBS# 1 [Fig. 4.1(b)]. Thirdly, active FUE# 4 is moving towards edge (outer region) [4] of active FAP# 3. Active FUE# 3 goes to the edge of active FAP# 2 and near to neighbor active FAP# 1, and active FUE# 1 becomes idle FUE# 1 [Fig. 4.1(c)]. Fourthly, active FUE# 4 is about to leaving the edge of active FAP# 3 and moving towards the serving region of MBS# 1 alone. Active FUE# 3 is trying to move towards active FAP# 1 and to do so, FGW start processing of HO related activities between active FAP# 2 and active

FAP# 1 [Fig. 4.1(d)]. Fifthly, active FUE# 4 can be designated as active MUE# 5 under MBS# 1. After HO process, active FUE# 3 moves in the edge of coverage area of active FAP# 1 [Fig. 4.1(e)]. Finally, active MUE# 5 and active FUE# 3 move to the centre of MBS# 1 and FAP# 1, respectively [Fig. 4.1(f)]. Since MBS# 1, FAP# 1, FAP# 2, and FAP# 3 are always in full power mode so that, macrocell-to-macrocell/femtocell and femtocell-to-femtocell/macrocell communications exists all the time. Hence, interference effect is more in FAPs single power mode deployment scheme shown in Fig. 4.1.

4.2 Pictorial representation of the ODSC scheme

Fig. 4.2 shows proposed ODSC scheme where a FAP is not in FAM at every time because FAP activeness depends on demand creation. Here, demand creation depends on different situations. From Fig. 4.2(a) it is clear that all FAPs are in idle mode because there is no demand. When an active femto/macro user wants to use any idle FAP or comes to edge region of any idle FAP or sends request for a macrocell/femtocell-to-femtocell HO but not in direct connection with desired idle FAP then, requested idle FAP becomes active. For instance, FAP# 3 becomes active due to active FUE# 4 [Fig. 4.2(b)]. So, FAP# 3 starts continuous power transmission. However, in idle mode, FAP# 3 transmits beacons only with regular interval instead of continuous power transmission. Again in proposed ODSC scheme it is seen from Fig. 4.2(a) that FAP# 1 has no femto user so no demand exists here and FAP# 1 is in FIM, FAP# 2 have two idle femto users (FUE# 1 and FUE# 3), so without any demand FAP# 2 is also in idle mode, FAP# 3 has a detached femto user (FUE# 2), so there is no demand and FAP# 3 remains in idle mode and in turns interference can be reduced by keeping active FAP in idle mode by creating no demand situation as explained earlier. Fig. 4.2 also shows the same common scenarios as explained earlier for Fig. 4.1. If we observe Fig. 4.2(a) minutely, it is found that, MUE# 2 is in active state and connected with reference MBS# 1 and moving towards idle FAP# 3. While active MUE# 2 moves certain distance to reach very near to edge region of idle FAP# 3, active MUE# 2 creates demand by creating a HO probability and idle FAP# 3 becomes active so that active FAP# 3 can take active MUE# 2 as active FUE# 4, which is shown in Fig. 4.2(b). Fig. 4.2(b) also shows that, any idle femto user (FUE# 1 or FUE# 3) or both idle femto users (FUE# 1 and FUE# 3) of FAP #2 become active and makes idle FAP# 2 into active. Fig. 4.2(c) depicts that, one of the active femto users of active FAP# 2 of Fig. 4.2(b) becomes idle (FUE# 1) and other active femto user is moving towards FAP# 1, but remains in active state (FUE# 3), so that, FAP# 2 remains active. Here, FAP# 1 has no active femto user, so that FAP# 1 remains in idle mode, meanwhile active FUE# 4 is moving towards edge region of active FAP# 3 [Fig. 4.2(c)]. But an active FUE# 3 moves towards edge of FAP# 1 and creates a HO probability so that, FAP# 1 changes its

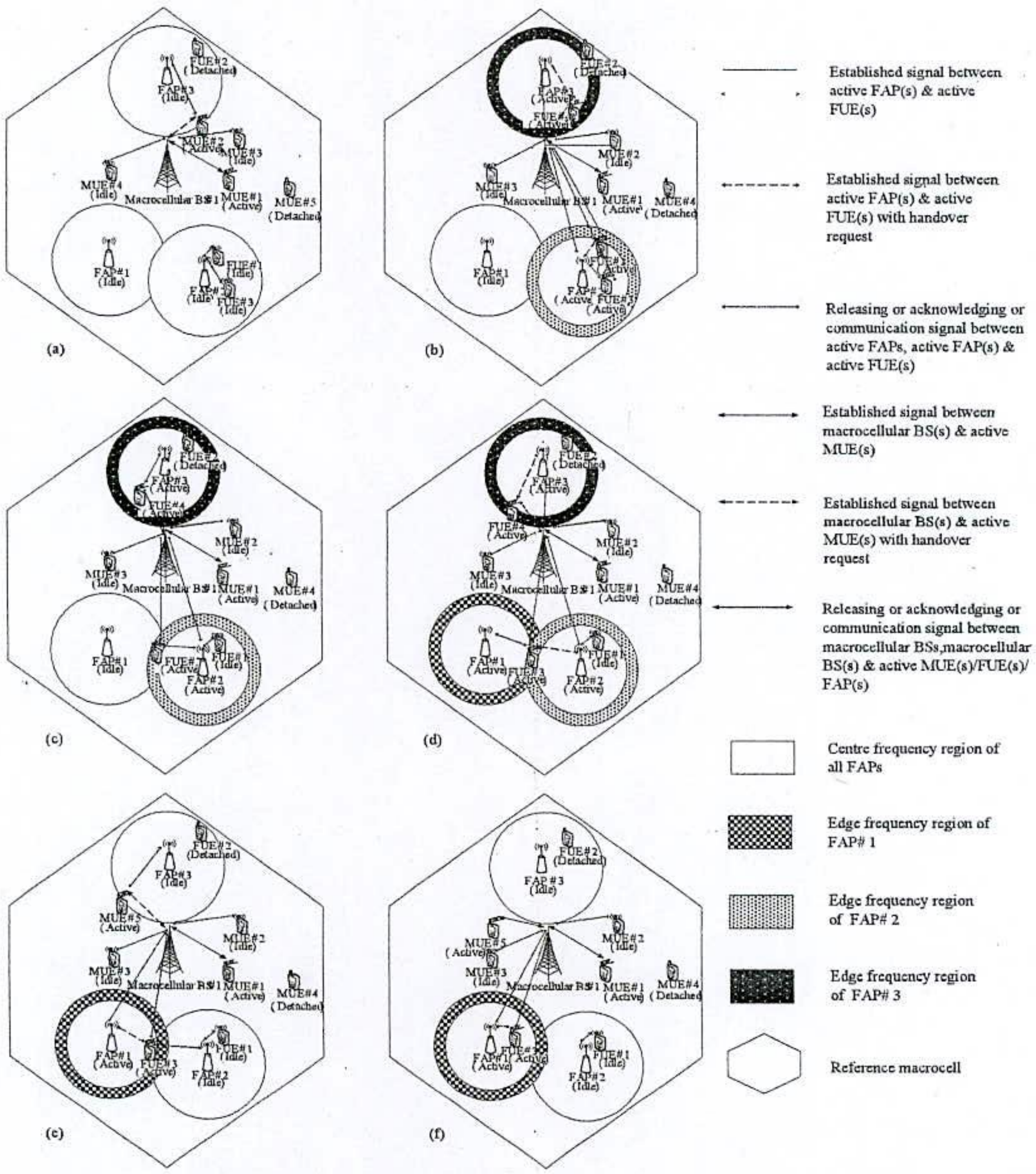


Fig. 4.2. Example of the proposed intelligent interference management scheme with on-demand power switching system.

mode from idle to active. Now, active FUE# 4 is ready to enter direct serving area under MBS# 1 [Fig. 4.2 (d)]. When active FUE# 3 fully goes to FAP# 1 then FAP# 2 has only idle FUE# 1 and thus active FAP# 2 becomes idle. Under MBS# 1 serving area active FUE# 4 can be treated as active MUE# 5 [Fig. 4.2(e)]. Active FUE# 3 is moving to the centre of active FAP# 1. Active MUE# 5 is moving towards centre of MBS# 1 [Fig. 4.2(f)]. It can be seen from Fig. 4.2 that, an idle FAP is in FAM if there is a demand for it. Since there are thousands of FAPs in a femtocell network deployment, interference can be reduced significantly if we can change several active FAPs into idle FAPs.

In proposed intelligent femtocell ODSC scheme, an active FUE always gets the prior notifications about the neighbor environment such as number of neighbor active FUEs and power statuses of neighbor FUEs within the coverage area of same serving active FAP, position of serving active FAP boundary area, interfering signal level of neighbor interfering active FUEs, and interfering signal level of neighbor interfering active FAPs (in dense deployment of femtocell networks) from the communication among FGW, active FAP, and active FUE. The above mentioned information of an active FUE's neighbor environment helps active FAP in reducing random unwanted femtocell-to-femtocell/macrocell and macrocell-to-femtocell HO, interference level, probability of outage so that, serving active FAP can afford seamless connectivity to its serving active FUE. Thus, overall system performance increases and so as system capacity of femtocell equipped macrocell networks.

4.3 Tabular representation of the ODSC scheme and FAP continuous service scheme

Table 4.1 and Table 4.2 summarize the power status and communication status of all FAPs along with all FUEs shown in Fig. 4.1 and Fig. 4.2, respectively. Also communication statuses of reference MBS along with all MUEs, as well as with some FUEs are given in Table 4.1 and Table 4.2. Only two states (active and idle) of all FUEs and MUEs are given in

Table 4.1. Summary of FAP(s) and macro BS(s) different status shown in Fig. 4.1

FAPs and MBSs status	Fig. 1(a)	Fig. 1(b)	Fig. 1(c)	Fig. 1(d)	Fig. 1(e)	Fig. 1(f)
Communication status of FAP# 1	FAP# 2^A, FUE# 1^I, FUE# 3^I, MBS# 1	FAP# 2^A, FUE# 1^A, FUE# 3^A, MBS# 1	FAP# 2^A, FUE# 1^I, FUE# 3^A, MBS# 1	FAP# 2^A, FUE# 1^I, FUE# 3^A, MBS# 1	FAP# 2^A, FUE# 1^I, FUE# 3^A, MBS# 1	FAP# 2^A, FUE# 1^I, FUE# 3^A, MBS# 1
Power status of FAP# 1	Active	Active	Active	Active	Active	Active
Communication status of FAP# 2	FAP# 1^A, FUE# 1^I, FUE# 3^I, MBS# 1	FAP# 1^A, FUE# 1^A, FUE# 3^A, MBS# 1	FAP# 1^A, FUE# 1^I, FUE# 3^A, MBS# 1	FAP# 1^A, FUE# 1^I, FUE# 3^A, MBS# 1	FAP# 1^A, FUE# 1^I, FUE# 3^A, MBS# 1	FAP# 1^A, FUE# 1^I, FUE# 3^A, MBS# 1
Power status of FAP# 2	Active	Active	Active	Active	Active	Active
Communication status of FAP# 3	MUE# 2^A, MBS# 1	FUE# 4^A, MBS# 1	FUE# 4^A, MBS# 1	FUE# 4^A, MBS# 1	MUE# 5^A, MBS# 1	MBS# 1
Power status of FAP# 3	Active	Active	Active	Active	Active	Active
Communication status of MBS# 1	FAP# 1^A, FAP# 2^A, FAP# 3^A, MUE# 1^A, MUE# 2^A, MUE# 3^I, MUE# 4^I	FAP# 1^A, FAP# 2^A, FAP# 3^A, FUE# 1^A, FUE# 3^A, FUE# 4^A, MUE# 1^A, MUE# 2^I, MUE# 3^I	FAP# 1^A, FAP# 2^A, FAP# 3^A, FUE# 3^A, FUE# 4^A, MUE# 1^A, MUE# 2^I, MUE# 3^I	FAP# 1^A, FAP# 2^A, FAP# 3^A, FUE# 3^A, FUE# 4^A, MUE# 1^A, MUE# 2^I, MUE# 3^I	FAP# 1^A, FAP# 2^A, FAP# 3^A, FUE# 3^A, MUE# 1^A, MUE# 2^I, MUE# 3^I, MUE# 5^A	FAP# 1^A, FAP# 2^A, FAP# 3^A, FUE# 3^A, MUE# 1^A, MUE# 2^I, MUE# 3^I, MUE# 5^A

Table 4.2. Summary of FAP(s) and macro BS(s) different status shown in Fig. 4.2

FAPs and MBSs status	Fig. 2(a)	Fig. 2(b)	Fig. 2(c)	Fig. 2(d)	Fig. 2(e)	Fig. 2(f)
Communication status of FAP# 1	None	None	None	FUE# 3^A	FUE# 3^A, MBS# 1	FUE# 3^A, MBS# 1
Power status of FAP# 1	Idle	Idle	Idle	Active	Active	Active
Communication status of FAP# 2	FUE# 1^I, FUE# 3^I	FUE# 1^A, FUE# 3^A, MBS# 1	FUE# 1^I, FUE# 3^A, MBS# 1	FUE# 1^I, FUE# 3^A, MBS# 1	FUE# 1^I, FUE# 3^A	FUE# 1^I
Power status of FAP# 2	Idle	Active	Active	Active	Idle	Idle
Communication status of FAP# 3	MUE# 2^A	FUE# 4^A, MBS# 1	FUE# 4^A, MBS# 1	FUE# 4^A, MBS# 1	MUE# 5^A	None
Power status of FAP# 3	Idle	Active	Active	Active	Idle	Idle
Communication status of MBS# 1	MUE# 1^A, MUE# 2^A, MUE# 3^I, MUE# 4^I	FAP# 2^A, FAP# 3^A, FUE# 1^A, FUE# 3^A, FUE# 4^A, MUE# 1^A, MUE# 2^I, MUE# 3^I	FAP# 2^A, FAP# 3^A, FUE# 3^A, FUE# 4^A, MUE# 1^A, MUE# 2^I, MUE# 3^I	FAP# 2^A, FAP# 3^A, FUE# 3^A, FUE# 4^A, MUE# 1^A, MUE# 2^I, MUE# 3^I	FAP# 1^A, FUE# 3^A, MUE# 1^A, MUE# 2^I, MUE# 3^I, MUE# 5^A	FAP# 1^A, FUE# 3^A, MUE# 1^A, MUE# 2^I, MUE# 3^I, MUE# 5^A

Table 4.1 and Table 4.2. Here, to indicate the power mode of FAPs, FUEs, and MUEs, a common superscript notation is used in Table 4.1 and Table 4.2. Table 4.1 show that, all FAPs are in FAM all the time. Reference MBS# 1 always communicates with all FAPs. FAP-to-FAP communication exists all the time whether there is any active FUE or not. So, interference effect is high in the single power mode FAPs deployment scheme. From Table 4.2 it can be seen that FAPs are in active mode when they need to be active. So, without active FUE, any FAP (or reference FAP) goes to FIM. From Table 4.2, it can also be seen that, FAP# 1 of Fig. 4.2(a) to Fig. 4.2(c) and FAP# 3 of Fig. 4.2(f) have no effective communication with any other active FAPs, active FUEs, MBS or active MUEs so, communication status is "None" and power status of FAP# 1 and FAP# 3 is "Idle" here, respectively. Also FAP# 2 of Fig. 4.2(a), Fig. 4.2(e), Fig. 4.2(f) and FAP# 3 of Fig. 4.2(a), Fig. 4.2(e) has their power statuses as "Idle" mode and communication statuses are shown in Table 4.2.

4.4 Basic architecture of the ODSC scheme

The basic flow diagram of the proposed ODSC scheme is given in Fig. 4.3. Whenever, a new FAP is ready to be deployed (or there is any active FAP), at first, the new FAP does its system parameter selection job as to recognize its neighbor environment. Then the FAP selects its type from neighbor environment, as it is in standalone or dense femtocell environment. Sizing the system/network area and own coverage area is done by the FAP from the necessary measurements. Femtocell-to-femtocell (in dense femtocellular system only) or femtocell-to-macrocell (in standalone/dense femtocellular system), interference analysis is done with the help of FGW and neighbor environment. When an active femto user exists in the new FAP coverage area, the link quality between femto user and FAP, between FAP and FGW etc. are checked in order to response to a HO request of serving active FAP through FGW for a successful HO between active FAPs or active FAP and macrocell. Now, all active neighbor FAPs list (in dense femtocellular system only), all active neighbor FAPs signal strength and all active femtocell users (under serving active FAP) distance (or position co-ordinates) monitoring, sharing and updating are done (under same FGW) between the FGW and active FAP, and between the FGW and all neighbor active FAP, in order to avoid unwanted HOs and probability of outage, and high interference effects. When active femtocell user satisfies all conditions of the femtocellular system relating to successful HO process under serving active FAP, then active FAP is ready for initializing a HO process with the help of FGW, else HO processes aborts. Finally, optimum HO is done with lower interference effect. After a successful HO, the whole process repeats for other active femtocell user, otherwise active FAP goes to idle mode, if no active femtocell user exists therein.

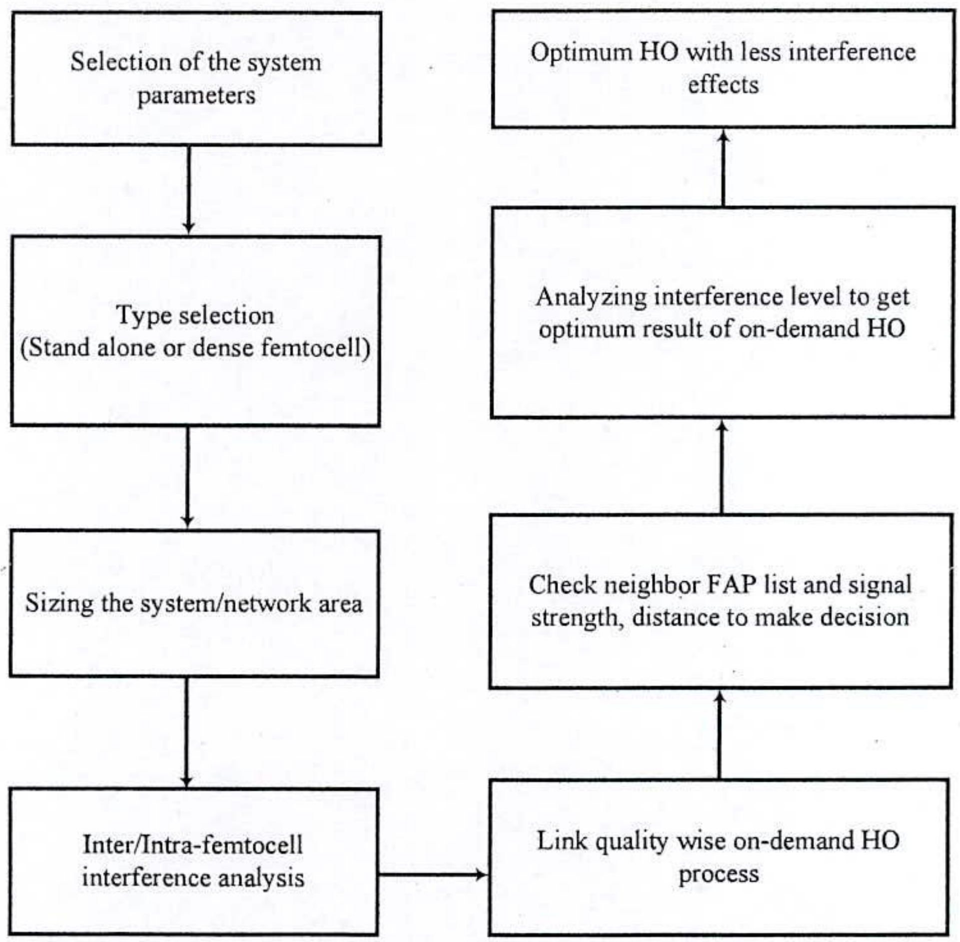


Fig. 4.3. Flow diagram of HO mechanism with ODSC scheme.

4.5 Working process of the ODSC scheme

Fig. 4.4 shows the basic flow diagram how an idle FAP becomes active. Here, it is assumed that, initially reference FAP contains no active user. So, according to proposed ODSC scheme this reference FAP initially should be in FIM. At first, reference FAP starts searching of FUE which need to be served with beacon transmit. If there is existence of any FUE within the coverage area of reference FAP, then the FAP starts checking FUE states such as active or idle. After that, if FUE is found to be active FUE, then reference FAP changes its mode from idle to active and serves the active FUE until it becomes idle. However, if FUE is detected as idle FUE by the reference FAP, and no other FUE is there to get served by this reference FAP, then active FAP becomes idle. During the UE detection process, if reference FAP detects any active MUE within its edge region, then reference FAP waits for HO request to serve the MUE. While active MUE moving from edge to centre of the reference active FAP, then reference active FAP gets HO request from the HO requesting active MUE and reference active FAP gets ready to serve that active MUE by treating active MUE as active FUE. After this, if reference active FAP gets no HO request, no active femto user is there, and FAP remains idle. Then repeats the whole process discussed above.

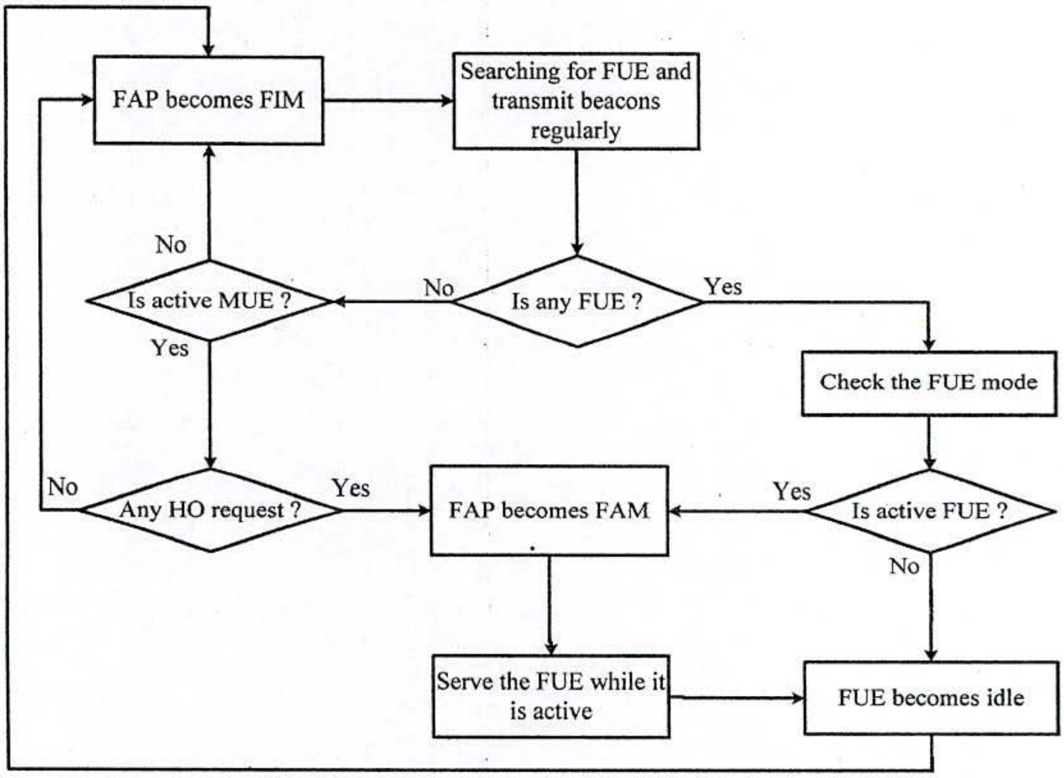


Fig. 4.4. Flow diagram of reference FAP mode selection mechanism.

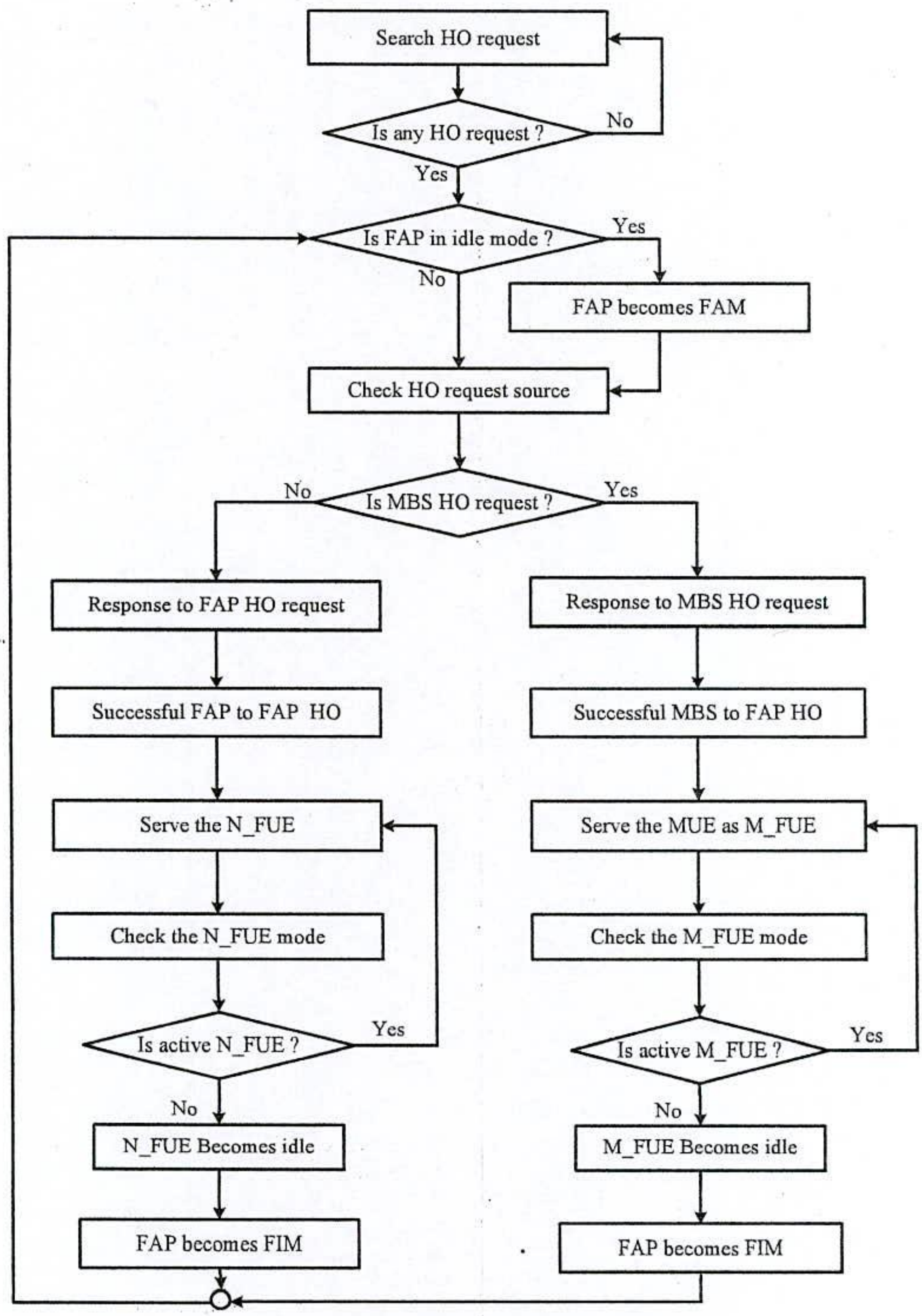


Fig. 4.5. Flow diagram of reference FAP HO response mechanism.

Flow diagram of the HO response procedure is shown in Fig. 4.5. It is assumed that, no active user is served by reference FAP. So, reference FAP is initially in FIM. At first, reference FAP starts searching HO request with beacon transmit. If reference FAP gets any HO request, then knowing FAP mode is an important issue. In this case, reference FAP is initially in FIM, so changes its mode from idle to active occurs before checking the source of HO request. Now, if reference FAP is initially in FAM, then reference FAP does not need to change its present mode, because in that case, reference FAP has at least one active FUE within its coverage area and, then reference FAP starts checking the source of HO request. There is two possible sources from which HO request may come to reference FAP. One source is MBS and, the other source is neighbor FAPs. If HO request is initiated from MBS, then reference active FAP response to HO request in order to successful HO and here handed over UE is active MUE but treating as active M_FUE (M_FUE denotes FUE but handed over from MBS) while MUE moves from edge to centre of serving reference active FAP. This active M_FUE is served during its active period. Again, if UE is idle M_FUE and no other active FUE is there, then active FAP becomes idle. Now, if HO request is originated from neighbor FAP, then reference active FAP responses to HO request in order to successful HO and UE is active FUE but treating as active N_FUE (N_FUE denotes FUE but handed over from neighbor FAPs) while FUE moves from edge to centre of serving reference active FAP. Also this active N_FUE is served during its active period. Here, if UE is idle N_FUE and no other active FUE is there, then active FAP becomes idle. If no HO request is there, then repeats HO request searching process from beginning.

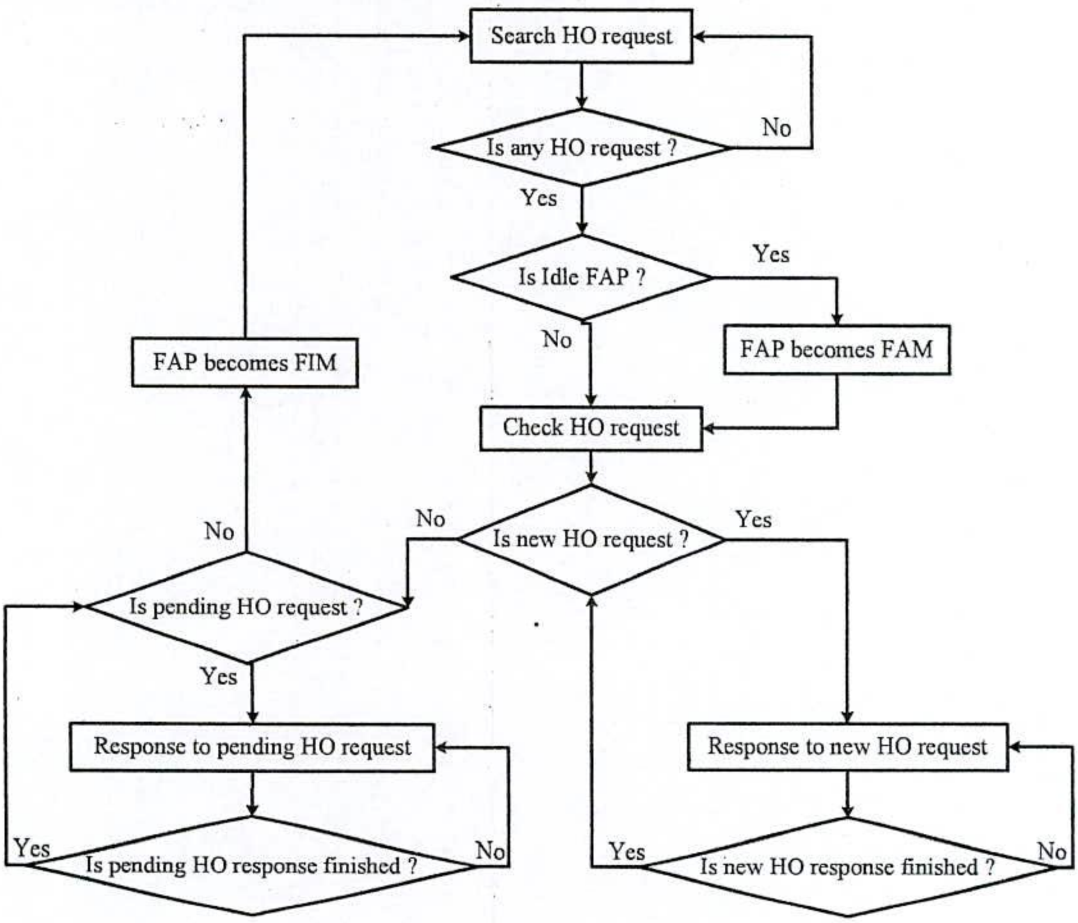


Fig. 4.6. Flow diagram of reference FAP pending HO response mechanism.

During HO response processing time there is a possibility of multiple HO requests initiation from different sources for same reference FAP at the same time. In a situation, where both MBS and neighbor FAP sends HO request to same reference FAP but reference FAP responses neighbor FAP HO request first, because of acknowledging the HO request from any neighbor FAPs is easy and faster than acknowledging the HO request from MBS, while neighbor FAPs are located very close to reference FAP. From this simple case it is obvious that, sometimes there are possibilities that pending HO request may occur. Fig. 4.6 depicts the basic flow diagram of pending HO request processing by any reference FAP. Here considering that, initially reference FAP is in idle mode with no active user. Now, at the beginning of the process shown in Fig. 6, reference FAP starts searching HO request with beacon transmit. If reference FAP detects any HO request, then reference FAP changes its mode according to requirement from idle to active or vice-versa and start checking HO type. There are two types of HO requests. Firstly, pending HO request, which is initiated from different source while reference FAP is acknowledging HO request not belong to that source and secondly, new HO request, which is initiated from same source successively and reference FAP acknowledges all HO requests accordingly. If HO request is new request, then reference serving FAP responses to new HO request. Otherwise, if HO request is pending request, then reference serving FAP responses to pending HO request. If no HO request is there after acknowledging all HO requests, then reference FAP repeats HO request searching procedure with FIM or FAM depending on requirement of reference FAP present state.

Chapter 5

Mathematical Model for Capacity Analysis

There are various interference sources present in the femtocell network; in particular, among femtocells, and between femtocells and macrocells. In addition, the noise is an element of the wireless environment. These interferences and the noise affect the capacity of the wireless link. In this section, the SNIR level, throughput, and probability of activeness of a FAP analyses are provided.

5.1 SNIR and capacity analysis

The path loss model [19], [26] used for reference macrocell is

$$L_m = 36.55 + 26.16\log_{10}(f_{ue}) - 3.82\log_{10}(h_m) - [1.1\{\log_{10}(f_{ue}) - 0.7\}(h_{ue}) \\ - \{1.56\log_{10}(f_{ue}) - 0.8\}] + [44.9 - 6.55\log_{10}(h_m)]\log_{10}(d_m) + L_{sh} \quad (1)$$

where L_m is path loss exponent for reference macro-BS in dB, f_{ue} is centre frequency of the macrocell in *MHz*, d_m is distance between the reference macro-BS and the active FUE in *kilometer*, h_{ue} is height of mobile station in meter, h_m is height of macro-BS in meter, L_{sh} is shadowing standard deviation in dB.

The path loss model [4] used for reference femtocell is

$$L_r = 20\log_{10}(f_{ue}) + N\log_{10}(d_r) - 28 \quad (2)$$

where L_r is path loss exponent for reference FAP in dB, f_{ue} is centre frequency of the femtocell in *MHz*, d_r is distance between the reference FAP and the active FUE in *meter*, N =28 (a constant value).

The path loss model [19], [26] used for neighbor femtocell is

$$L_i = 20\log_{10}(f_{ue}) + N\log_{10}(d_i) + 4(n_i)^2 - 28 \quad (3)$$

where L_i is path loss exponent for i-th active neighbor FAP in dB, d_i is the distance between *i*-th neighbor FAP and the active FUE in *meter*, n_i is number of walls between the FUE and the *i*-th neighbor FAP.

The equation of received power [19], [26] for reference femtocell is calculated as

$$P_R = P_o 10^{(\frac{-L_r}{10})} \tag{4}$$

where P_R is power received by reference FAP, P_o is power of the signal from the reference FAP.

The equations of SNIR for a user within the reference femtocell without ODSC scheme (typical) [19], [26] and with ODSC scheme (proposed) are, respectively

$$SNIR_r = \frac{P_R}{P_o 10^{(\frac{-L_r}{10})} + I_m + N} \tag{5}$$

$$SNIR_r = \frac{P_R}{a_r P_o 10^{(\frac{-L_r}{10})} + I_m + N} \tag{6}$$

where $SNIR_r$ is signal-to-noise plus interference ratio level for a user within the reference FAP having typical (without ODSC scheme) power transmission mode and FAP having proposed (with ODSC scheme) power transmission mode, respectively, a_r is activity factor of all interfering idle FAPs, I_m is total power of the interference from all of the interfering macrocells, N is total power of the received noise.

The equations of SNIR for a user within the neighbor femtocell without ODSC scheme (typical) [19], [26] and with ODSC scheme (proposed) are, respectively

$$SNIR_i = \frac{P_R}{\sum_{i=1}^{N_F} P_o 10^{\frac{-L_i}{10}} + I_m + N} \tag{7}$$

$$SNIR_i = \frac{P_R}{\sum_{i=1}^{N_F} a_i P_o 10^{\frac{-L_i}{10}} + I_m + N} \tag{8}$$

where $SNIR_i$ is signal-to-noise plus interference ratio level for a user within the i-th active neighbour FAP having typical (without ODSC scheme) power transmission mode and FAP having proposed (with ODSC scheme) power transmission mode, respectively, a_i is activity factor of i-th interfering active FAP, N_F is total number of neighbor FAPs, N is total power of the received noise.

Assuming that the spectrums of the transmitted signals are spread, we can approximate the interference as additive white Gaussian noise (AWGN). The Shannon equation [4] for capacity is known as

$$C = W \log_2(1 + SNIR) \tag{9}$$

where C is the capacity used in Shannon equation in bps/Hz, W is the bandwidth used in Shannon equation in Hz.

5.2 Probability of outage analysis

In general, the probability of outage of a FUE is calculated [4] as

$$P_{out_{fue}} = P_r(SNIR < \gamma_o) \tag{10}$$

where $P_{out_{fue}}$ is the probability of outage of an active FUE within FAP having typical (without ODSC scheme) power transmission mode, γ_o is a threshold value of $SNIR$ below which there is no acceptable reception in FAP coverage area.

In proposed ODSC scheme, the probability of outage of a FUE is calculated as

$$P_{out_{fue}} = P_A P_r(SNIR < \gamma_o) \tag{11}$$

where $P_{out_{fue}}$ is the probability of outage of an active FUE within FAP having proposed (with ODSC scheme) power transmission mode, P_A is the probability of activeness of a FAP.

Considering in typical scheme reference active femtocell and interfering reference macrocell, the probability of outage can be expressed [4] as

$$\begin{aligned} P_{out_r} &= \left(1 - e^{-\frac{\gamma_o}{SNIR_r}}\right) \\ &= \left(1 - e^{-\frac{\gamma_o}{P_R}\left(P_n 10^{\left(\frac{-L_f}{10}\right)} + I_m + N\right)}\right) \end{aligned} \tag{12}$$

where P_{out_r} is the probability of outage of an active FUE under coverage area of reference active FAP in single power mode FAP deployment with all neighbor active FAPs.

Considering in proposed scheme reference active femtocell and interfering reference macrocell, the probability of outage can be expressed as

$$P_{out_r} = P_A\left(1-e^{-\frac{\gamma_o}{SNIR_r}}\right) = P_A\left(1-e^{-\frac{\gamma_o}{P_R}(a_r P_o 10^{(\frac{-l_r}{10})}+I_m+N)}\right) \tag{13}$$

where P_{out_r} is the probability of outage of an active FUE under coverage area of reference active FAP in dual power mode FAP deployment with all neighbor idle FAPs.

Considering in typical scheme all the interfering neighbor active femtocells and interfering reference macrocell, the probability of outage can be expressed [4] as

$$P_{out_i} = \left(1-e^{-\frac{\gamma_o}{SNIR_i}}\right) = \left(1-e^{-\frac{\gamma_o}{P_R}(\sum_{i=1}^{N_F} P_o 10^{\frac{-l_i}{10}}+I_m+N)}\right) \tag{14}$$

where P_{out_i} is the probability of outage of an active FUE under coverage area of reference active FAP in single power mode FAP deployment with all neighbor active FAPs.

Considering in proposed scheme half of all the interfering neighbor active femtocells and interfering reference macrocell, the probability of outage can be expressed as

$$P_{out_i} = P_A\left(1-e^{-\frac{\gamma_o}{SNIR_i}}\right) = P_A\left(1-e^{-\frac{\gamma_o}{P_R}(\sum_{i=1}^{N_F} a_i P_o 10^{\frac{-l_i}{10}}+I_m+N)}\right) \tag{15}$$

where P_{out_i} is the probability of outage of an active FUE under coverage area of reference active FAP in dual power mode FAP deployment with all neighbor active FAPs.

5.3 Probability of activeness of a FAP analysis

The FUE state defines the average duration (T_{av}) of any FAP active mode. We can define maximum probability (P_{max}) of all FAPs active mode when number of K users use discrete time while using a particular FAP as

$$P_{\max} = \begin{cases} \dfrac{N_u T_{av}}{24N_F}, & N_u T_{av} \le 24N_F \\ 1, & N_u T_{av} \ge 24N_F \end{cases} \tag{16}$$

where $P_{\max}$ is the maximum probability of activeness of all active FAP, T_{av} is the average service time per day per user in *hour*, N_u is the maximum number of total users.

Assume maximum K number of users can be supported by any FAP. Probability of serving FUE is

$$P_1 = P_2 = \cdots = P_j = \frac{1}{K}, \qquad 1 \le j \le K \tag{17}$$

where P_j is the probability of j number of FUE which is connected with active FAP.

The probability of not serving any FUE by any FAP is

$$P_I = 1 - P_A \tag{18}$$

where P_I is the probability of idle FAP which serves no user.

Now probability that any FAP is in active mode is

$$P_A = \begin{cases} 1, & 24N_F K \le \sum_{J=1}^{K} N_u T_{av} j^{-1} \\ \dfrac{1}{24N_F K} \sum_{J=1}^{K} N_u T_{av} j^{-1}, & 24N_F K > \sum_{J=1}^{K} N_u T_{av} j^{-1} \end{cases} \tag{19}$$

where P_A is the probability of activeness of a FAP.

Chapter 6

Simulation Results

In this section, by using Matlab simulation results of SNIR level, throughput, and probability of activeness of a FAP are provided. Table 6.1 summarizes the values of the parameters that are used in analysis. Femtocell in the multistoried building or home environment and the overlaid macrocell are deployed through dynamic frequency-reuse scheme are assumed.

Table 6.1. Summary of the parameter values used in analysis

Parameter	Value
Femtocell coverage area	10 m [4]
Distance between the FAP and active FUE	5 m
Distance between two FAP centers	20 m
Carrier frequency	1800 MHz [4]
Transmit signal power by the macrocellular BS	1.5 kW [4]
Transmitted signal power by a FAP	15 mW [4]
Height of a macrocellular BS	100 m [4]
Height of a FAP	2 m
Threshold value of SNIR at FAP inner boundary region for active FUE (γ_i)	12.55 dB
Threshold value of SNIR at FAP outer boundary region for active FUE (γ_o)	8.21 dB
Noise power (N)	6.9882×10^{-7} mW
Number of walls between the active FUE and the i-th neighbor FAP (n_i)	1 (for 1st tier), 2 (for 2nd tier) [4]
Number of neighbor FAPs (N_F) for SNIR and throughput analyses	30(for SNIR, throughput), 50(for P_A)
Activity factor for reference FAP (a_r)	0 (for FIM), 1 (for FAM)
Activity factor for neighbor FAP (a_i)	0 (for FIM), 1 (for FAM)

6.1 SNIR comparison

Fig. 6.1 shows the SNIR analysis with (a) probability that a neighbor FAP is in active mode, (b) number of neighbor active FAPs. Probability zero means no neighbor FAP is in active mode in proposed ODSC scheme [Fig. 6.1(a)]. For instance, probability factor 0.4 indicates total number of active FAPs is 12 out of 30 neighbor active FAPs. When all FAPs are in active mode i.e. single power mode FAPs deployment scheme, then probability factor is always unity. From the Fig. 6.1(a), it can be seen that, when probability factor is zero, then SNIR is at maximum level for proposed ODSC scheme and for other scheme its value is always constant. At the unity probability factor, the SNIR for both cases are equal. The performance curve of proposed ODSC scheme is always higher than other performance curve, but both curves intersect only at unity probability factor point. More SNIR means better the signal quality for serving any active FUE and SNIR varies in proposed ODSC scheme in

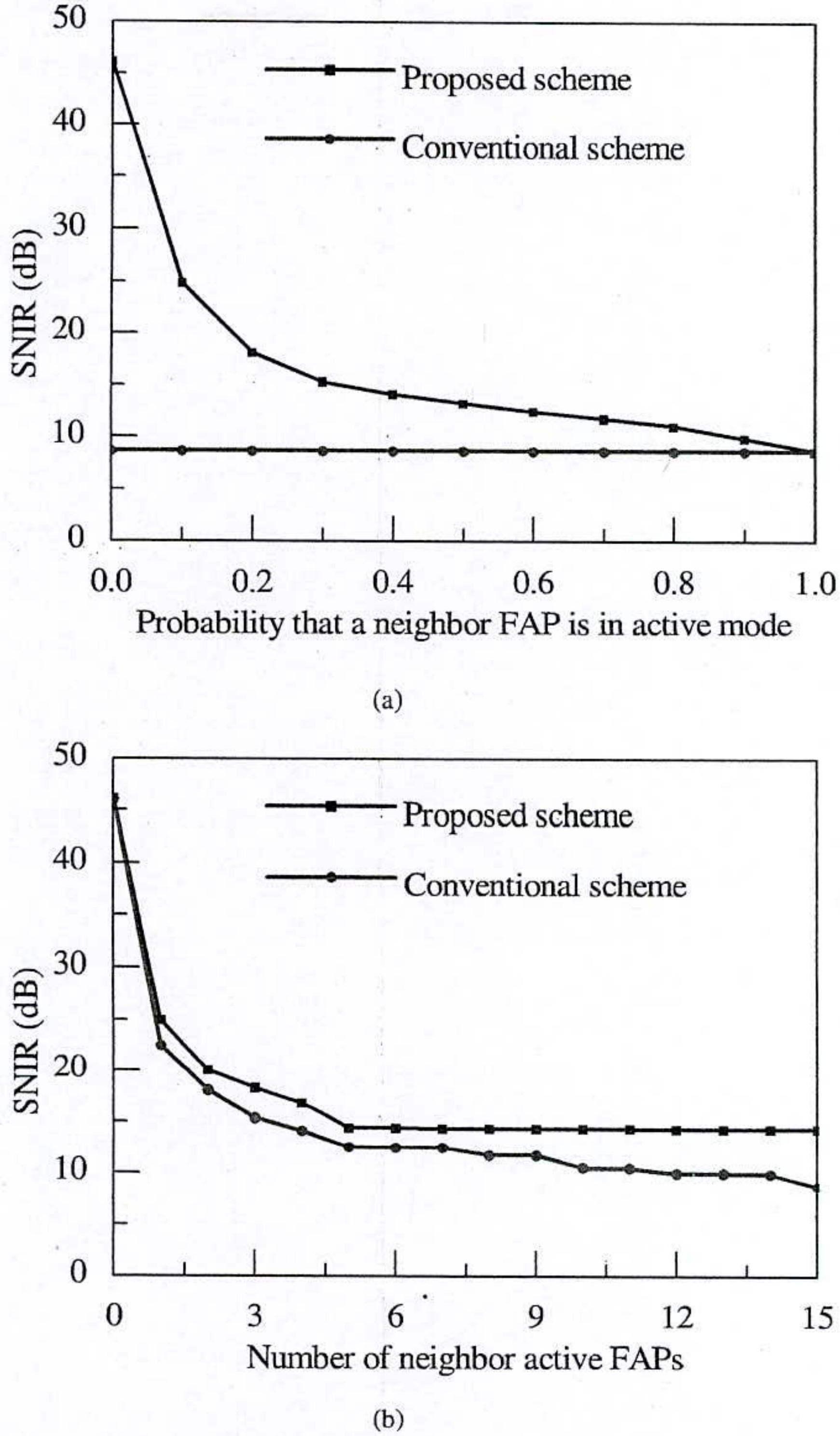


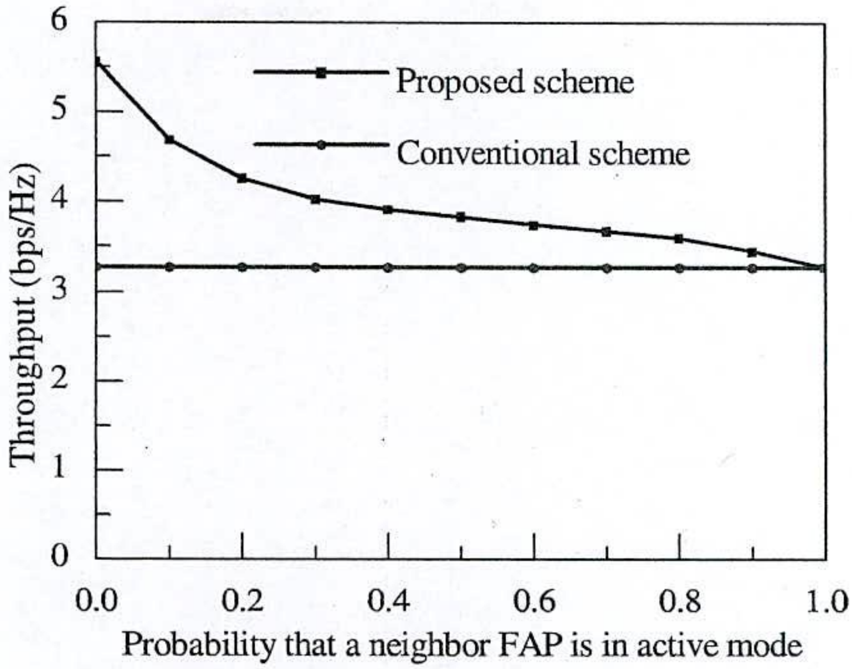
Fig. 6.1. SNIR analysis with (a) probability that a neighbor FAP is in active mode, (b) number of neighbor active FAPs.

accordance with probability of neighbor active FAPs. So, lower interference effect can be achieved. In proposed ODSC scheme [Fig. 6.1(b)] maximum and minimum SNIR occurs at zero and fifteen (randomly chosen) neighbor active FAP point, respectively, depicts the wide range of throughput variation. But the performance curve with single power mode FAPs deployment scheme is a straight line with a constant throughput value. The performance curve of proposed ODSC scheme is always above than the other curve. The higher value of SNIR in ODSC scheme provides less interference effect in serving any active FUE by reference active FAP.

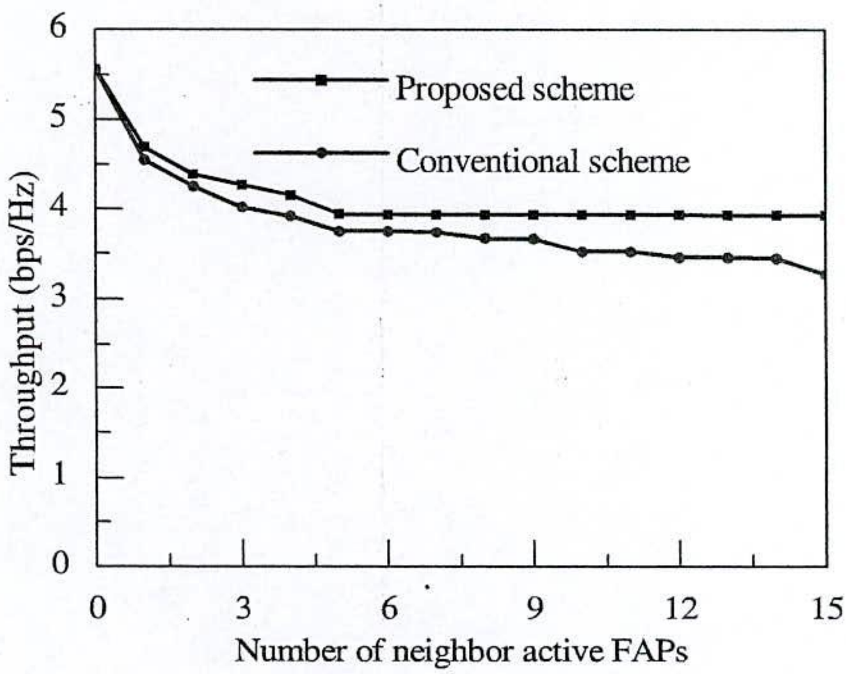
6.2 Throughput comparison

Fig. 6.2 shows the throughput analysis with (a) probability that a neighbor FAP is in active mode, (b) number of neighbor active FAPs. Performance curve [Fig. 6.2(a)] of proposed ODSC scheme is higher than that of the performance curve where all FAPs are always active. Throughput of proposed ODSC scheme varies in accordance with number of neighbor active FAPs, but for other scheme it is constant. More throughput means higher capacity per head user and hence, it varies in proposed ODSC scheme in accordance with probability factor of active FAPs. So, better QoS can be ensured. The throughput performance curve [Fig. 6.2(b)] follows the SNIR performance curve shown in Fig. 6.1(b). Hence, in proposed ODSC scheme maximum throughput per head user gives femtocell user connectivity with higher capacity. So, better QoS can be ensured with proposed ODSC scheme.

All four performance curves in Fig. 6.1 and Fig. 6.2 show that, the radio resource used is variable in accordance with number of active FAPs. So, intelligent interference management system is ensured efficiently because when all FAPs are in FIM, then very low power is consumed by all FAPs.



(a)

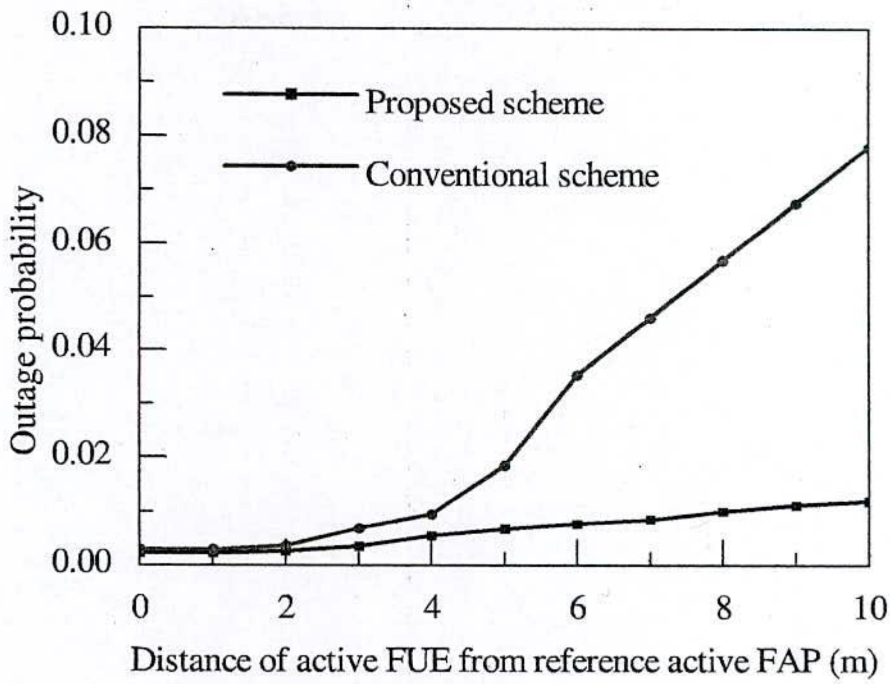


(b)

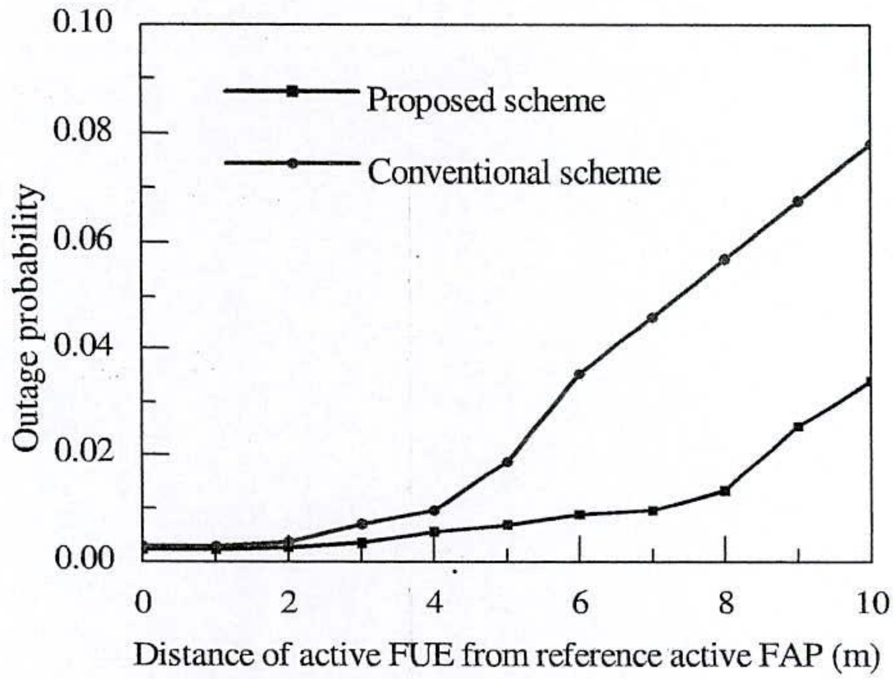
Fig. 6.2. Throughput analysis with (a) probability that a neighbor FAP is in active mode, (b) number of neighbor active FAPs.

6.3 Probability of outage observation

Fig. 6.3 shows the probability of outage of an active FUE under reference active FAP for K=1 with (a) all neighbor idle FAPs, (b) 50% neighbor idle FAPs. Fig. 6.3(a) shows the probability of outage of an active FUE under coverage area of reference active FAP of dual power mode with all neighbor idle FAPs and single power mode with all neighbor active FAPs, respectively. Here, probability of outage of single power mode reference active FAP is initially very low and it increases gradually because all neighbor FAPs are active. However, probability of outage curve for dual power mode reference active FAP remains almost near the zero probability line because of all neighbor FAPs are in idle mode and always less than other scheme curve. Fig. 6.3(b) shows the probability of outage of an active FUE under coverage area of reference active FAP of dual power mode with 50% neighbor idle FAPs and single power mode with all neighbor active FAPs, respectively. Here, probability of outage of an active FUE under coverage area of single power mode reference active FAP is same as that shown in Fig. 6.3(a), but probability of outage curve in dual power mode reference active FAP is more than that of Fig. 6.3(a).



(a)



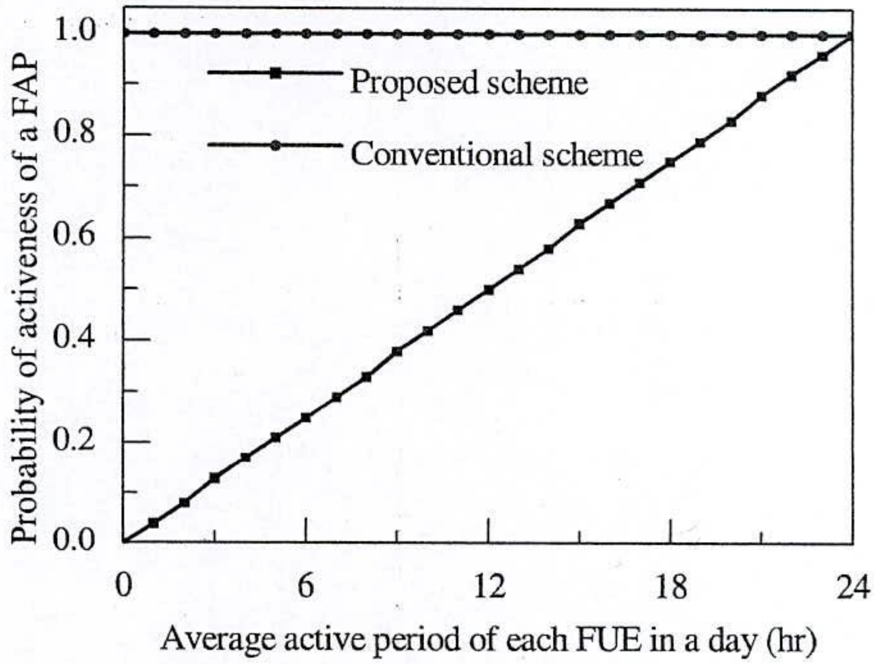
(b)

Fig. 6.3. Probability of outage of an active FUE under reference active FAP for K=1 with (a) all neighbor idle FAPs, (b) 50% neighbor idle FAPs.

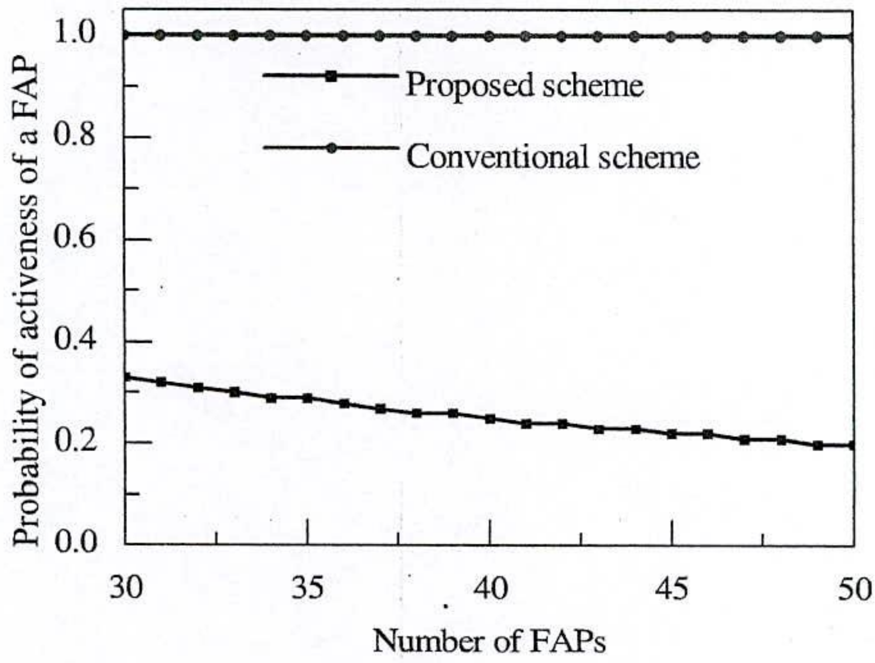
6.4 Probability of activeness of a FAP observation

Fig. 6.4 shows the probability of FAP activeness analysis for K=1 and FUE=30 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of

8 hrs for each FUE at a day. From Fig. 6.4, it can be seen that, all FAP support one (as K=1) FUE. Fig. 6.4(a) shows the probability of FAP activeness curve, increasing in nature and becomes unity after a certain period for proposed ODSC scheme. The probability curve of other scheme is always unity. The probability of FAP activeness curve [Fig. 6.4(b)] of proposed ODSC scheme decreasing in nature with increasing number of FAPs and never touches the unity probability curve of single power mode FAPs deployment scheme.



(a)



(b)

Fig. 6.4. Probability of FAP activeness analysis for K=1 and FUE=30 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day.

Fig. 6.5 shows the probability of FAP activeness analysis for K=3 and FUE=30 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day. From Fig. 6.5, it can be seen that, all FAP support one (as K=3) FUE. Fig. 6.5(a) shows the probability of FAP activeness curve, increasing in nature and never becomes unity after a certain period for proposed ODSC scheme. The probability curve of other scheme is always unity. The probability of FAP activeness curve [Fig. 6.5(b)] of proposed ODSC scheme decreasing in nature with increasing number of FAPs and never touches the unity probability curve of single power mode FAPs deployment scheme.

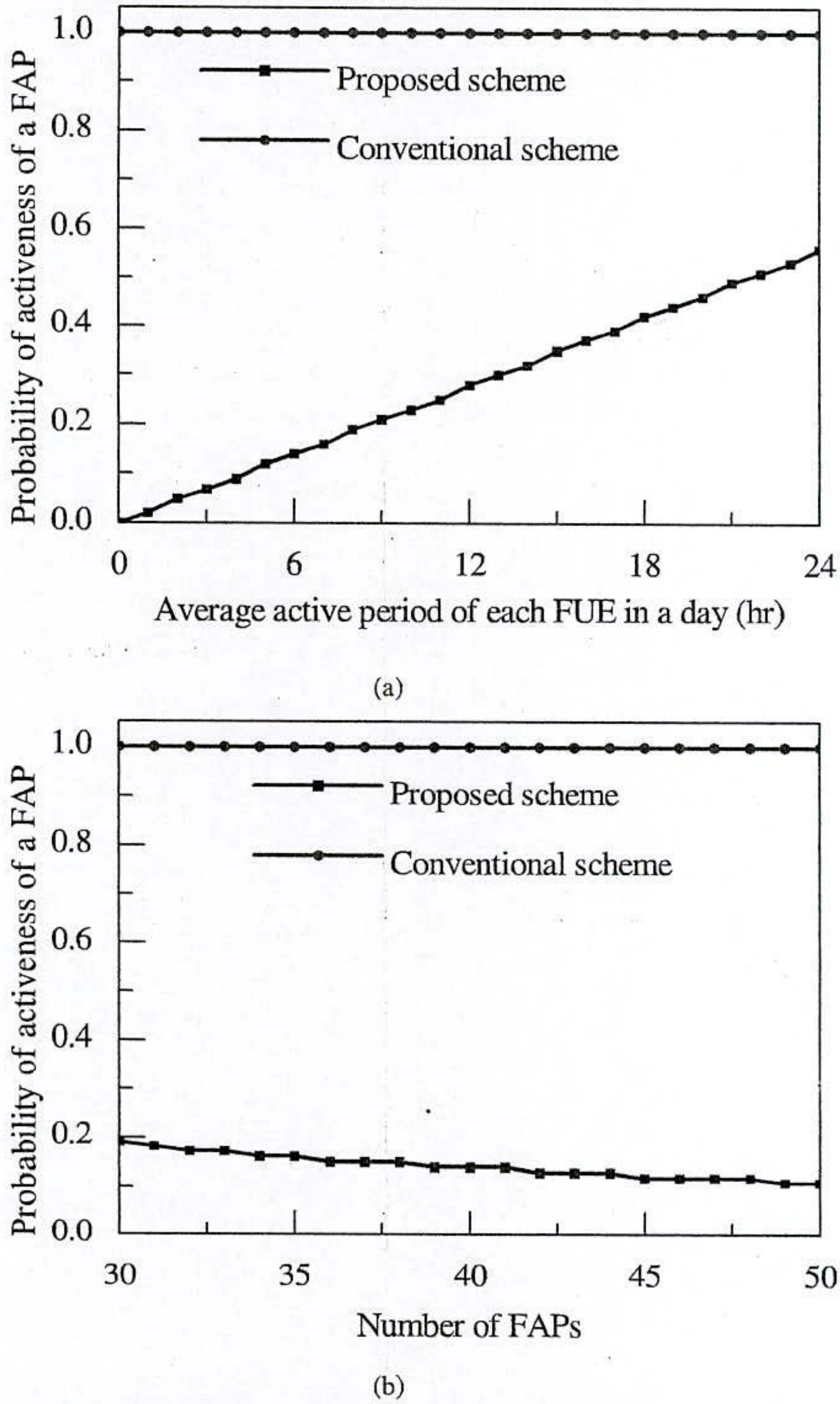
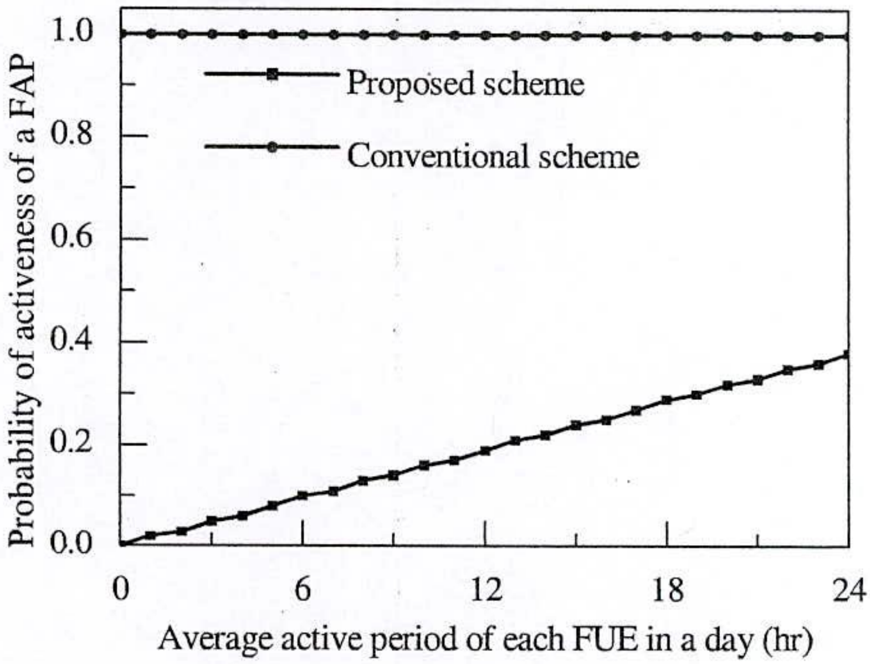
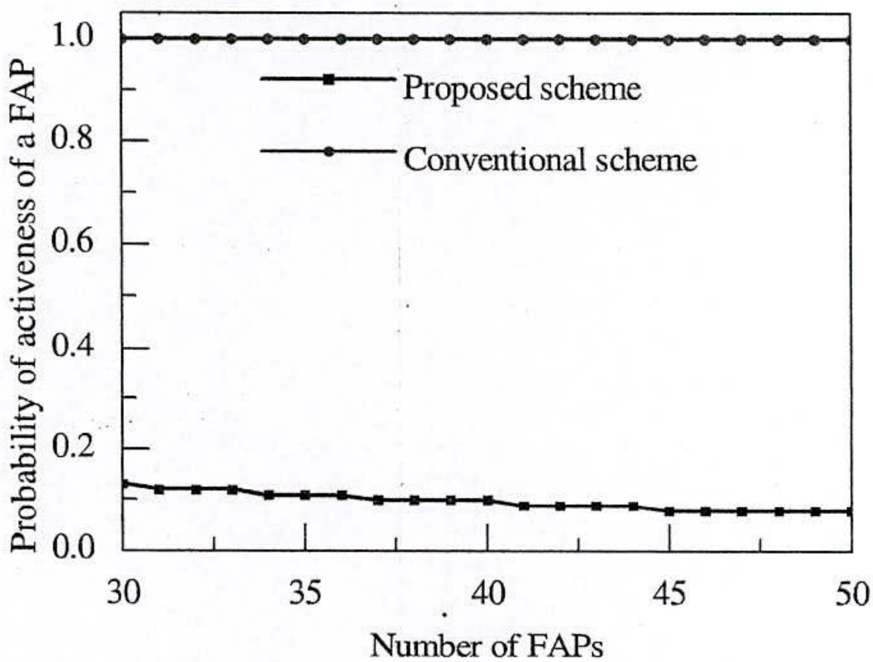


Fig. 6.5. Probability of FAP activeness analysis for K=3 and FUE=30 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day.

Fig. 6.6 shows the probability of FAP activeness analysis for K=6 and FUE=30 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day. From Fig. 6.6, it can be seen that, all FAP support one (as K=6) FUE. Fig. 6.6(a) shows the probability of FAP activeness curve, increasing in nature and never becomes unity after a certain period for proposed ODSC scheme and below the performance curve shown in Fig. 6.5(a). The probability curve of other scheme is always unity. The probability of FAP activeness curve [Fig. 6.6(b)] of proposed ODSC scheme decreasing in nature with increasing number of FAPs and never touches the unity probability curve of single power mode FAPs deployment scheme.



(a)



(b)

Fig. 6.6. Probability of FAP activeness analysis for K=6 and FUE=30 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day.

Fig. 6.7 shows the probability of FAP activeness analysis for K=1 and FUE=50 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day. From Fig. 6.7, it can be seen that, all FAP support one (as K=1) FUE. Fig. 6.7(a) shows the probability of FAP activeness curve, increasing in nature and becomes unity after a certain period for proposed ODSC scheme. The probability curve of other scheme is always unity. The probability of FAP activeness curve [Fig. 6.7(b)] of proposed ODSC scheme decreasing in nature with increasing number of FAPs and never touches the unity probability curve of single power mode FAPs deployment scheme.

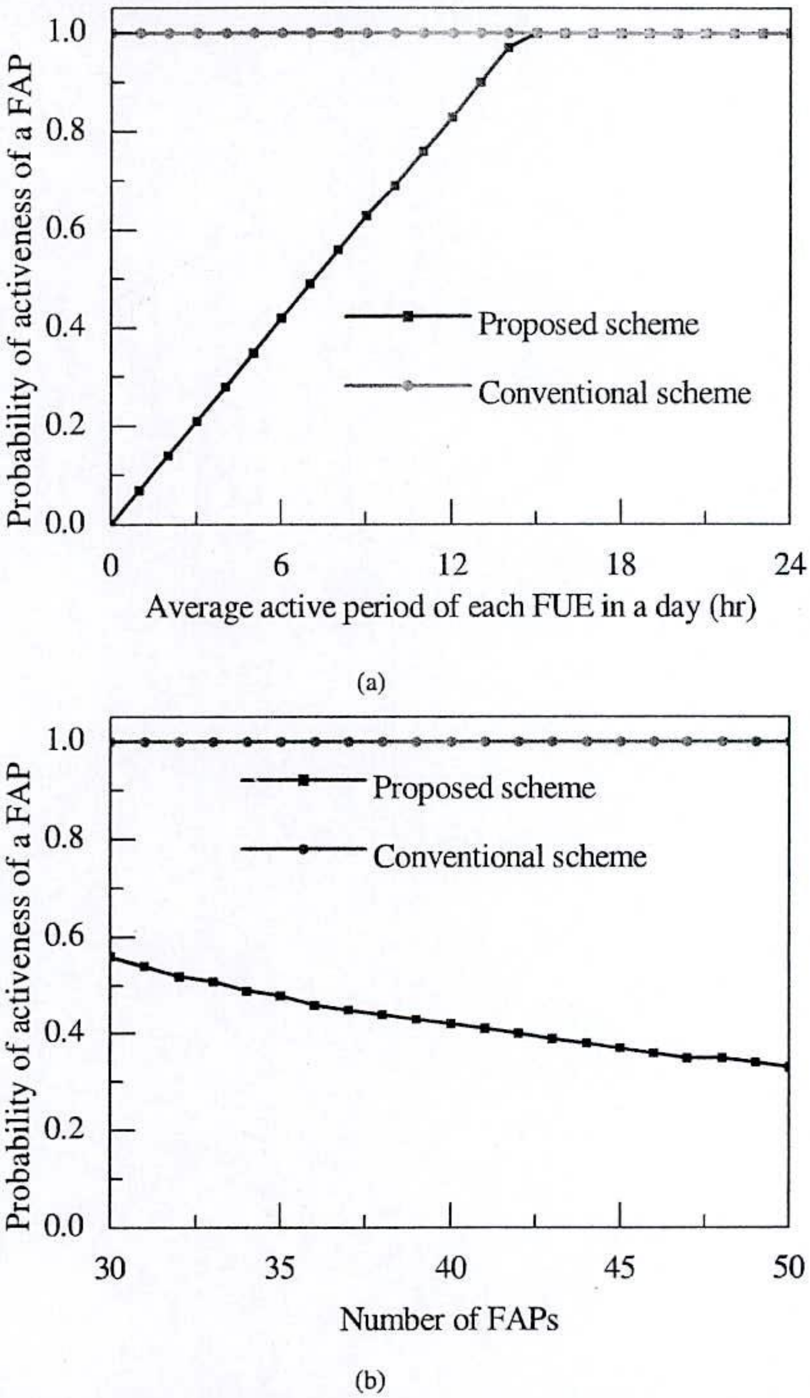


Fig. 6.7. Probability of FAP activeness analysis for K=1 and FUE=50 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day.

Fig. 6.8 shows the probability of FAP activeness analysis for K=3 and FUE=50 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of

8 hrs for each FUE at a day. From Fig. 6.8, it can be seen that, all FAP support three (as K=3) FUEs. Fig. 6.8(a) shows the probability of FAP activeness curve, increasing in nature and stays below unity probability of FAP activeness point for proposed ODSC scheme. The probability curve of other scheme is always unity. Fig. 6.8(b) also shows the same characteristics as given by Fig. 6.7(b), but starting or maximum probability of FAP activeness point is almost half of that as shown in Fig. 6.8(b).

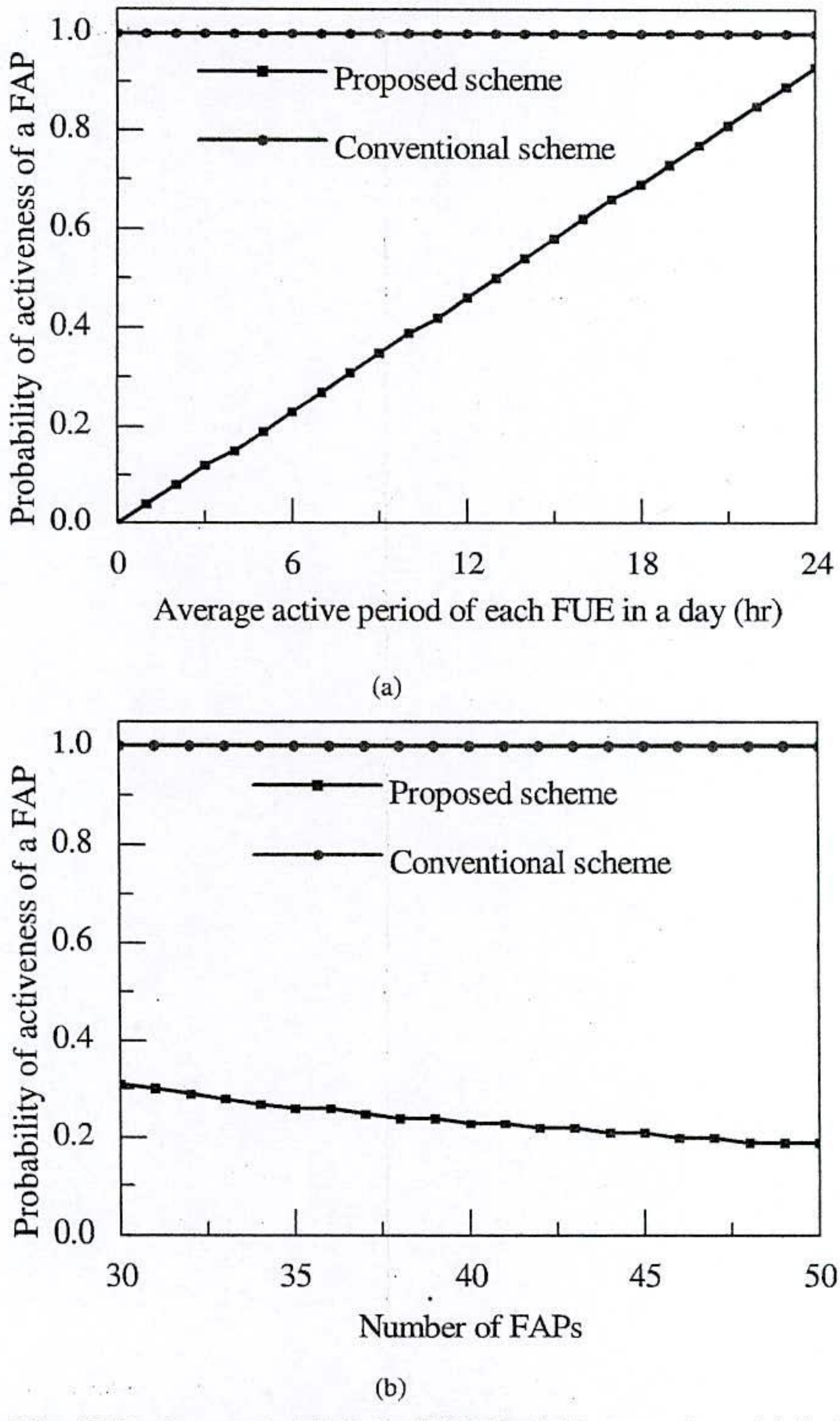
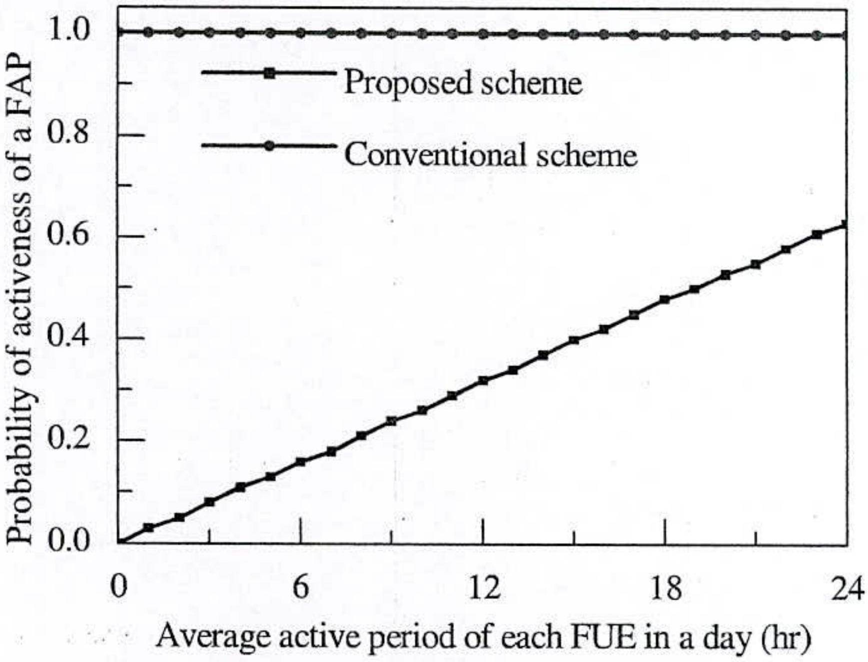
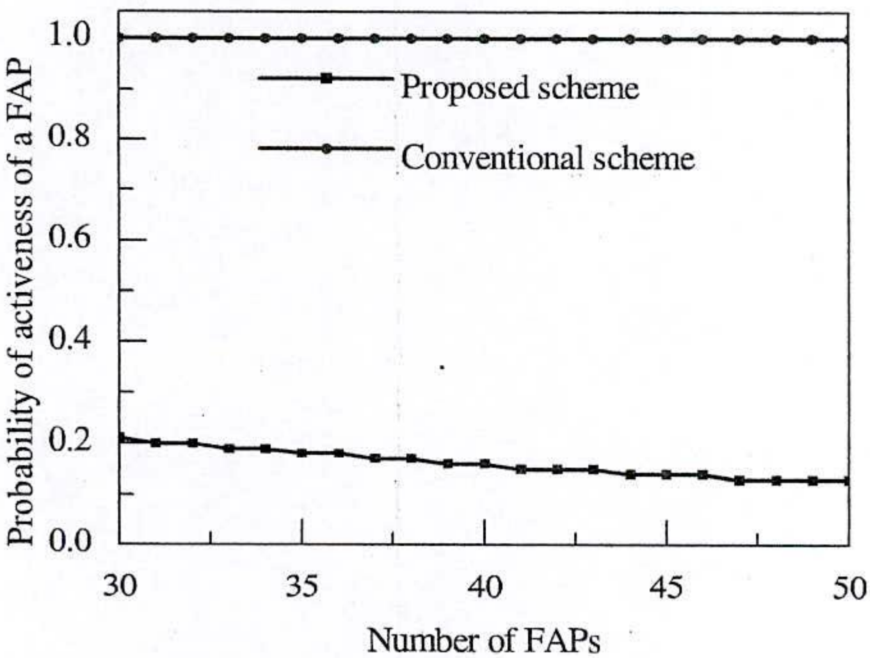


Fig. 6.8. Probability of FAP activeness analysis for K=3 and FUE=50 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day.

Fig. 6.9 shows the probability of FAP activeness analysis for K=6 and FUE=50 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day. From Fig. 6.9, it can be seen that, all FAP support one (as K=6) FUE. Fig. 6.9(a) shows the probability of FAP activeness curve, increasing in nature and never becomes unity after a certain period for proposed ODSC scheme and below the performance curve shown in Fig. 6.8(a). The probability curve of other scheme is always unity. The probability of FAP activeness curve [Fig. 6.9(b)] of proposed ODSC scheme decreasing in nature with increasing number of FAPs and never touches the unity probability curve of single power mode FAPs deployment scheme and below the performance curve shown in Fig. 6.8(b).



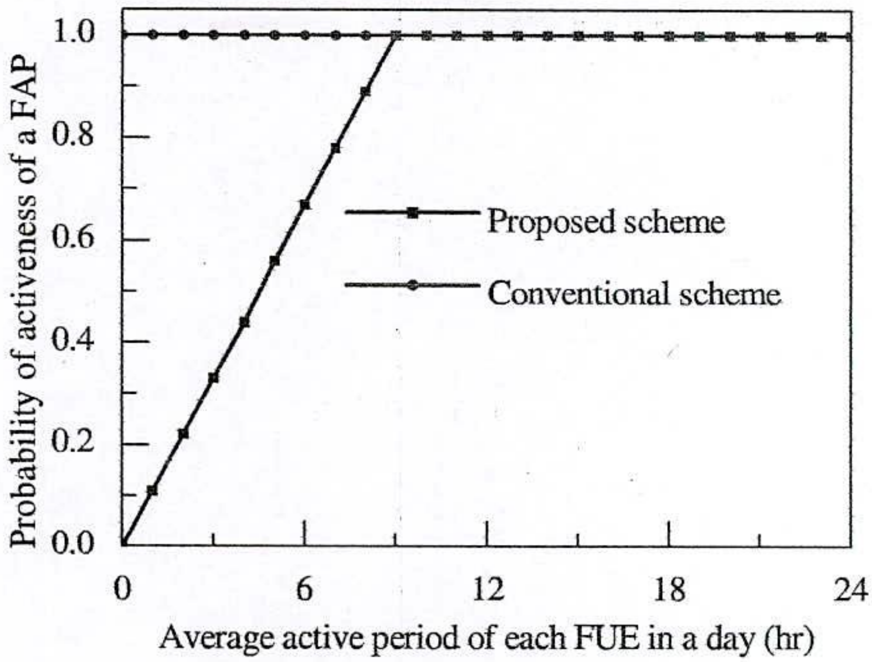
(a)



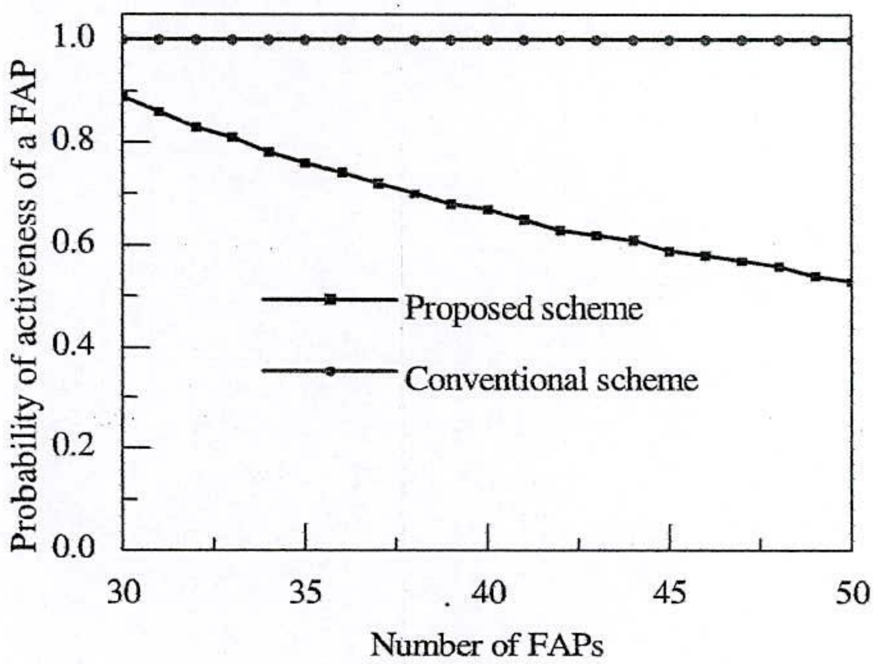
(b)

Fig. 6.9. Probability of FAP activeness analysis for K=6 and FUE=50 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day.

Fig. 6.10 shows the probability of FAP activeness analysis for K=1 and FUE=80 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day. From Fig. 6.10, it can be seen that, all FAP support one (as K=1) FUE. Fig. 6.10(a) shows the probability of FAP activeness curve, increasing in nature and becomes unity after a certain period for proposed ODSC scheme. The probability curve of other scheme is always unity. The probability of FAP activeness curve [Fig. 6.10(b)] of proposed ODSC scheme decreasing in nature with increasing number of FAPs and never touches the unity probability curve of single power mode FAPs deployment scheme.



(a)



(b)

Fig. 6.10. Probability of FAP activeness analysis for K=1 and FUE=80 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day.

Fig. 6.11 shows the probability of FAP activeness analysis for K=3 and FUE=80 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day. From Fig. 6.11, it can be seen that, all FAP support one (as K=3) FUE. Fig. 6.11(a) shows the probability of FAP activeness curve, increasing in nature and becomes unity with delayed than shown in Fig 6.10(a) after a certain period for proposed

ODSC scheme. The probability curve of other scheme is always unity. The probability of FAP activeness curve [Fig. 6.11(b)] of proposed ODSC scheme decreasing in nature with increasing number of FAPs and never touches the unity probability curve of single power mode FAPs deployment scheme and this curve is below the performance curve shown in Fig. 6.10(b).

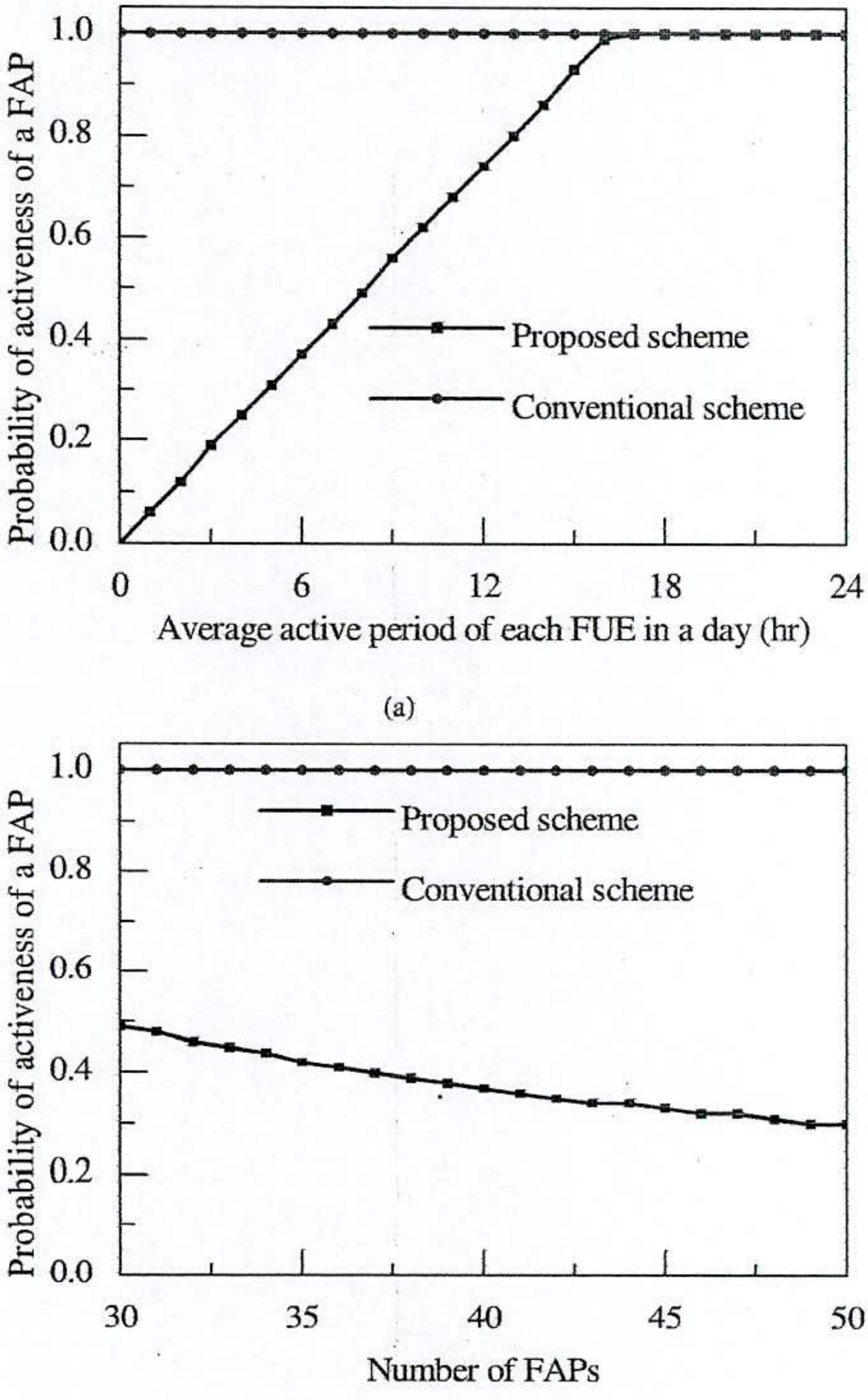
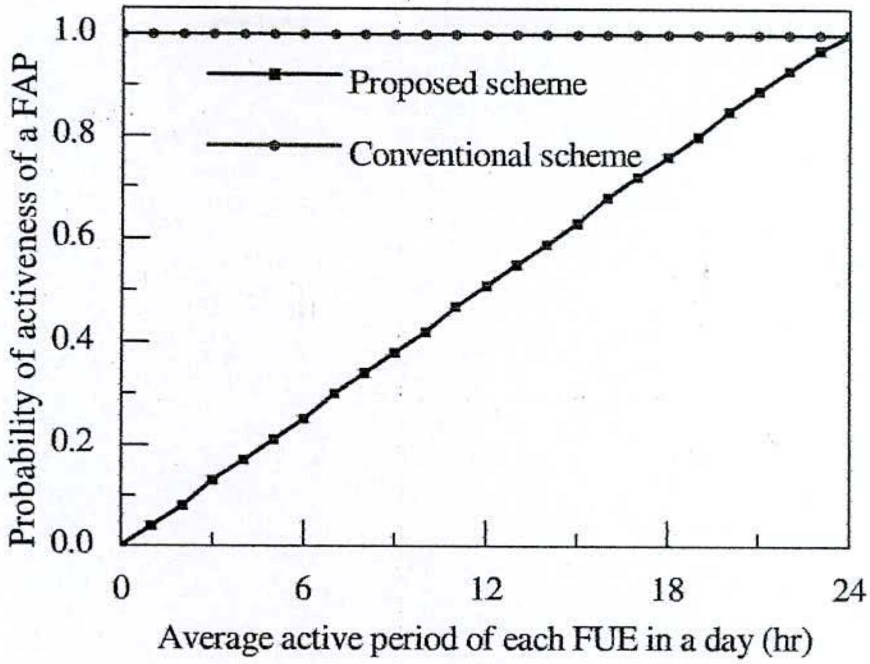
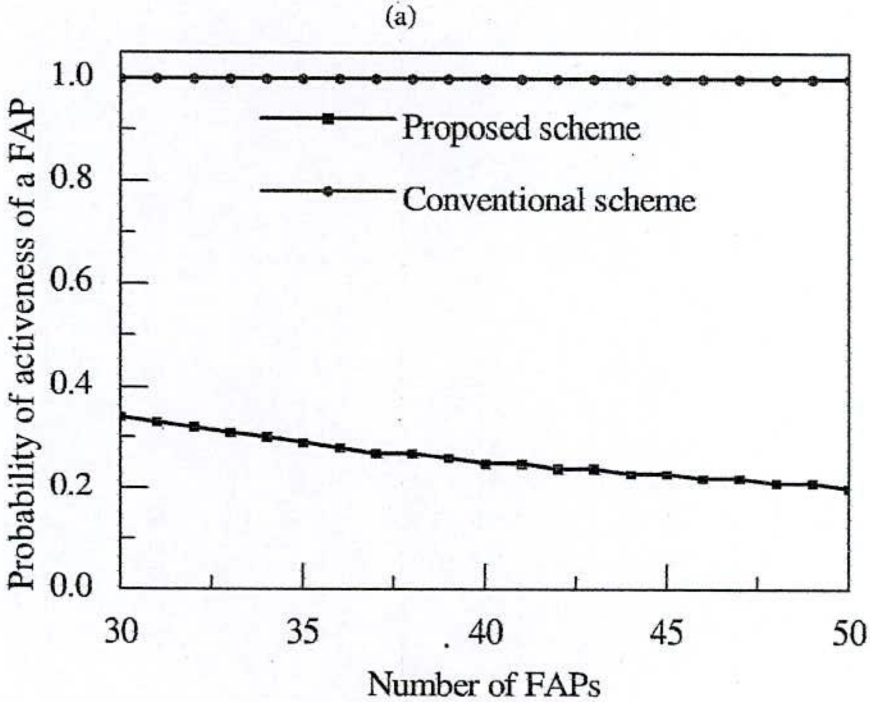


Fig. 6.11. Probability of FAP activeness analysis for K=3 and FUE=80 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day.

Fig. 6.12 shows the probability of FAP activeness analysis for K=6 and FUE=80 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day. From Fig. 6.12, it can be seen that, all FAP support one (as K=6) FUE. Fig. 6.12(a) shows the probability of FAP activeness curve, increasing in nature and becomes unity with more delayed than curve shown in Fig. 6.11(a) after a certain period for proposed ODSC scheme. The probability curve of other scheme is always unity. The probability of FAP activeness curve [Fig. 6.12(b)] of proposed ODSC scheme decreasing in nature with increasing number of FAPs and never touches the unity probability curve of single power mode FAPs deployment scheme and much below than the curve shown in Fig. 6.11(b).



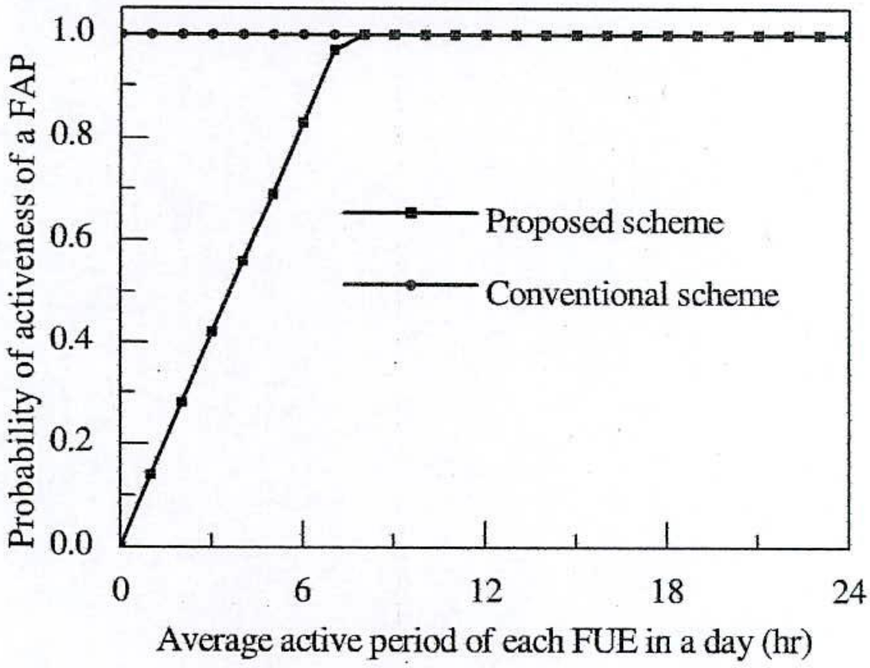
(a)



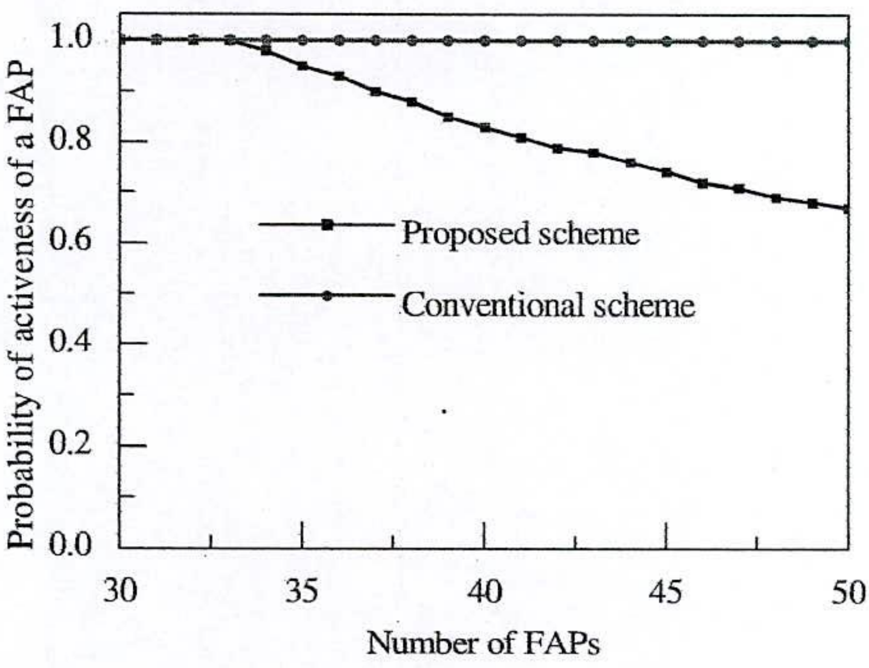
(b)

Fig. 6.12. Probability of FAP activeness analysis for K=6 and FUE=80 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day.

Fig. 6.13 shows the probability of FAP activeness analysis for K=1 and FUE=100 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day. From Fig. 6.13, it can be seen that, all FAP support one (as K=1) FUE. Fig. 6.13(a) shows the probability of FAP activeness curve, increasing in nature and becomes unity after a certain period which is earlier than, that shown in Fig. 6.7(a) for proposed ODSC scheme. The probability curve of other scheme is always unity. The probability of FAP activeness curve [Fig. 6.14(b)] of proposed ODSC scheme which is much higher than, that shown in Fig. 6.7(b), after a certain period it touches the unity probability curve of other scheme and, then decreasing in nature with increasing number of FAPs.



(a)



(b)

Fig. 6.13. Probability of FAP activeness analysis for K=1 and FUE=100 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day.

Fig. 6.14 shows the probability of FAP activeness analysis for K=3 and FUE=100 with

(a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day. From Fig. 6.14, it can be seen that, all FAP support one (as K=3) FUE. Fig. 6.14(a) shows the probability of FAP activeness curve, increasing in nature and becomes unity after a certain period which is delayed than, that shown in Fig. 6.13(a) for proposed ODSC scheme. The probability curve of other scheme is always unity. The probability of FAP activeness curve [Fig. 6.14(b)] of proposed ODSC scheme which is much lower than, that shown in Fig. 6.13(b), after a certain period it touches the unity probability curve of other scheme and, then decreasing in nature with increasing number of FAPs.

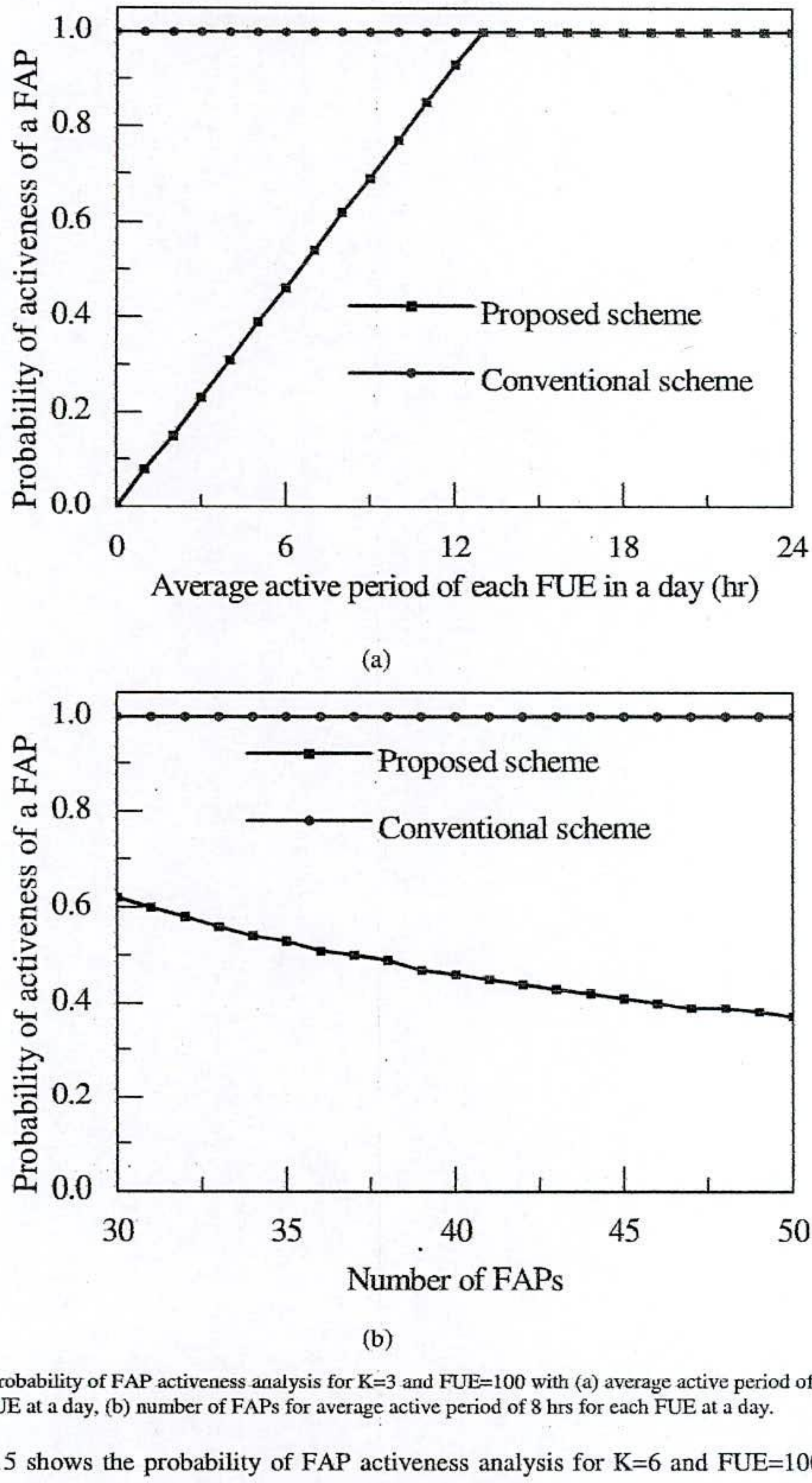
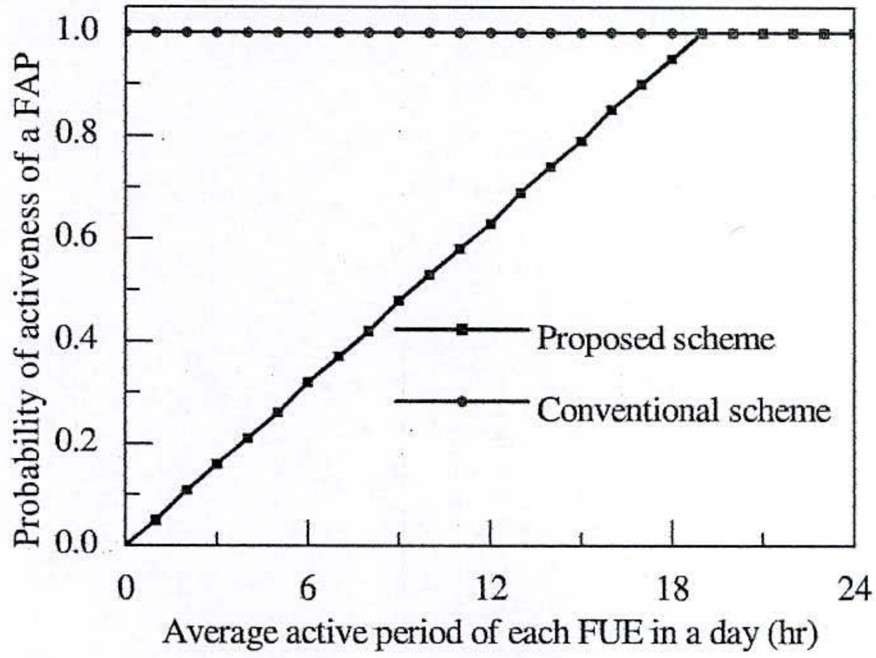


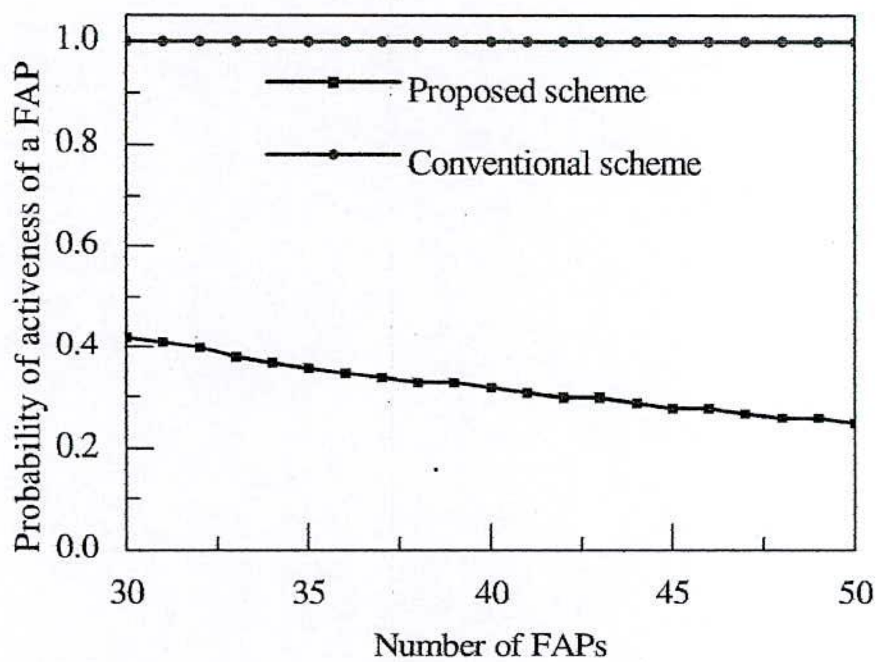
Fig. 6.14. Probability of FAP activeness analysis for K=3 and FUE=100 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day.

Fig. 6.15 shows the probability of FAP activeness analysis for K=6 and FUE=100 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day. From Fig. 6.15, it can be seen that, all FAP support six (as K=6) FUEs. Fig. 6.15(a) shows the probability of FAP activeness curve, increasing in nature and becomes unity after a certain period which is more delayed than, that shown in Fig.

6.14(a) for proposed ODSC scheme. The probability curve of other scheme is always unity. Fig. 6.15(b) also shows the same characteristics as given by Fig. 6.14(b), but starting or maximum probability of FAP activeness point is just lower than, that shown in Fig. 6.14(b).



(a)



(b)

Fig. 6.15. Probability of FAP activeness analysis for K=6 and FUE=100 with (a) average active period of each FUE at a day, (b) number of FAPs for average active period of 8 hrs for each FUE at a day.

Fig. 6.3(a) depicts very small probability of outage near edge region of reference active FAP for proposed ODSC scheme when reference active FAP supports one FUE with all neighbor idle FAPs. Fig. 6.3(b) shows, that the probability of outage of a FUE increases under reference active FAP when number of neighbor idle FAPs decreases near edge region of reference active FAP in proposed ODSC scheme. But for other scheme probability of outage is more due to all neighbor FAPs are always in active mode. Fig. 6.4(a), 6.5(a), 6.6(a), 6.7(a), 6.8(a), 6.9(a), 6.10(a), 6.11(a), 6.12(a), 6.13(a), 6.14(a), and 6.15(a) reveals that when FAPs support more FUEs, more time requires reaching the maximum probability point in proposed ODSC scheme. Fig. 6.4(b), 6.5(b), 6.6(b), 6.7(b), 6.8(b), 6.9(b), 6.10(b), 6.11(b), 6.12(b), 6.13(b), 6.14(b), and 6.15(b) shows, that the probability of activeness increases when number of FAP are less for fixed (say, 8 hrs) average service period.

Proposed ODSC scheme shows [Fig. 6.3 to Fig. 6.15] less interference effect due to small probability of outage and probability of FAP activeness than other scheme, always having probability of activeness of a FAP at maximum point. Hence, ODSC scheme provides more use of valuable one of the radio resources such as frequency with seamless connectivity.

Chapter 7

Conclusions

Femtocellular network system is a small and low cost alternative for meeting the demand of increasing data traffic in existing cellular networks. The wireless engineering community has been searching for low-cost indoor coverage solutions since the beginning of mobile networks. Femtocellular network technology is one of such solutions. The FAPs enhance the service quality for the indoor mobile users. Some key advantages of femtocellular network technology are the improved coverage, reduced infrastructure as well as the capital costs, low power consumption, improved SNIR level at the MS, and improved throughput. Femtocells operate in the spectrum which is licensed for cellular service providers thus, it can provide high performance. Here, the key feature of the femtocell technology is that, user do not require any new FUE. Femtocellular technology does not use any dual mode terminal, but WLAN uses dual mode terminal. One of the key advantages of the femtocellular technology is that, it uses the similar frequency bands which is used by the macrocellular networks, thus there is no need to introduce new user equipment. However, the use of the same frequency spectrum can also cause interference if no necessary interference management scheme is introduced into the network design, infrastructure, and the future extension plan.

7.1 Discussion and recommendations

Femtocell overview along with its advantages, technical challenges and type of deployments in macrocell network are given in details at beginning of this thesis paper. Then interference related issues such as interference scenarios, source of interference, effects of interference in femtocell deployment are provided. Also the solutions to mitigate interference are discusses along with effect of interference of the dense femtocell deployment in macrocell. After these, proposed ODSC scheme is introduced. With the proposed ODSC scheme interference effects can be managed intelligently than typical management technique because here this thesis proposes a new approach, where a FAP has low-power FIM and high-power FAM operations. Next mathematical model used for analysis of SNIR and capacity, probability of outage, and probability of activeness of a FAP are given. While FAPs are in idle mode, all the FAPs uses very low power and in the active mode case here, probability factor is considered, and compare proposed ODSC scheme performances with continuous power transmission mode FAPs (conventional FAPs) deployment scheme performances (always 100% neighbor FAPs are active) for SNIR and throughput calculation. Probability of outage analyses shows almost zero probability of outage for all neighbor idle FAPs and a small increase of probability of outage for 50% neighbor idle FAPs case, respectively with proposed ODSC scheme. Probability of outage observation curve of other scheme is always higher than proposed ODSC scheme performance curve. From the probability of activeness of a FAP analyses for different conditions, proposed ODSC scheme shows small probability of FAP activeness. Here, small probability of FAP activeness means less interference effect which implies that, better frequency utilization can be ensured than conventional FAPs deployment scheme. Then the simulation results are done by *Matlab* of SNIR, throughput has presented, and also the observations of probability of outage along with probability of activeness of a FAP are given. For all cases proposed ODSC scheme performance shows better performance and hence, ensures higher QoS, less power consumption due to two operational modes of FAP, which is an intelligent way to reduce the interference effect, and lower unwanted HO and probability of outage by ODSC scheme. From the probability of activeness of a FAP observation, it is obvious that power consumption of FAPs is reduced significantly with proposed ODSC scheme. But only limitation of the proposed scheme is that, when all FAPs are in active mode then the proposed and conventional schemes are same in nature. However, this situation is least likely to be possible for the femtocell network with small duration. Thus, FAP with proposed ODSC scheme contributes to less interference problem and this proposed scheme is recommended to use where femtocell is required densely.

7.2 Future work

For more improved technological support to FUE from FAP, more user supporting capability with less interference effect is the basic requirement of future densely deployed femtocells. Here, maximum six numbers of supported FUEs by each FAP is considered with proposed ODSC scheme. As future work further analysis is required to increase the maximum supporting number of FUE by each FAP.

References

1 S.-P. Yeh, S. Talwar, S.-C. Lee, and H. Kim "WiMAX Femtocells: A Perspective on Network Architecture, Capacity, and Coverage," *IEEE Communications Magazine*, vol. 46 no. 10, pp. 58-65, Oct. 2008.

2 M. Z. Chowdhury, Y. M. Jang, and Z. J. Haas, "Cost-Effective Frequency Planning for Capacity Enhancement of Femtocellular Networks," *Wireless Personal Communications*, vol. 60, no.1, pp. 83-104, Sept. 2011.

3 V. Chandrasekhar, J. G. Andrews, and A. Gatherer "Femtocell Networks: A Survey," *IEEE Communications Magazine*, vol. 46, no. 9, pp. 59-67, Sept. 2008.

4 M. Z. Chowdhury, S. Q. Lee, B. H. Ru, N. Park, and Y. M. Jang, "Service Quality Improvement of Mobile Users in Vehicular Environment by Mobile Femtocell Network Deployment," in Proceeding of *IEEE International Conference on ICT Convergence (ICTC)*, Sept. 2011, pp. 194-198.

5 R. Y. Kim, J. S. Kwak, and K. Etemad, "WiMAX Femtocell: Requirements, Challenges, and Solutions," *IEEE Communications Magazine*, vol. 47, no. 9, pp. 84-91, Sept. 2009.

6 J. D. Hobby and H. Claussen, "Deployment Options for Femtocells and Their Impact on Existing Macrocellular Networks," *Bell Labs Technical Journal*, vol. 13, no. 4, pp. 145-160, Feb. 2009.

7 M. Z. Chowdhury and Y. M. Jang, "Handover Management in High-dense Femtocellular Networks," *EURASIP Journal on Wireless Communications and Networking*, pp. 1-17, Jan. 2013.

8 Y. Kim, S. Lee, and D. Hong, "Performance Analysis of Two-tier Femtocell Networks with Outage Constraints," *IEEE Transactions on Wireless Communications*, vol. 9, no. 9, pp. 2695–2700, Sept. 2010.

9 V. Chandrasekhar, J. G. Andrews, Z. Shen, T. Muharemovic, and A.Gatherer, "Power Control in Two-tier Femtocell Networks," *IEEE Transactions on Wireless Communications*, vol. 8, no. 8, pp. 4316–4328, Aug. 2009.

10 H.-S. Jo, C. Mun, J. Moon, and J.-G. Yook, "Interference Mitigation Using Uplink Power Control for Two-tier Femtocell Networks," *IEEE Transactions on Wireless Communications*, vol. 8, no. 10, pp. 4906-4910, Oct. 2009.

11 3GPP TS 32.500, "Telecommunication Management; Self-Organizing Networks (SON); Concepts and Requirements," Jun. 2011.

12 H.-S. Jo, C. Mun, J. Moon, and J.-G. Yook, "Self-Optimized Coverage Coordination in Femtocell Networks," *IEEE Transactions on Wireless Communications*, vol. 9, no. 10, pp. 2977-2982, Oct. 2010.

13 M. Yavuz, F. Meshkati, S. Nanda, A. Pokhariyal, N. Johnson, B. Raghothaman, and A. Richardson, "Interference management and performance analysis of UMTS/HSPA+ femtocells," *IEEE Communications Magazine*, vol. 47, no. 9, pp. 102–109, Sept. 2009.

14 M. Z. Chowdhury, Y. M. Jang, and Z. J. Haas, "Interference Mitigation Using Dynamic Frequency Re-use for Dense Femtocell Network Architectures," in Proceeding of *IEEE International Conference on Ubiquitous and Future Networks (ICUFN)*, Jun. 2010, pp. 256-261.

15 H. Claussen, L. T. W. Ho, and L. G. Samuel, "An Overview of the Femtocell Concept," *Bell Labs Technical Journals*, vol. 13, no. 1, pp. 221–245, May 2008.

16 3GPP TR25.967 V8.0.1, "FDD Home NodeB RF Requirements Work Item Technical Report," Apr. 2009.

17 S-E. Elayoubi, O. B. Haddada, and B. Fouresti´e, "Performance Evaluation of Frequency Planning Schemes in OFDMA-based Networks," *IEEE Transactions on Wireless Communications*, vol. 7, no. 5, pp. 1623–1633, May 2008.

18 S. H. Ali and Victor C. M. Leung, "Dynamic Frequency Allocation in Fractional Frequency Reused OFDMA Networks," *IEEE Transactions on Wireless Communications*, vol. 8, no. 8, pp. 4286–4295, Aug. 2009.

19 Femtoforum, "OFDMA Interference Study: Evaluation Methodology Document," Nov. 2008.

20 H. Claussen, L. T. W. Ho, and L. G. Samuel, "Self-optimization of Coverage for Femtocell Deployment," in Proceeding of *IEEE Wireless Telecommunication Symposium (WTS)*, Apr. 2008, pp. 278–285.

21 Femtoforum white paper, "Interference Management in UMTS Femtocells," Dec. 2008.

22 M. Rahman, H. Yanikomeroglu, and W. Wong, "Interference Avoidance with Dynamic Inter-Cell Coordination for Downlink LTE System," in Proceeding of *IEEE Wireless Communications and Network Conference (WCNC)*, Apr. 2009, pp. 1–6.

23 J.-H. Yun and K. G. Shin, "Adaptive Interference Management of OFDMA Femtocells for Co-Channel Deployment", *IEEE Journal on Selected Areas in Communications*, vol. 29, no. 6, pp. 1225–1241 Jun. 2011.

24 D. N. Knisely, T. Yoshizawa, and F. Favichia, "Standardization of Femtocells in 3GPP," *IEEE Communications Magazine*, vol. 47, no. 9, pp. 68–75, Sept., 2009.

25 M. Rahman and H. Yanikomeroglu, "Enhancing Cell-Edge Performance: A Downlink Dynamic Interference Avoidance Scheme with Inter-Cell Coordination", *IEEE Transactions on Wireless Communications*, vol. 9, no. 4, pp. 1414–1425, Apr. 2010.

26 K. Pahlavan and P. Krishnamurthy, Principles of Wireless Networks, Prentice Hall PTR, New Jersey, 2002.

List of Publications

1 **K. N. Azam,** M. Z. Chowdhury, and Y. M. Jang, "On-Demand Service Connectivity for Intelligent Interference Management in Macrocell/Femtocell Integrated Networks" *Journal of Microwaves, Optoelectronics and Electromagnetic Applications,* Mar. 2014, (under review).

2 **K. N. Azam** and M. Z. Chowdhury, "Intelligent Interference Management Based on On-Demand Service Connectivity for Femtocellular Networks" in Proceeding of *IEEE International Conference on Informatics, Electronics & Vision (ICIEV),* May 2013.

3 M. Z. Chowdhury, **K. N. Azam**, R. K. Mondal, and Y. M. Jang, "Interference Mitigation for Femtocellular Network Deployment in Train Environment," in Proceeding of *International Conference on Electrical, Computer and Telecommunication Engineering (ICECTE),* Dec. 2012, pp. 218-221.