Mobility Management
in
Wireless Broadband Femtocells

Mahmoud Qutqut and Hossam Hassanein

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Queen's University
Kingston, Ontario, Canada

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Abstract

Current Wireless Broadband Networks (WBN) are facing several limitations and considerations, such as poor indoor coverage, explosive growth in data usage, and massive increase in number of WBNs' subscribers. Various inventions and solutions are used to enhance the coverage and increase the capacity of wireless networks. Femtocells are seen as a key next step in wireless communication today. Femtocells offer excellent indoor voice and data coverage. As well Femtocells can enhance the capacity and offload traffic from Macrocell networks. There are several issues that must be taken into consideration for the successful deployment of Femtocells. One of the most important issues is mobility management. Since Femtocells will be deployed densely, randomly, and by the millions, providing and supporting seamless mobility and handoff procedures is essential. This paper presents a broad study on mobility management in Femtocell networks. Current issues of mobility and handoff management are discussed. Several research works are overviewed and classified. Finally, some open and future research issues are discussed.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

3G	3rd Generation
3GPP	3rd Generation Partnership Project
4G	4th Generation
AAS	Advanced Antenna System
ACL	Access Control/CSG List
AP	Access Point
ARPU	Average Revenue Per User
BS	Base Station
CN	Core Network
CPE	Consumer Premises Equipment
CSG	Closed Subscriber Group
DA	Distributed Antenna
DL	Downlink
DSL	Digital Subscriber Line
eNB	enhanced NB
E-UTRAN	Evolved UTRAN
FAP	Femto AP
FBS	Femto BS
FDD	Frequency Division Duplex
Femto-GW	Femto Gateway
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HCS	Hierarchical Cell Structure
HLR	Home Location Register
HO	Handoff
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSPA+	Evolved HSPA
HSUPA	High Speed Uplink Packet Access
IEEE	Institute of Electrical and Electronics Engineers
IMT-2000	International Mobile Telecommunications 2000
IP	Internet Protocol
ITU	International Telecommunication Union
Kph	Kilometre per hour
LAI	Location Area Identify
LAU	Location Area Update
LTE	Long Term Evolution
LTE-A	LTE-Advanced
MAC	Media Access Control
MBN	Mobile Broadband Networks
Mbps	Megabits per second

MHz	Megahertz
MIMO	Multiple-Input Multiple-Output
MOG	Multimedia Online Gaming
NCL	Neighbour Cell List
NB	NodeB
OA&M	Operations, Administration, and Management
OFDMA	Orthogonal Frequency Division Multiplexing Access
OSG	Open Subscriber Group
PCI	Physical Cell Identifiers
PLMN ID	Public Land Mobile Networks Identity
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RNC	Radio Network Controller
RSS	Relative/Received Signal Strength
RSSI	Received Signal Strength Indication
SAE	System Architecture Evolution
SC-FDMA	Single Carrier Frequency Division Multiple Access
SeGW	Security Gateway
SINR	Signal-to-interference ratio
SOHO	Small Office, Home Office
SON	Self Organization Network
TAI	Tracking Area Identity
TDD	Time Division Duplex
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System
USIM	Universal Subscriber Identity Model
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
VoIP	Voice over IP
WBN	Wireless Broadband Networks
WCDMA	Wideband Code Division Multiple Access
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Networks
WWAN	Wireless Wide Area Networks

1 Introduction

There has been a significant interest in wireless broadband technologies over the past few years. Wireless Broadband Networks (WBNs) such as 3rd Generation (3G) and the subsequent 4th Generation (4G) networks offer high data rates, large coverage areas, and high quality multimedia. Most of 3G and 4G networks share similar drawbacks such as the limitation of data capacity of each cell site, and poor indoor coverage. The reason behind poor indoor coverage is that the radio signals, especially at high frequency bands do not penetrate walls well. Currently up to 60% of voice and 70% of data traffic occurs indoors [1], and there is huge growth of data usage in cell phones, driven by the popular data-hungry applications such as Multimedia Online Gaming (MOG), Mobile TV, Voice over IP (VoIP), Video Calling, Streaming TV, Web2.0, Video-on-Demand, Location-Based services, social networks (Facebook, Google+, MySpace). The aforementioned factors indicate the need for a solution that remedies the above mentioned constraints and limitations. Therefore, several solutions are proposed to solve these issues. The solutions can range from deployment of heterogeneous networks with Wireless Fidelity (WiFi) for dual mode devices to installation of more cell sites and relay stations as well as signal boosters. Femtocells are introduced as a cost effective and beneficial solution that addresses both limitations mentioned above.

Femtocell networks are seen as a promising solution for enhanced indoor coverage and increased network capacity, as well as offloading traffic from the Macro/Micro-cells. Perhaps one of the key requirements for mass deployments and feasibility of Femtocells is mobility management. Femtocells have many special characteristics that make mobility management a crucial and challenging process. Such challenges include random deployment in an ad-hoc manner, working in a licensed spectrum, overlaying with Macro/Micro-cells and backward compatibility requirements with the existing infrastructures and devices.

This paper gives an overview of Femtocell networks and mobility management. Also, it presents currents problems and issues in mobility management. The paper discusses, reviews, and classifies several recent research efforts on mobility management in Femtocell networks.

The remainder of this paper is organized as follows. An overview of the background topics related to the depth paper is presented in Section 2. In Section 3, mobility management and Femtocell networks challenges are discussed. The related and common research efforts are studied in Section 4, as well as classifications and comparisons of proposed solutions. Finally, Section 5 discusses the open research issues and concludes paper.

2 General Overview

This section provides background material related to this paper. In Section 2.1, we provide a brief overview of WBNs. In Section 2.2, we present principles of mobility management in wireless networks. An overview of the Femtocell networks is provided in Section 2.3.

2.1 Overview of WBNs

The term Broadband commonly refers to Internet connection via a diversity of high speed networks such as Digital Subscriber Line (xDSL), cable, WiFi, 3G, 4G, and Fiber networks. WBN is considered broad because it can transfer multiple types of services (video, voice) across a wide frequency band [2]. WBNs are sometimes called Mobile Broadband Networks (MBNs) and offer these services via 3G and 4G wireless networks [2]. Wireless broadband includes local and wide area categories. Wireless Local Area Networks (WLANs) are called Wi-Fi, as well as Wireless Wide Area Networks (WWANs) provided by 3G and 4G cellular networks. An overview of the current WBNs is presented in Appendix 1.

Wireless systems are mostly cellular in nature, where coverage is divided into a number of geographic coverage areas called cells. In each cell site there is a Base Station (BS) [3]. Each BS can support one or more cells, dependent on the manufacturers' equipment [4]. Also BSs provide the radio communication of cell phones within the cell. Each cell phone uses radio channels to communicate with the cell site. Channels use a pair of frequency bands- one band, the Downlink (DL), for transmitting from the cell site [4], and one band, the Uplink (UL), for the cell site for receiving call and data from the cell phone. The cells are normally illustrated as a hexagonal shape, but in practice they may have irregular shapes. The cell's coverage range depends on a number of factors, such as BSs transmit power, BS's height [4]. Each type of cells differs from the other by the size [4]. Macrocells (radius 1-10 Km) has the widest coverage and used in rural areas or highways. Microcells (radius 200 m - 1 Km) are used in urban and high density areas. Picocells (radius100– 200 m) have smaller coverage than Microcells and used in malls or train stations. Femtocells (radius is less than 100 m) are having the smallest coverage and a typical Femtocell is used indoor (homes or offices).

The BSs, BS Controllers (BSC) and the radio communication together are called Radio Access Network (RAN) [5]. The BSC manages several BSs at a time and connects all cell sites to the operator's Core Network (CN). The CN gathers traffic from dozens of cells and passes it on to the public network [5]. The CN also provides other central functions, including call processing, traffic management, and transferring calls as a phone moves between cell sites [4]. Figure 1 shows a typical cellular network.

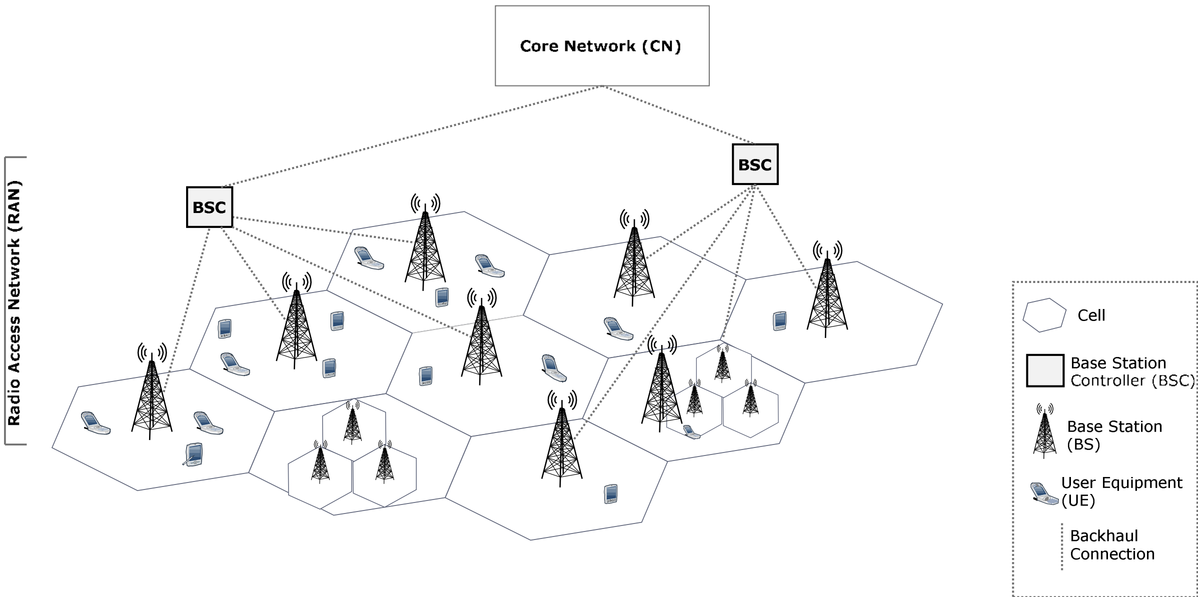

Figure 1: Typical Cellular Network

2.2 Mobility Management in WBNs

Mobility Management is a set of tasks for controlling and supervising mobile User terminals or Equipments (UE)[1] in a wireless network to locate them for delivery services, as well as, to maintain their connections while they are moving [6]. Mobility management is concerned with many aspects, e.g. Quality of Service (QoS), power management, location management, handoff management, and admission control. It is one of the most critical features in wireless communications due to the direct effect on user experience, network performance and power consumption [5]. The two kernel components of mobility management are location management and handoff management [7]. In the following subsections, several mobility management procedures and aspects are presented.

2.2.1 Location Management

Location management includes two aspects registration and paging. **Registration** is the task of knowing where the UE is located to handle incoming and outgoing calls. The registration process is performed via a database called Home Locations Register (HLR). The HLR contains information about the UE and its capabilities. It also describes the home area of the user [8]. Another database is the Visitor Location Register (VLR); it is attached to the HLR to provide the latest location of the user. The VLR is updated whenever the user moves from one area to another area [5]. **Paging** is a process that allows the network to page the UE when it is setting up a call. The paging process is a

[1] We refer to any mobile user terminals (e.g. Laptop, cell phone, smart phone, PDA) as User Equipment (UE)

message to be sent to the serving BS in order to get a response from the UE before sending a call or message [8].

2.2.2 Mobile Modes

1. Idle Mode: This mode applies when the UE has no ongoing service (data, voice). The UE is in this mode most of the time after turning-on and registering its location, it monitors for page message from the networks [5]. When the UE is moving with idle mode, it performs a reselection of BS on the way. **Cell Reselection** helps to transfer registration (VLR) and aims to stay camped on the best available cell during the idle mode. UE periodically searches for a better cell according to the reselection criteria [5]. Another mobility procedure is selection. **Cell Selection** is the procedure of selecting a suitable cell to camp on when a UE is powered on or after having lost coverage.

2. Connected Mode: This mode is when the UE has ongoing service (data, voice). After the UE releases its active session will switch to the idle mode. When the UE is moving with connected mode, **Handoff** occurs from one BS to the next. More details in Section 2.2.3 [5].

2.2.3 Handoff Management

Handoff (HO) management is the key function by which wireless network support mobility and to maintain quality of service. HO enables the network to maintain the UE's connection while it moves from the coverage area of one cell/sector to another [8]. HO is the process of transferring an ongoing voice call or data session from one cell connected to the CN to another. HO is divided into two broad categories: Hard and Soft HOs [9]. In Hard HO, current resources are released before new resources are used. However in Soft HO, both existing and new resources are used during the HO process.

HO Initiation

HO initiation is the process of deciding when to request a HO. The four basic HO initiation techniques are [10]:

1. **Relative Signal Strength (RSS):** In this technique, the Received Signal Strength indication (RSSI)[2] is measured over time, and the UE chooses the BS with the strongest signal to handoff.
2. **Relative Signal Strength with Threshold**: This technique introduces a threshold value. If the current signal is weak (less than threshold) and the other signal is stronger than the current signal and the threshold, then the UE will handoff.

[2] RSSI is a measurement of the power present in a received radio signal.

3. **Relative Signal Strength with Hysteresis**: In this technique, the UE will be allowed to handoff if the new BS is sufficiently stronger than the current BS (via Hysteresis)
4. **Relative Signal Strength with Hysteresis and Threshold:** This technique allows a UE to handoff to a new BS if and only if the current signal level is below a certain threshold and signal of the target BS is stronger than the current BS by a given hysteresis margin.

HO Decisions

There are many methods for performing HO. The main HO decision protocols include [11, 10]:

1. **Network-Controlled HO**: The network is responsible for overall HO decision, and handles the necessary RSS measurements.
2. **Mobile-Controlled HO:** The UE completely controls the handoff process. The UE and BS make the necessary measurements and the BS sends them to the UE. The UE then decides when to handoff.
3. **Mobile-Assisted HO:** The UE makes RSS measurements and then sends them to the network or BS to decide when to handoff.

2.3 Femtocells

In the following sections, we provide an overview of Femtocells and some related aspects.

2.3.1 What are Femtocells?

A Femtocell is a cell in a cellular network that provides radio coverage and is served by a Femto-BS (FBS)[3]. FBS also known as a Home-BS or a Femto-Access Point (FAP)**,** is a mini low-power BS installed by end users. FBSs are typically deployed indoors residential, Small Office Home Office (SOHO) and enterprise to offer better coverage, especially where access would otherwise be limited or unavailable. FBSs also offer enhanced data capacity and offload traffic from the Macro/Micro networks. FBSs look like broadband modems, and some FBS manufacturers offer a choice of all in one box (DSL modem, WiFi router, and FBS) [12]. Femtocells operate in the licensed spectrum, and basically have tens of meters of coverage range and can support up to ten active users in a residential setting. FBSs connect to standard cellular phones and similar devices through their wireless interfaces (LTE, WiMAX, HSDPA+) [13]. Traffic is then routed to the cellular operator's network via broadband connection (e.g. xDSL, cable) as shown in Figure 2.

[3] In this document, we use FBS to stand for the device itself (BS), and use Femtocell to refer to the coverage area that covered by a FBS.

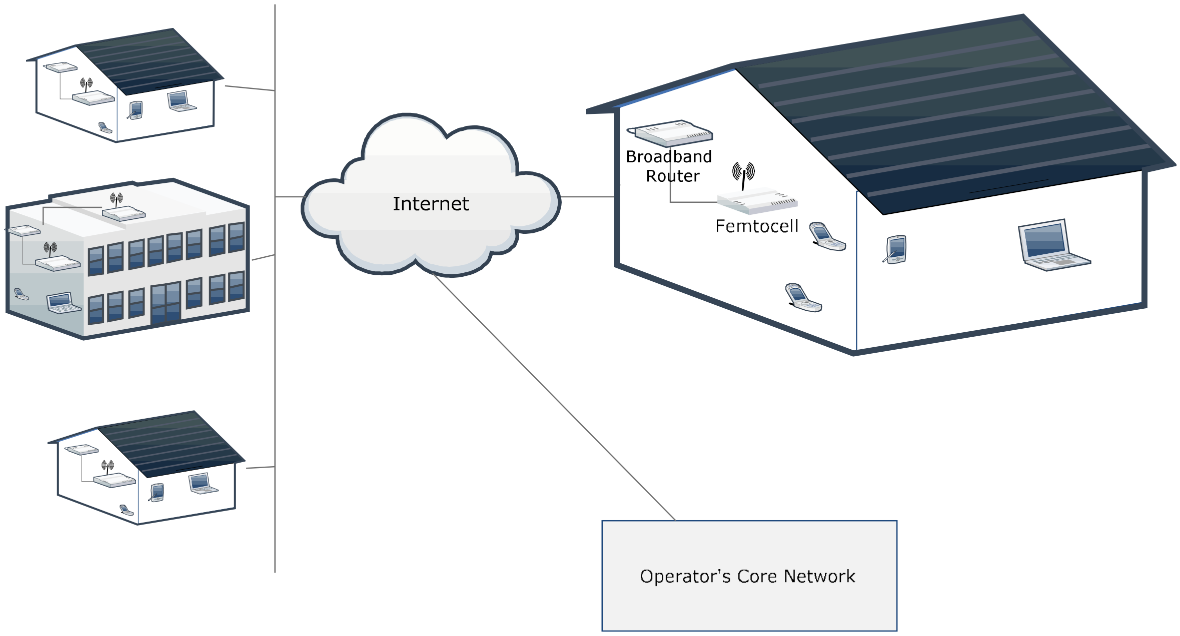

Figure 2: Femtocell Network Overview

Femtocells can also be deployed outdoors, and can be used in urban areas and subway stations [14, 15].

2.3.2 Brief History and Current Status

The home base station concept was introduced by Bell Labs of Alcatel-Lucent in 1999 [16]. In 2002 Motorola announced the first 3G home base station [16]. In 2006, Femtocell as a term was introduced [17]. In late 2007, the Femto Forum was founded as a non-profit membership organization to promote and enable Femtocell technologies worldwide. The forum supports the adoption of industry wide standards, regulatory and interoperability of Femtocells by telecom operators around the world [17]. Currently, Femto Forum includes more than 60 mobile operators and 74 vendors. Furthermore, 27 FBS vendors, and more than 20 telecom providers have announced commercial launches of FBSs [17].

2.3.3 Comparison between Femtocells with other coverage solutions

There are many coverage solutions that have been developed to solve the problem of indoor converge. In **Microcell and Picocell** solutions**,** operator installs Micro-BSs (with smaller coverage area than Macrocells) to improve coverage and capacity in urban or high density areas with poor reception. The **Distributed Antenna (DA)** solutions, operator installs DA elements as signal boosters, which are connected to Macro-BS via a dedicated Fiber or Microwave link. These coverage enhancement solutions are typically expensive and need operator's involvement. Table 1 presents a comparison between these solutions.

	Femtocell	Microcell	Distributed Antenna (DA)
Cost	low	High	Low
Network Capacity	Very increased	Increased	Limited to BS capacity
Install	User	Operator	Operator
Capital Expenditure	Purchase a FBS	Installing new cell BS	Antenna element and backhaul installation
Operating Expenditure	Provide a broadband connection	Electricity, site lease, maintenance, and backhaul	Antenna maintenance and backhaul connection
Indoor coverage problem	Enhance indoor coverage	Does not completely solve indoor coverage	Doesn't solve indoor coverage

Table 1: Comparison between Femtocell, Microcell, and Distributed Antenna (DA)

As discussed in Table 1, the cost of a FBS is less than $200, which is a relatively low-cost solution. Whereas the cost of a Micro-BS is between $200,000-400,000 and that of a DA is between $200-400. Deploying Femtocells will particularly increase the network capacity via used the broadband connections for Femto-BSs' backhaul; where deploying more Microcells will also increase the network capacity, but not as much in Femtocell deployment, due to the limitations of the dedicated backhaul for Microcells. DAs will not increase the capacity since they are connected to the Macro-BSs. Femto-BSs are installed as end user devices, where Micro-BSs and DAs are installed by operators. The capital expenditure of Femtocells is the hardware cost. However in Microcells, the capital expenditure is in installing new BS and its cell site, where for DA, installing of antenna elements and backhaul installation add to the cost. The operating expenditure of Femtocells is in providing broadband connection. The operating expenditures of Microcells are electricity, site lease, maintenance, and backhaul, and for DAs is antenna maintenance and backhaul connection. Femtocells solve the indoor coverage problem, Microcells and DAs do not completely solve indoor coverage.

2.3.4 Benefits of using FBSs for Users and Operators:

There are many potential benefits from the deployment of Femtocells. These benefits are summarized below [18, 19, 20, 12, 21].

User's benefits:

- Improved indoor coverage for both data and voice services, since FBS is closed to the users.
- Improved data rate capacity, because FBS utilize the user's high data rate broadband connection as its backhaul.
- Reduced indoor cost charged (zone pricing). As the operators will offer special pricing plan for indoor calls and data.
- Reduced power consumption for UEs due to the lower transmit power of FBS when compare to Macro/Micro-BSs.
- Ability to offer new services, e.g., Home Gateway, Connected Home, location based services.
- Simple deployment, as FBS works as a "plug-and-play" device.
- No need for new expensive dual mode UEs, as current UEs work with Femtocells.

Operator's benefits:

- Reduced capital expenditures, since no new expensive Macro/Micro-BSs are needed.
- Lower operational expenditures, because no new cell site, cell site backhaul, and maintenance are needed.
- Increased mobile usage indoors due to the low-cost fare, hence increasing the Average Revenue Per User (ARPU).
- Reduced customers churn rate. This is because customers will be potentially more satisfied with the offered services through Femtocells.

2.3.5 Femtocell Network Architecture and Functionalities

The following is a description of the main common components of a Femtocell network (shown in Figure 3).

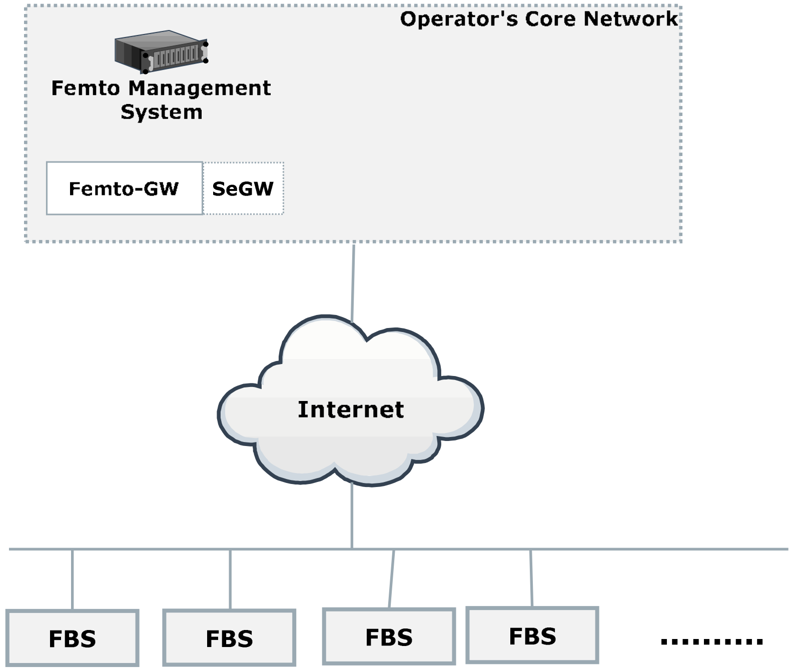

Figure 3: Femtocell Network Architecture

FBS is a device located at the customer's premise that interfaces with mobile devices over-the air radio interface that functions as a BS [22].

Femto Gateway (Femto-GW) is an entry element to the operator's core network. It acts as concentrator to aggregate traffic from a large number of FBSs [21]. Also the Femto-GW could perform as security gateway to provide authentication to allow data to/from authorized FBSs to protect operator's CN from the public environment of the Internet, and to terminate large numbers of encrypted IP data from hundreds of thousands of FBSs. Or could be another element implanted separately called Security Gateway (SeGW) [23].

Femto Management System provides management protocols for "plug-and-play" Operations, Administration, and Management (OA&M) of FBSs [24]. Broadband Forum TR-069 [4] has been selected as the framework for Femtocell management and was widely supported by 3GPP2 and 3GPP vendors and carriers, as the Femtocell management protocol [20, 25, 13].

2.3.6 Deployment Configurations

There are many possible cases of deployment configurations for FBSs. The possible configurations are classified depending on: access mode, spectrum allocation types, and transmit power.

[4] Technical Report 069 (TR-69) is a Broadband Forum technical specification entitled CPE WAN Management Protocol (CWMP). It defines an application layer protocol for remote management for end-user devices.

Access Modes

An important property of FBSs is their ability to control access. There are two common access control modes: Open and Closed, and lately another access mode has been proposed called Hybrid [26].

1. **Closed Access Mode** also known as Closed Subscriber Group (CSG). In this scenario, a FBS serves a limited number of UEs they defined before in its Access Control List (ACL) [27]. This can be used in home or enterprise environments.
2. **Open Access Mode** also known as Open Subscriber Group (OSG). In this scenario, any UE can connect to the FBS without restrictions. This can be used in hotspots, malls and airports.
3. **Hybrid Access Mode** is an adaptive access policy between CSG and OSG. In this scenario, a portion of FBS resources are reserved for exclusive use of the CSG and the remaining resources are allocated in an open manner [27].

Spectrum Planning

Allocation of the available spectrum in Femtocell deployments can be one of following [19, 28]:

1. **Dedicated Spectrum:** In this approach, different frequencies are assigned for Femtocells and Macro/Micro-cells.
2. **Partial Co-Channel:** In this approach, Macro/Micro-cells and Femtocells share some spectrum and the rest of the spectrum is reserved for Macro/Micro-cells only.
3. **Shared Spectrum:** In this approach, Macro/Micro-cells and Femtocells share all available spectrum.

Transmit Power Configuration

The configuration process of downlink and uplink transmit power of FBSs can be fixed maximum or adaptive [29].

2.3.7 Femtocells Challenges and Open Issues

Despite many benefits and advantages of Femtocell networks, they also come with their own issues and challenges. These issues and challenges need to be addressed for successful mass deployment of Femtocell networks. The most relevant issues include:

- **Interference:** unplanned deployment of a large number of FBSs introduces interference issues for the mobile networks. Frequency interference is one of the most important issues that impair Femtocell deployment. Frequency interference in Femtocells includes: Cross-tier and Co-tier interference [30]. In Cross-tier interference, a FBS interferes with Micro/Macro-BS or vice versa. In Co-tier interference, a FBS interferes with another neighbouring FBS or FBS user.

- **Security and QoS:** since FBSs use non-dedicated fixed broadband connections (i.e. xDSL) that carry femto and non-femto traffic, managing and controlling voice/data priority and security over third party becomes more difficult [31, 32] unless Internet backhaul belongs to the same cellular operator.
- **Location and Synchronization:** FBSs operate in the licensed spectrum, thus the exact locations need to be verified, as well as inter-cell synchronization for proper Femtocell deployments [19]. Also location information is important to provide tracking in emergency calls. However, Global Positioning System (GPS) that is used in Macro/Micro-BSs for synchronization and location cannot be used in FBSs due to the lack of the coverage of GPS indoor, since the typical deployed FBSs are indoors [33].
- **Integration of FBS into the CN:** traffic between FBS and the CN send/receive through broadband networks, so it is important to decide how FBSs integrate with CN, with or without gateways; and what interface they need to connect FBS with CN, or there might a need to upgrade the CN (Software/Hardware) to be connected to Femto-GW. Many possible configurations are available [31].
- **Self Organization Network (SON) and Auto Configurations:** FBS as a Consumer Premise Equipment (CPE) are deployed as plug-and-play devices, so it shell integrate itself into the mobile network without user intervention [15, 34]. Hence, different SON and auto configuration algorithms and techniques are needed.
- **Mobility and Handoff Management:** considering that FBSs will be deployed densely and by the millions [34], and may not be accessible to all users, mobility management in Femtocell Networks (such as searching for FBS, Handoff from/to Macro/Micro-BS, access control) becomes one of the most challenging issues [33]. (More details in Section 3.6.)

3 Mobility Management in Femtocell Networks

In this section, we describe the mobility management procedures and issues in Femtocell networks.

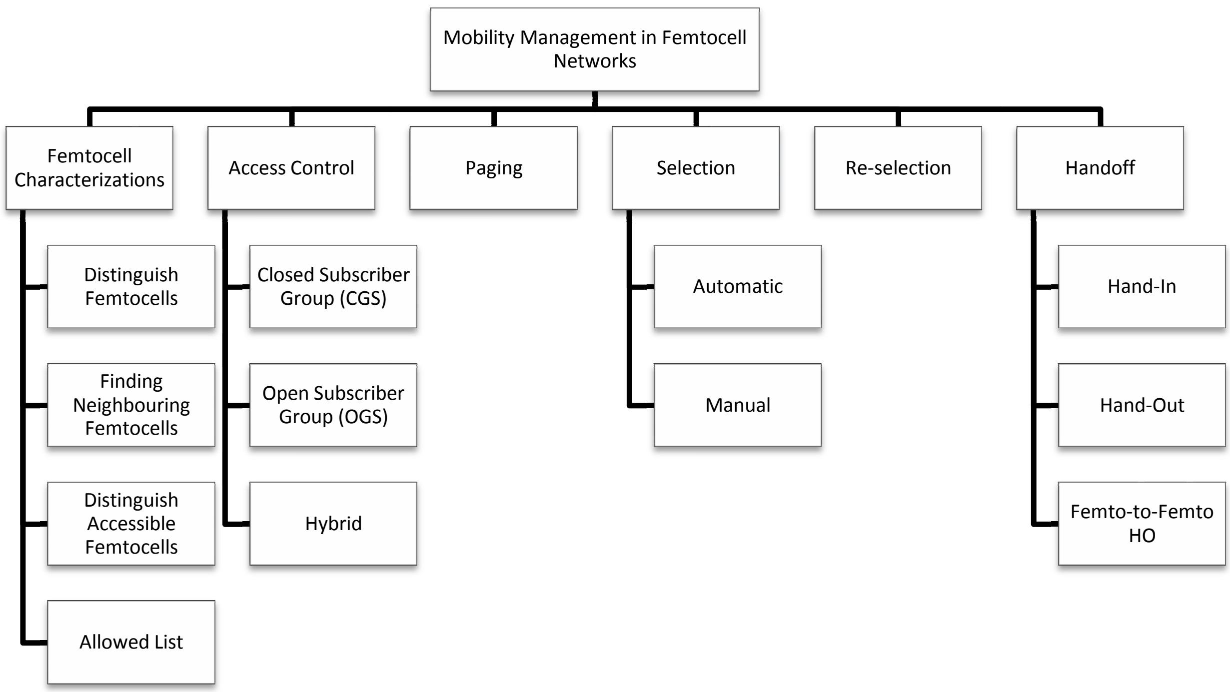

Figure 4: Overview of Mobility Management Functionalities in Femtocell Networks

3.1 Femtocell Characterizations

Nowadays, there are more than 100 million users of Femtocell on more than 30 million access points [35]. Hence, with a large number of Femtocells randomly deployed, it is difficult to treat it as a normal Macro/Micro-cell. In addition, the network cannot afford broadcasting the Femtocell information as this will impact the overall performance of the network [36]. However, some identifiers and techniques for Femtocells are needed to reduce the impact and enhance the mobility management of Femtocell networks.

3.1.1 Femtocells Vs. Macro/Micro-cells

With the identifiers and techniques that can distinguish Femtocells from Macro/Micro-cells the network can be divided into two tiers [37] as shown in Figure 5. In this way, the signalling overhead across tiers can be minimized as well as the Neighbor Cell List (NCL) that the UE scans when performing a HO. The methods that have been proposed for such classification are listed below.

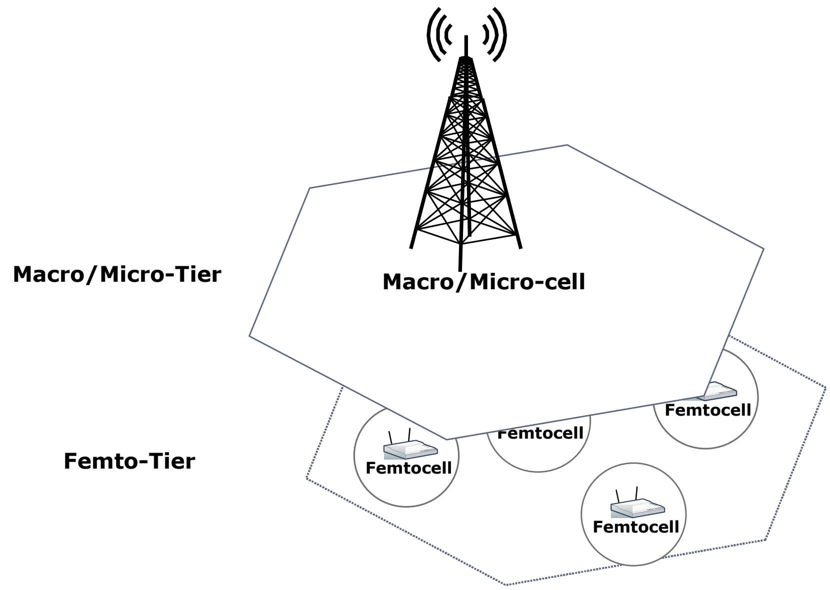

Figure 5: Two Tier Network

- **Hierarchical Cell Structure (HCS):** HCS can be used to distinguish between the different network cells. Each tier can be assigned different access priority (i.e. HCS_0, HCS_1).
- **Separate Femtocell PLMN ID:** This technique uses a separate Public Land Mobile Network Identity (PLMN ID) for the Femtocells [38]. PLMN ID is an identifier for the operator's networks, and each operator has its own PLMN [37]. In this way, Femtocells will be assigned a different PLMN ID from Macro/Micro-cells to secure Femtocells selection and minimize impact on Macro/Micro-cells users (i.e. PLMN ID_0, PLMN ID-1) [37]. Hence, more PLMN IDs are required for operators.
- **CSG PSC/PCI**: A set of Primary Scrambling Codes (PSC) (in UMTS) or Physical Cell Identifier (PCI) [5] in LTE is reserved for identifying CSG cells of a specific frequency [38].
- **Dedicated CSG frequency list:** Specifies the frequencies dedicated for UMTS CSG cells only [38].
- **CSG Indicator**: Another approach is to use a CSG Indicator to define whether a Femtocell is a CSG or not [36], this is used in LTE networks.
- **CSG ID** [37]: One or more CSG cells are identified by a unique numeric identifier called CSG identity (CSG ID). When the UE is not authorized to access the target Femtocell a new reject message is used. The UE will then bar the corresponding

[5] Physical Cell Identifier (PCI) is an ID used to identify a cell for radio purpose.

CSG ID, for a configurable duration, instead of the whole frequency (in LTE system).

- **Femtocell Name** [38]: A text based name for the Femtocell sent only by CSG and hybrid cell. UE may display the Femtocell name.

3.1.2 Finding Neighbouring Femtocells

Depending on the above techniques, UEs are able to distinguish between Femtocells and other kinds of cells, but it is not easy to find neighboring Femtocells due to the large numbers of FBSs. The following are techniques that have been proposed to find femtocells.

- **NCL:** The NCL can be created by the FBS through self-configuration algorithms implemented by the vendor, and it might be updated when the FBS senses any changes of the neighboring cells or when the FBS is turned on [37].
- **UE Autonomous Search:** The objective for the autonomous search is to decide when the UE should begin searching for a Femtocell to which it can have access and whether the CSG cell is valid or not [36]**.** Due the limited area coverage of Femtocells, the UE only starts searching for a Femtocell when the UE is in its vicinity [36]. The autonomous search function is not specified and is left to UE manufactures.
- **Manual CSG Search:** This approach is specified in LTE and UMTS, where a user can find a CSG cell. On request of the user (e.g. via UE application), the UE is expected to search for available CSG IDs by scanning all frequency bands for CSG cells, and then the UE reports the CSG ID of the strongest or higher priority to higher tiers [36].

3.1.3 Distinguishing Accessible (CSG and Hybrid) Femtocell

By knowing whether a Femtocell is accessible or not, unnecessary signalling overhead can be avoided. The following CSG related identification parameters used to distinguish accessible Femtocell are:

- **LAI/TAI** [37]: For Femtocell, the Location Area Identity (LAI)/Tracking Area Identity (TAI) of neighbours needs to be different for the purpose of user access control. The LAI of unauthorized Femtocells will be put in the UE's Universal Subscriber Identity Model (USIM) after it receives the Location Area Update (LAU) rejection from the these Femtocells.
- Also CSG Indicator, CSG ID, and Femtocell name are used to distinguish accessible Femtocell. Whereas only CSG or Hybrid cells broadcast their CSG ID or Femtocell Name.

3.1.4 Handling Allowed List

The allowed list is essential in order to check whether the UE is allowed or not to access the target Femtocell. The allowed list could be in:

- **Allowed List in FBS or Femto-GW:** This is a list stored locally in the FBS or Femto-GW that contains the UEs that are allowed access [37]. The operator or owner can manage the allowed list. This approach is used in UMTS.
- **Allowed List in CN:** In LTE, a UE's Allowed CSG List (ACL) [36] is provided. ACL is the list of CSG IDs (FBSs) that the UE belongs to [36]. The ACL is stored with the user's subscriber information in the CN, as well as, it may keep a copy in UEs.

3.2 Access Control

Access control mechanisms play an important part in Handoff management, as well as when a user tries to camp on a Femtocell to prevent unauthorized use of that Femtocell and in mitigating cross-tier interference. Users of Femtocells in two-tier networks are classified into [30]:

- **Subscribers** of a Femtocell, which are users registered in it, and they have the right to use it. Femtocell subscribers could be any UEs, for instance cell phone, laptop, etc.
- **Nonsubscribers,** which are users not registered in a Femtocell

Location Access Control: There are many possible locations of access control in the Femtocell network. The possible locations are [37, 36]:

- **Access Control in FBS or Femto-GW:** Access control is performed in FBS or Femto-GH for Femtocell while for Macro/Micro-cell in CN. For instance in LTE, Femto-GW shall perform access control, and FBS may optionally perform access control as well.
- **Access Control in UE:** In LTE, UE can perform the basic access control in the registration procedure to enhance the mobility procedure.
- **Access Control in CN:** In WiMAX and LTE, one of the CN entities (such as admission server) checks the access of the UE to the target Femtocell by the ACL after it receives information from the Femtocell.

Access Control Types: Femtocells support flexible access control mechanisms (as mentioned in page 9).

3.3 Paging

For OSG and hybrid Femtocells, the CN pages the UE in all cells that the UE is registered in [37]. For CSG Femtocells, there may be many CSG Femtocells that the UE is registered in but the UE is not allowed to camp on. So, the paging procedure needs to be optimized, in term of minimizing the amount of paging messages used to page a UE in Femtocells [38]. CN and/or Femto-GW can perform the paging optimization [37]. If the paging is managed by the Femto-GW, this is left to vendor implementation [38].

3.4 Idle Mode, Cell Selection and Cell Reselection

It is desirable for the UE to switch to its Femtocell when the received signal from the Femtocell is strong enough to support service, even when the Macro/Micro-cell can still provide reliable service [39]. Hence, cell selection and reselection in Femtocell environments are more complicated than in Macro/Micro-cell networks [37]. There are few alternatives to enabling cell selection and reselection in Femtocells depending on the technology used.

Cell Reselection

An UE in idle mode changes (reselects) the cell it is camped at as it moves across cells. Reselection requires parameters broadcast by the cell sites [39]. To increase battery life of the UE (with idle mode), the UE scans other radio channels only when the signal-to-noise ratio (SNR or S/N) of the current cell is lower than a certain threshold. In UMTS and LTE networks, this threshold is defined by parameters called *S Intersearch* and *S Intrasearch* [39]. Cell reselection may also be as an autonomous search function which is intended to find CSG/Hybrid Femtocell to the UE to camp on it [38]. The autonomous search function is not specified and is left to vendor implementations [38].

Cell Selection

There are two modes for network selection, manual and automatic. Automatic Cell Selection is similar to that for Macro/Micro-cells. An extra CSG ID check is performed when the target cell is CSG or Hybrid, to check whether the CSG/Hybrid cell is suitable for the UE or not [39]. This technique is used in WiMAX and LTE. On the other hand, in Manual Cell Selection, the UE is supported to select their serving CSG manually. But in the connected mode, the UE is not allowed to support manual selection [36, 37]. This technique is used in UMTS and LTE. UMTS and LTE also use the HCS in the selection of a FBS by given the Femtocell higher priority than Macro/Micro-cells [37].

3.5 Connected Mode and Handoff

When a UE in connected mode is moving with an active voice or data session, and it changes its serving cell, a process is known as Handoff (HO). There are three scenarios of the HO in Femtocell Networks: Hand-In, Hand-Out and Femto-to-Femto HO, as shown in Figure 6.

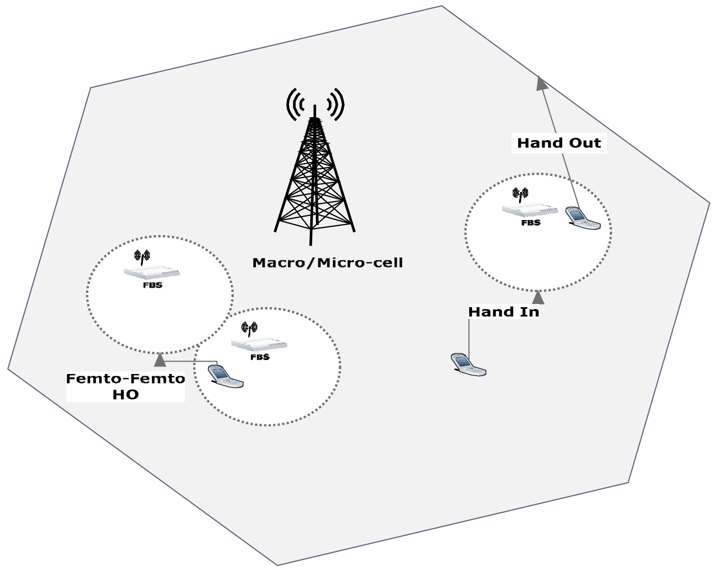

Figure 6: HO Scenarios in Femtocell Networks

1. **Hand-In** takes place when a UE moves from a Macro/Micro-cell to a Femtocell. Hand-In is the most complex scenario since it requires the UE to select an appropriate FBS while considering neighbour cells. As well, there is no simple mechanism for the Macro/Micro-BS to determine the identity of the target FBS from the measurement reports sent by the UE.
2. **Hand-Out** takes place when a UE moves out of a Femtocell to a Macro/Micro-cell. Hand-Out process is supported in Femtocells almost without any changes to the existing Macro/Micro-cell network or to the UE. The handling neighbor cell is easier than Hand-In case, since the target cell is always one.
3. **Femto-to-Femto HO** takes place when a UE moves out of a Femtocell to another Femtocell, and requires handling long NCLs.

Access control in Femtocell networks makes the HO procedures more complex than in Macro/Micro-cell networks, especially in Hand-In and Femto-to-Femto HO [37]. In addition, in Macro/Micro-cell networks, HOs are triggered when users enter the coverage area of other cells. However, given the coverage size of open/hybrid access Femtocells, this occurs more often than in the Macro/Micro-cell case. Hence, different HO management procedures are needed to allow non-subscribers to camp for longer periods at nearby Femtocells.

In 3G Femtocell networks, there no support for soft HO [37]. In LTE Release 8, there is no support for Hand-In and Femto-Femto HO. However, 3GPP Release 9 supports Hand-In. 3GPP Release 10 will enable Femto-to-Femto HO [37, 39].

3.6 Mobility Management Issues

Mobility management in Femtocells should offer a seamless experience for users as they move in and out of Femtocell coverage. Since, existing cellular networks and mobile devices have been designed without awareness of Femtocells; these requirements must be met without requiring changes to existing infrastructure or to mobile devices. Dense deployments will cause serious issues on mobility management between the Macro/Micro-cells and Femtocells. The importance of mobility management in Femtocell networks is due to the following reasons:

- Large number of FBSs that are usually overlaid with Macro/Micro-BS coverage
- High density of FBSs
- Dynamic neighbour cell lists
- Variant access control mechanisms
- Different user preferences
- Different operator policies and requirements

The above characteristics pose the following issues:

1. Neighbour Advertisement Lists and Messages
Since large numbers of FBSs may be within the range of a single Macro/Micro-cell, a long list of neighbouring FBSs would be broadcast via neighbour advertisement messages. This leads to a waste of the wireless resources and makes the process of scanning all neighbouring Femtocells time consuming [40].

2. HOs
Current Macro/Micro-cells share the radio frequency with potentially huge numbers of Femtocells. Hence, a UE may face up continual HOs, especially when it moves around the home or enters areas where the received signal from the Macro/Micro-cell is greater than that from the Femtocell [41]. In addition, leakage of coverage to the outside of a house may occur and can lead to highly increased number of unnecessary HO of Macro/Micro-cell users, which may lead to higher call dropping probability. Femtocells also introduce specific complexities in Hand-In and Femto-to-Femto HO [34, 40, 42, 43].

3. HO Decision Parameters
In Femtocell environments, new and flexible decision parameters will influence the HO other than existing parameters, such as serving cost, user’s status and preferences, load balancing, [42, 44] etc. In other words, the serving cell and/or UE should decide to handoff to a target cell based on multiple parameters. There is a need for algorithms to optimize and adapt these and other parameters.

4. Searching for FBS in Different Access Scenarios

In order to manage the mobility procedures in both idle and connected modes, with the case of hybrid and CSG scenarios, there are two problems to be solved. The first problem is how the mobile devices will find out that the target is the CSG or not. The second problem is how to identify target CSG cell as the mobile device's own accessible FBS among many of FBS [44, 36].

5. Idle Mode Mobility Procedures

Additional energy consumption should be taken into account due to the high dense deployment of Femtocells and their continuous receiving and transmission signals [45]. The increase of the number of cells can result in a large increase in the traffic and load of the CN for idle mode mobility procedures [45, 46].

4 Related Work

Several research efforts have been done to modify and adapt the existing mobility management procedures in cellular networks to be used with Femtocells. In this section, we provide a literature review of mobility management schemes in Femtocell networks. In Section 4.1 we describe the mobility management techniques. In Section 4.2, we define a set evaluation criteria. This is followed by a thorough analysis of proposed schemes in different categories in Section 4.3.

4.1 Mobility Management Techniques

Network-based Mobility Management: In this type of mobility management protocols, the network takes care for all aspects of mobility management without requiring participation from the UE in any related mobility procedures and their signalling**.** This domain does not require the UE to be involved in the exchange of signalling messages between itself and the network.

Mobile-based Mobility Management: This type requires the participation of the UE in all aspects of the mobility management. However, the participation of the UE in the mobility management and associated resources and software has become a hurdle for standards and protocols.

Mobile-Assisted Mobility Management: In this type, the information and measurement from the UE are used by the network to take care of all aspects of the mobility management.

4.2 Evaluation Criteria

In order to evaluate the schemes proposed, we define a set evaluation criteria to compare the various mobility schemes in first and second categories. These are:

- **Access control type(s):** This criterion shows the type(s) of access control supported (CSG, OSG, and Hybrid).
- **HO scenario:** This criterion contains the HO scenario(s) supported (Hand-In/Out, Femto-to-Femto HO).
- **HO objective(s):** This criterion shows the target goal(s). The goal could be to reduce the number of HO or unnecessary HO, decrease signalling overhead, etc.
- **Additional HO parameter(s):** This criterion shows the additional HO parameter(s) used, such as QoS, user’s state, etc.
- **HO latency:** This criterion shows the HO latency in the proposed HO is low or high or medium via comparing with the standards.

- **Signalling traffic overhead:** This criterion shows whether the control data load is increased or decreased. The number of signalling packets should be lowered to within an acceptable range.
- **QoS support:** A HO algorithm should be reliable and the call should have good quality after handoff, as well as it should be fast so that the user does not experience service degradation or interruption. This criterion shows the QoS types used, such as real-time support, packet lost, HO delay, etc.
- **Special support required:** This criterion shows if there is any change required to the infrastructure and/or the UE. The fewer changes required is better and more feasible.

4.3 Proposed Mobility Management Schemes

There are several ways in which the proposed solutions can be categorized. The categorizations can be based on Open System Interconnection (OSI) layer. Also we can categorize schemes based on the target technologies. Existing mobility management schemes can be categorized based on the target problem for each scheme, such as HO schemes, reselection and scanning.

4.3.1 Handoff Schemes

Schemes belonging to this category are not complete mobility management schemes. They provide new HO protocols and algorithms in Femtocells, in addition to schemes that deal with different aspect that are related to the HO processes, such as, optimization HO process, new HO decision, context transfer stages, reading system information in Hand-In, etc. In this section, many protocols and algorithms are discussed. Table 2 shows a comparison of the schemes that surveyed below based on the evaluation criteria in Section 4.3.

Zhang et al. [40] propose a modified signalling flow of HO in LTE network with CSG scenario for Hand-In and Hand-Out. This mechanism is applied in the Femto-GW. The HO algorithm is based on the user's speed and QoS. The proposed scheme integrates the measurement value, maximal capacity and current load of the cell as the input of HO judgment. This algorithm does not allow the high speed user HO's (>30 Kph) from Macrocell to Femtocell, while low speed users are allowed. The algorithm distinguishes between real time users and non-real time users with moderate speed (>15 Kph), it allows the real time moderate speed users to handoff. However, it does not allow moderate speed users HOs without real time. The proposed algorithm performs better in reducing the unnecessary HOs and the numbers of HOs compared to the traditional HO algorithms especially in medium and high speed users with a small penalty of signalling overhead.

Wang et al. [34] propose two mobility management schemes applied in the Femto-GW at Radio Network Layer (RNL) for LTE Femto-to-Femto HO. In **method I**, the authors propose the Femto-GW to act as a mobility anchor, and let it make the HO decisions. When Femto-GW receives a HO request from the source FBS, the Femto-GW checks the target ID. If the target cell is under its control, it will handle the HO. In **method II**, Femto-GW operates as a transparent node and simply forwards the HO messages between the FBS and MME. S-GW has to be notified with the change of end point after HO. Moreover, Method I is more suitable for enterprise use, because it is reduces the signalling traffic with the CN. On the other hand, method II is more suitable for home use, because more signalling messages are exchanged.

Chowdhury et al. [47] propose a signalling flow for Hand-In and Hand-Out in UMTS networks with Call Admission Control (CAC). In the proposed signalling flow, there are two phases: HO preparation phase (information gathering about HO candidates and authentications, HO decision to determine the best HO candidate), and HO execution phase. The proposed procedure considers the interference level as additional HO decision parameters for Hand-In procedure, and uses the proposed CAC to reduce unnecessary HOs. Three parameters are considered for the proposed CAC: received signal, duration of a UE maintains the minimum required signal level, and signal to interference level. The results show that the number of unnecessary HOs is minimized due to the proposed CAC.

As an extension work of [47], **Chowdhury** and **Jang** [48] propose a modified signalling flow for Hand-In and Hand-Out for small and medium scale Femtocell network deployments. The authors present the details HO call flow for these two femtocell deployments and the proposed CAC scheme to minimize the unnecessary HO. The proposed queuing scheme optimizes the new call blocking probability, HO call blocking probability, and bandwidth utilization. Simulation results show that the number of unnecessary HOs is minimized due to the proposed CAC. As well, the proposed scheme is able to provide a seamless and reliable HO for both small and medium scale deployments.

Kim and **Lee** [49] propose a signalling flow for Hand-In and Hand-Out in UMTS networks with CAC in the Hybrid access mode. The proposed Hand-In procedure makes a decision based on the new CAC. The new CAC takes into consideration the residence time in a cell, user types, RSS level, the duration a UE maintains the signal level above the threshold level, the signal to interference level, and the capacity that one FBS can support. If the received signal level from the Femtocell is higher than the threshold, the Femto-GW checks whether the UE is preregistered or not. If the UE is pre-registered, the next handover procedure is performed. If the UE is not pre-registered, UE must stay in the femtocell area for the threshold time interval during which a signal level is higher than the threshold signal level before continuing to the next handover procedure. Results show that the number of unnecessary HOs is reduced via the Hybrid access CAC.

Ulvan et al. in [42] and [50], propose an adapted signalling flow for the three types of HO based LTE networks. The proposed scheme considers the Movement Prediction mechanism as an additional parameter for HO decision. This HO is a client-based HO. Reactive and Proactive HO (PHO and RHO) procedures are proposed to trigger the HO, since the HO procedure may be initiated by FBS, Macro/Micro-cell, and UE. In RHO, the HO is trigged when the UE almost lose its serving cell signal or the most probable position of UE is predicted. RHO aims to postpone the HO as long as possible to prevent the frequent and unnecessary HO, and mitigate the generated overhead of HO. However, in PHO, the HO may occur any time before the level of RSSI of current BS reaches the HO threshold via estimate of a specific position before the UE reaches that position. After the UE discovers the new target cell RSSI, the UE calculates the time remaining before the normal HO is triggered, then the HO triggers before the HO threshold. RHO is expected to minimize packet loss (PL) and latency in HO.

Ellouze et al. [51] propose a modified HO procedure between WiMAX Macro-BSs and FBSs. The proposed HO scheme takes QoS and load balancing into account in two ways, first, by limiting the break time connection caused by the scanning interval. Second, the HO selection procedure decides either to connect the user to FBS or other BSs according to the user's QoS profile. The proposed solution reduces the HO delay and balances the load over the network.

De Lima et al. [52] propose a stochastic association mechanism for Hand-In with OSG. The proposed mechanism introduces a new distributed HO procedure, which does not rely on any centralized coordination. The proposed solution uses a modified multi-stage Dutch auction to autonomously coordinate and prioritize bidding FBSs. As well, the solution uses a stochastic process to separate candidate FBSs to reduce probability of collision. Macrocell user plays an 'auctioneer', while target FBS play 'bidders'. A stochastic election process is incorporated to the selection process to reduce the probability of multiple bidders. Femtocell users faced some QoS degradation

Xu et al. [53] propose a user's state and signal-to-interference ratio (SINR) based Hand-In algorithm for 3G networks, to overcome the drawbacks of the large asymmetry transmit power between FBSs and Macro-BSs in two-tier networks. The proposed algorithm uses SINR to avoid the asymmetry transmit power, and user's state to reduce the unnecessary HOs. The authors add user state such as velocity, QoS, etc., with SINR as HO decision. On the one hand, the results show that the new algorithm cuts down the number of unnecessary HOs due to taking user's state into account. On the other hand, the total number of HOs is increased.

Shaohong et al. [54] propose two HO algorithms for 3G networks using the mathematical concept of ‘set’. In Velocity and Signal HO algorithm (VSHO), they consider the velocity and RSS of UE, hence, the frequent HO of high speed UEs are avoided. In the other improved algorithm called Unequal HO algorithm (UHO), the scheme considers the difference between Macro-BSs and FBSs to consider the issue that the UE receives a higher signal strength from a FBS in a house than from the Macrocell outside. In other words, UHO sets a higher signal level limit for Femtocells than Macrocell to serve as a chief BS. The results of the two proposed algorithms show that HO probabilities decreased for high speed users and the total throughput of Macrocell networks is increased. The above algorithms do not represent the power asymmetry by adding a constant value to received signal from FBSs. In addition, the user state is not considered as factor for HO. Hence, the Hand-In process may trigger with no guarantee of QoS from the Femtocells, and then it may lead to HO failure.

Wu et al. [55] propose Hand-In and Hand-Out procedures for LTE Femtocells. The authors consider a group of parameters for the HO decision which are interference level, RSS, user’s velocity, available bandwidth and QoS level. The Hand-In has two kinds of procedures. The First is for CSG users where the UE should chose the most appropriate target FBS. The second is for non-CSG users, if a non-CSG UE causes too much interference; it can handoff to FBS to reduce interference. This HO is different than the normal situation, because the HO is triggered by FBS. The proposed solution does not consider the co-tier interference.

Becvar and Mach [56] propose an adaptive hysteresis margin for HO for LTE networks. The proposed solution utilizes the reported metrics (RSSI or CINR) for the dynamic adaptation of an actual value of hysteresis margin according to the position of the user in a cell. The hysteresis margin decreases with UE’s moving closer to the cell border. This proposed solution shows reduction of redundant HO by mainly focusing on avoids ping-pong effects. However, this is not a proper way to prevent unnecessary HOs caused by femtocell visitor.

Moon and **Cho** [57, 58] propose a modified HO decision algorithm for Hand-In procedure in LTE networks based on RSS. They combine the value RSS from the serving Macro-BS and a target FBS to derive a reasonable HO criterion using the concept of combination factor, and takes into consideration that the UE has a capability to detect neighbouring Femtocells. Results show that there is an enhancement of the assignment probability to the Femtocell while keeping the same level of the number of HOs. In the problem of the asymmetry transmit power for the above two proposed algorithms, the user’s state is not considered as a factor for HOs, hence, the HOs may trigger with no guarantee of QoS from the Femtocells, and then it may lead to HO failure.

In order to mitigate the interference problem that may take place when a non CSG user comes to a Femtocell, **Fan** and Sun in [43] propose a method for access and HO management for OFDAM Femtocell networks. In CSG scenario, when a UE comes near a FBS, its serving BS will check the UE's ID, if within the allowed list for the target FBS, the BS informs the FBS to start the HO procedure. Otherwise, the BS should notify the FBS to start the proposed proactive interference management procedure. As well, the authors propose a hybrid access to the same situation. After a non CSG UE enters a Femtocell, a FBS measures the UE's signal strength, and decides whether the potential interference caused by the UE is above the interference threshold or not. If so, the FBS will request a HO procedure from the serving BS for the UE, and informs that this is an avoid interference HO. The CSG scenario reduces the unnecessary HOs and signalling load. However in the Hybrid scenario, the number of HOs is increased.

To solve the same problem presented in [43], **Li** et al. in [59] propose a pseudo HO based on the scheduling information exchange method, subchannel and power adaptation to avoid collision interference in LTE/-A networks. The pseudo HO is executed in the Radio Access Network (RAN), not referring to MME, which significantly reduced signalling overhead. When the UE tries to camp on a CSG FBS, if the UE belongs to this Femtocell, the regular HO is triggered; or else, the pseudo HO is triggered. The FBS will set up and maintain a table that contains the ID of non-CSG called pseudo-HO users.

Discussion

Although there are numerous proposed solutions for HO in Femtocells, most of the solutions have targeted only one or two parts of the HO procedure, such as HO preparation, HO decision parameter, HO signalling, Hand-In algorithm, etc. A few solutions have proposed a comprehensive HO procedure. Table 2 provides a detailed comparison between the schemes. Zhang [40], Wang [34], Chowdhury [47], Chowdhury & Jang [48], Kim [49], Ulvan [42, 50], and Wu [55] provide schemes for the signalling flow of the HO process with different additional parameters to reduce the number of unnecessary HOs. For example, Wang [34] supports CSG and OSG scenarios in the Femto-Femto HO. The scheme uses the user speed, QoS, and load balancing as additional parameters for the HO decision. The HO latency and signalling overhead are increased due to additional gateway (Femto-GW) that is installed.

Ellouze [51], de Lima [52], Xu [53], Shaohong [54], Becvar [56], and Moon [57, 58] provide HO algorithms and decision parameters with more details to enhance the HO process and reduce the number of unnecessary HOs. In [52], the scheme just targets the OSG scenario to enhance the Hand-In process. The HO process triggers by using the CINR as an additional parameter for the HO. The proposed scheme enhances the selection process of a target FBS to Hand-In, where there is and an obvious degradation of the QoS. [51] provides Hand-In/Out algorithm under the OSG scenario. This scheme is a complete solution due to inclusion of scanning and selecting procedures which are the two main processes before the HO process, in addition to the proposed HO procedures.

	Access Control Type(s)	HO Scenario(s)	HO Objective(s)	Additional HO Parameter(s)	HO Latency	Signalling Overhead	QoS Support	Special support required
Zhang **[40]**	CSG	In, Out	Reduce no. of unnecessary HO	User's velocity, QoS, load balancing	High	High	Real-time	Femto-GW
Wang **[34]** Method I	All	F-F	Enhance HO	N/A	Medium	Low	No	Femto-GW
Wang **[34]** Method II	All	F-F	Enhance HO	N/A	High	High	No	Femto-GW
Chowdhury [47]	All	In, Out	Reduce no. of unnecessary HO	CAC, interference level, time duration [6]	High	Medium	No	Femto-GW
Chowdhury & Jang **[48]**	All	In, Out	Reduce no. of unnecessary HO	CAC, interference level, time duration	Low	Medium	Call/HO blocking probability	Small Depl.: new server Medium Depl.: Femto-GW
Kim & Lee **[49]**	Hybrid	In, Out	Reduce no. of unnecessary HO	Hybrid access CAC and other	High	Medium	No	Femto-GW
Ulvan **[42, 50]**	OSG	All	Prevent frequent & unnecessary HOs	Movement prediction	Medium in RHO, low in PHO	Low in RHO	Minimized PL in PHO	Femto-GW
Ellouze **[51]**	OSG	In, Out	Achieve load balancing & enhance QoS	Load balancing, QoS	Low	Low	Yes	No
De Lima **[52]**	OSG	In	Enhance the HO	CINR	High	Medium	Real-time	No
Xu **[53]**	OSG	In	Solve the asymmetry transmit power in Hand-In	User's state, SINR	Medium	High	Minimized PL	No
Shaohong **[54]**	OSG	In	Cut down the no. of unnecessary HO & increase throughput	User velocity	High	High in UHO	No	No
Wu **[55]**	Hybrid	In, Out	Reduce no. of unnecessary & failure HOs	Velocity, bandwidth, QoS, Interference	High	High	Real-time	Femto-GW
Becvar **[56]**	OSG, Hybrid	All	Reduce of redundant HO	CINR	High	N/A	N/A	No
Moon & Cho **[57, 58]**	OSG	In	Enhance assignment probability	Combine RSS from serving & target BSs	High HO failure	High	N/A	No
Fan **[43]**	CSG, Hybrid	All	Interference mitigation & reduce no. of HOs	Interference threshold	N/A	Low	No	Femto-GW
Li **[59]**	CSG, Hybrid	All	Avoid collision interference	Interference threshold	N/A	Low	No	No

Table 2: Comparison of HO Schemes

[6] Duration of a UE maintains the minimum required signal level.
F-F: Femto-to-Femto, In: Hand-In, Out: Hand-Out

Summary

A good HO solution should take into account a number of factors in order to be a comprehensive and reliable. For instance, an additional HO parameter must be considered for the HO decision and triggering process in the Femtocells, viz. the user state (e.g. velocity, preference) in Shaohong [54] and Zhang [40]. Also the operator's preference, bandwidth and load balancing should take place in any HO process as in Ellouze [51] and Wu [55]. The HO latency and signalling overhead must be minimized as in Ellouze [51].

4.3.2 Scanning and Selection Schemes

As aforementioned, scanning is the process that used to find a cell for the UE to camp on. Schemes in this category propose mechanisms and algorithms to enhance the scanning and selection processes.

Nam et al. [60] propose a network-assisted FBS management scheme in Mobile WiMAX networks using a triangulation mechanism and FBS monitoring scheme to reduce the number of scanning operations, as well as the size of neighbour advertisement messages. The proposed scheme uses a FBS monitoring mechanism to provide UE with the nearest FBS information under the OSG scenario. The authors assumed that every FBS has two interfaces. One is used to communicate with the attached UE, while the other is used to monitor signals of candidate UE. Results show that the proposed scheme improves scanning performance and to reduces wasting air resources.

Han et al. [61] propose an automatic generation scheme of neighbouring BS lists for Femtocell networks under the OSG scenario. This scheme is utilized by a UE to determine a target FBS for HO. A neighbour list automatically generates by jointly utilizing the measurement of multiple neighbour BSs to include the all the neighbouring BSs for a proper HO. The proposed scheme operates in three steps. First, a BS measures the RSS of the neighbouring BSs locally and reports the measurement results. Then the BS requests the other BSs' measurements. Second, a BS reconstructs the topology of the identified neighbours, and then the topology is used to find hidden neighbouring FBSs. Third, a BS discovers hidden neighbouring BSs with the support of other identified neighbours. These three steps can repeat periodically or be triggered whenever the network topology changes. The scheme shows good results regardless the shadowing effects.

Jung et al. [62] propose a scanning scheme to minimize unnecessary scanning procedures for an accessible FBS (CSG) to minimize the power consumption. The scheme uses an adaptive threshold with a margin for RSSI. Using thresholds within a serving Macrocell, the target region is separated into smaller regions, hence the UE only scans for the FBS within a small region satisfying triggering conditions. Results show that the proposed scheme can reduce scanning time and power usage.

Chowdhury et al. [63] propose an optimized NCL for Femto-to-Femto HO and Hand-In in dense Femtocell networks. The proposed algorithm considers the received signal level from FBSs; open or closed scenarios; detected frequencies from the serving FBS and the neighbour FBSs, and location information (using SON capabilities of the FBSs) for the optimal neighbour FBS. The authors try to reduce power consumption for scanning many FBSs and the Media Access Control (MAC) overhead. Femtocells are categorized in two categories. First category contains the FBSs from which the received signals are greater than or equals to a threshold level. The FBSs that are in the second category from which the received signals are less than a threshold level or the serving FBS and the neighbour FBSs use the same frequency. The results show that the proposed scheme is able to maintain minimum number (not optimal) of neighbour FBS list for the Femto-to-Femto HO.

Kwon and Cho [64] propose a load based cell selection algorithm for faulted HO. The proposed cell selection algorithm allows each UE to choose a target Femtocell based on the basis of information of other UEs that have previously made their selection. The proposed scheme minimizes HO blocking probability and achieves load balancing between neighbouring cells when the FBS generates a fault. In contrast, the scheme increases signalling overhead.

	Access Control	Scheme Objective(s)
Nam **[60]**	OSG	Reduce scanning overhead
Han **[61]**	OSG	Generate automatic neighbouring list
Jung **[62]**	CSG	Minimize unnecessary scanning
Chowdhury **[63]**	OSG, CSG	Optimize the NCL
Kwon **[64]**	OSG	Balance load among cells; minimize HO blocking probability

Table 3: Comparison of Scanning Schemes

4.3.3 Reselection Schemes

Schemes in this category propose mechanisms and algorithms to enhance the reselection process, which is the process that happens when the UE needs to change its serving cell to other cell, while it does not has active session.

In [65], the authors target the issue of when a UE searches for a Femtocell. The UE needs to scan the whole femto spectrum in order to switch from Macrocell to Femtocell. The authors propose a cache scheme for Femtocell reselection. The proposed scheme considers the UE’s movement history by storing the cell information of the recently visited

FBSs. The aim is to obtain the most recently visited order of FBSs that have been stored in the cache. The scheme seems useful in the OSG scenario with a large number of FBSs, otherwise it is inefficient.

The authors in [45] propose two dynamic idle mode procedures for Femtocells. The first procedure activates the FBS only to serve active calls from its registered users. This is achieved by a low power “sniffer” capability in the FBS that allows the detections of an active call from an UE to the underlying Macro/Micro-cell based on a measured rise in noise that activates the FBS upon demand. The second procedure reduces the pilot power and adjusts the cell’s reselection thresholds when it is not serving an active call.

The authors in [66] address the issue of discovering a 3G Femtocell in multiple frequencies, and the impact of this issue on the UE battery life, as well as the impact of different cell reselection parameters on capacity offloads. For instance, with good Macrocell coverage, a UE may never initiate searches and would remain on the Macrocell even when it is in the vicinity of its own FBS. The authors enhance the idle mobility procedure to enable UEs to discover and camp on FBSs via three potential techniques: search threshold optimization, beacon-based approach for enhanced reselection procedure, and UE enhancement for enhanced the idle mode to the UE.

5 Conclusion and Open Issues

This paper presents a comprehensive study of mobility management in Femtocell networks. Issues in Handoff and other mobility management procedures in Femtocells are identified. Several research efforts have been presented and classified.

Building efficient mobility mechanisms will play an important role for successful deployment of Femtocells and for providing seamless services. We highlight some open problems and issues that can be derived from our study of the research efforts discussed in this paper as follows.

- The HO decision parameters must be adaptive and flexible based on the situation. For example, the HO decision parameter for the Hand-In in existing schemes is typically based on the user preferences, CINR or RSSI. There are cases where other factors must be considered as well. For instance a UE may receive a stronger RSSI from a Macrocell while it is under the coverage of a Femtocell, hence, the UE will not handoff to the Femtocell. This is due to the large asymmetry in transmitting power. Therefore, techniques to optimize and adapt multiple HO parameters depending on the situations need to be addressed.
- The service interruption time caused by reading system information of a target CSG FBS during Hand-In and Femto-to-Femto HO should be minimized. This is because UEs cannot receive data while reading system information. Existing schemes do not address such issue in a satisfactory manner.
- Mobile-based or mobile-assisted HOs will play a key role in Femtocell networks to satisfy user needs. Some research work has been proposed on proactive HO in Femtocells networks. These solutions focus on satisfying user needs only and ignore other networking requirements leading to unexpected results (e.g. whether they are more interested in service quality or cost, etc.).
- Mobile Femtocells on transit systems (e.g., buses and trains) will become more prominent in the future. These will typically be used to aggregate user traffic and relay it to the Macrocell networks or to other access networks. Means of offloading this aggregated traffic of these fast moving femtocells are needed. Hence, modified protocols for HO and location management for Mobile-Femtocells need to be developed.
- Methods and techniques that help in managing and updating the network topology are critical for efficient mobility procedures between Macro/Micro-cells and Femtocells and among Femtocells. All Macro/Micro-BSs and FBSs have to be aware if a FBS enters or leaves their coverage, hence changing the mobility conditions. For UEs to perform Handoff and cell searching in a more efficient way, the UE and/or FBS should acquire network topology.

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Appendix I

Wireless Broadband Networks (WBN)

UMTS, HSPA and HSPA+

The UMTS (Universal Mobile Telecommunication System) is designed as a 3G system. It carried over some features from the General System for Mobile Communication (GSM) and General Packet Radio Service (GPRS), and was standardized by Third Generation Partnership Project (3GPP) to meet the goals of International Mobile Telecommunications 2000 (IMT-2000) that where set by the International Telecommunication Union (ITU) [67, 68]. UMTS offers a much larger capacity compared to GSM and requires fewer cell sites. The first phase offered in 2001 with up to 2 Mbps and 1 Mbps for downlink and uplink respectively based on a completely new radio interface called Wideband Code Division Multiple Access (WCDMA). UMTS network consists of three interacting domains: Core Network (CN), UMTS Terrestrial Radio Access Network (UTRAN) and User Equipment (UE). The main function of the core network is to provide routing and transit for user traffic. CN also contains the databases and network management functions. The UTRAN provides the air interface access method. Base Station (BS) is referred as Node-B (NB) and control equipment for NB's is called Radio Network Controller (RNC) [68]. Meanwhile, an enhanced version of UMTS with a higher downlink and uplink rate called High Speed Packet Access (HSPA) was introduced. It contains two standards High Speed Uplink Packet Access (HSUPA) and High Speed Downlink Packet Access (HSDPA). HSDPA enables downlink rates up to 21 Mbps, and HSUPA enables uplink rates up to 14 Mbps [67]. An enhanced version of HSPA called Evolved HSPA (HSPA+) was introduced. It supports maximum theoretical data rates of 45 Mbps [67].

LTE

Long Term Evolution (LTE) is a major step towards achieving 4G wireless communication. LTE is a 3GPP radio access technology, but it is marketed as 4G. It is part of the GSM evolutionary path for wireless broadband. It is designed to offer high data rates (100 Mbps for downlink and 50 Mbps for uplink), reduced latency, and improved the use of the available spectrum compared to HSPA+ [69]. LTE uses different forms of radio interfaces, Orthogonal Frequency Division Multiple Access (OFDMA) for downlink, and Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink [5]. LTE system consists of three parts: Evolved UMTS Terrestrial Radio Access Networks (E-UTRAN), System Architecture Evolution (SAE), and UEs. E-UTRAN which is the radio access and it only contains enhanced BS called eNodeB (eNB). The SAE which is the new CN is a simplified and full Internet Protocol (IP) network architecture [67]. LTE uses advanced antenna technology called Multiple Input Multiple Output

(MIMO) to increase the throughout [5]. The next step for LTE evolution is LTE Advanced (LTE-A). LTE-A is fully 4G and designed to meet the goals of IMT-Advanced [69].

Mobile WiMAX

Worldwide Interoperability for Microwave Access (WiMAX) follows the IEEE 802.16 standard developed by the Institute of Electrical and Electronics Engineers (IEEE). WiMAX provides fixed and mobile broadband access. Mobile WiMAX (following the IEEE 802.16e standard) is a version of WiMAX that supports mobile broadband access, with data rates up to 128 Mbps for downlink and 56 Mbps for uplink [2]. Mobile WiMAX air interface is also based on OFDMA. Mobile WiMAX incorporates MIMO antenna technology, as well as Advanced Antenna Systems (AAS), which are all "smart" antenna technologies that significantly improve WiMAX system throughput [5]. WiMAX is an all IP network [5].