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Handover Techniques for coexisting LTE Macro and Femtocells

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Handover Techniques on coexistence of LTE Macro/Femtocells scenarios

By

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To my sister, Mom and Dad

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Sommario

Long Term Evolution (LTE) è il più recente standard nelle tecnologie di rete mobile ed è in fase di sviluppo nel 3rd Generation Partnership Project (3GPP). Il progetto è iniziato nel 2004 con l'obiettivo di migliorare la Universal Terrestrial Radio Access Network (UTRAN) e ottimizzare l'architettura di accesso radio, al fine di soddisfare l'aumento recente dell' utilizzo della telefonia mobile per il traffico dati e l'emergere di nuove applicazioni come il MMOG (Multimedia Online Gaming), TV mobile, Web 2.0, e contenuti in streaming.

La richiesta di una elevata qualità nell'esperienza della trasmissione mobile è in aumento e un miglioramento della tecnologia è necessario; tra queste esigenze viene incluso il miglioramento della capacità del sistema per i collegamenti wireless. Si ritiene che per conseguire tale miglioramento il trasmettitore e il ricevitore devono essere più vicini l'uno all'altro creando un doppio beneficio di qualità superiore e di riuso spaziale. Dato che in una rete mobile tutti gli utenti possono essere considerati come nomadi, il dispiegamento di ulteriori infrastrutture, in genere sotto forma di microcelle, hot-spot, antenne distribuite e ripetitori diventa inevitabile. Un'alternativa meno costosa sono i recenti punti di accesso Femtocell (FAP) - chiamati anche Stazioni Home Base - che sono i punti di accesso ai dati installati da utenti domestici per ottenere una migliore copertura per dati e voce nell'ambiente domestico. Quindi, per la diffusione dei sistemi LTE, i FAP diventano così un'importante sfida per quanto riguarda gli argomenti tecnici e di business che potrebbero rappresentare e il modo in cui potrebbero essere integrati efficacemente nell'architettura LTE.

Per questo motivo, l'obiettivo di questa tesi è quello di descrivere, sintetizzare ed esporre lo stato dell'arte dei diversi approcci per effettuare una migliore ed efficace integrazione delle macro e delle femtocelle negli scenari di coesistenza in rete LTE in termini di mobilità e esecuzione di procedure di Handover. Il documento è organizzato come segue: capitolo 1 e 2 contengono una panoramica dei sistemi LTE con le sue caratteristiche, l'architettura e le procedure di base per il livello fisico, il capitolo 3 contiene una descrizione della mobilità sui sistemi LTE, il capitolo 4 introduce gli aspetti fondamentali dei sistemi LTE con Femtocelle, il capitolo 5 presenta gli scenari impegnativi della coesistenza di macro e femtocelle LTE, e infine il capitolo 6 descrive le nuove tecniche e gli approcci che sono stati proposti e realizzati per mitigare e l'impatto e migliorare la capacità del sistema durante il passaggio di informazioni preliminari tra LTE macro e femtocelle.

Summary

Long Term Evolution (LTE) is the latest standard in the Mobile Network Technologies that is being developed by the 3rd Generation Partnership Project (3GPP). The project started in 2004 with the aim of enhancing the Universal Terrestrial Radio Access Network (UTRAN) and optimizing the radio access architectures in order to satisfy the recent increase of mobile data usage and the emerging of new applications such as MMOG (Multimedia Online Gaming), mobile TV, Web 2.0, and streaming contents.

The demand of a high quality in the mobile data transmission is rising and an improvement on the mobile technologies is needed; among these demands the enhancement of the system capacity for wireless links appears the most crucial objective. It is considered that for achieving such improvement the transmitter and receiver should be closer to each other creating dual benefits, higher-quality and more spatial reuse. Since in a mobile network all users can be considered as nomadic, the deployment of more infrastructures, typically in the form of microcells, hot-spots, distributed antennas and relays becomes inevitable.

However, a less expensive alternative is the recent concept of Femtocell Access Points (FAPs) - also called Home Base Stations – which are data access points installed by home users to get better indoor voice and data coverage. Therefore, for the deployment of the LTE systems the FAPs become a crucial, critical and challenging issue, especially regarding the technical and business arguments that it could represent and the way they could be integrated effectively into the LTE architecture.

For this reason, the aim of this thesis is to describe, summarize and expose the state of the art of the different approaches to perform a better and effective integration of the LTE macro and femtocell scenarios in terms of mobility and execution of handover procedures. The document is organized as follows: chapter 1 and 2 contain an overview of the LTE systems with its features, architecture and basic procedures on the physical layer, chapter 3 contains a description of the mobility on LTE systems, chapter 4 introduces the basic aspects of LTE Femtocell systems, chapter 5 presents the challenging scenarios of coexistence of LTE macro and femtocells and finally, chapter 6 describes the novel techniques and approaches that have been proposed and implemented in order to mitigate the impact and improve the system capacity during handover procedures between LTE macro and femtocells.

Contents

1. Introduction

The growing popularity of mobile technologies and their applications is attracting day by day users that are looking for new mobile broadband services that interweave their lives, their work, and the way they communicate and interact with their friends, family and colleagues. This popularity and new demands are simply the result and part of the impact that the development of the radio communication have had since the very moment when in the 1809s, Guglielmo Marconi and others invented the wireless telegraph.

Later on, the history of the Mobile Communications started in 1947 when the idea of dividing the coverage areas into cell was born in the well-known Bell Labs. The concept was simple: Each cell with its own base station operating on a different frequency in order to avoid the co-channel interference and allowing a higher system capacity. The development continued over the years but was until the 1980s when the real commercial growth began when analog systems like NMT (Nordic Mobile Telephone), AMPS (Advanced Mobile Phone System) or TACS (Total Access Communication System) were developed. These systems became known as the First Generation systems.

Afterwards in 1990, the collaborative effort of numerous companies around the world made possible the appearance of the first massive used standard; GSM (Global system for Mobile Communication). The GSM is considered into the Second Generation systems, and the success of GSM inspired further collaborative development and the same approach was used in developing its successor, the Third Generation (3G) system WCDMA (Wideband Code Division Multiple Access). WCDMA has been gradually adopted around the world and the continuous evolution to provide higher data rates through 3G technology is in progress. The latest step so far is a completely new system called LTE – Long Term Evolution.

1.1 Motivation

LTE (Long Term Evolution) is the latest standard in the Mobile Network Technologies that is being developed by the 3rd Generation Partnership Project (3GPP), a common project of regional standardization organizations ETSI (Europe), ARIB (Japan), TTC (Japan), TTA (Korea), CCSA (China) and ATIS (North America) that was established in 1998. 3GPP started the LTE project in 2004 with the aim of enhancing the Universal Terrestrial Radio Access Network (UTRAN) and optimizing their radio access architectures in order to satisfy the recent increase of mobile data usage and emergence of new applications such as MMOG (Multimedia Online Gaming), mobile TV, Web 2.0, and streaming contents. Among the requirements of the technology the provided downlink peak rates shall be of at least 100Mbit/s. (The technology in fact allows for speeds over 200Mbit/s) and also to have RAN round trips of less than 10ms, meaning that the LTE technology already meets the key 4G requirements expecting to boost the speed and capabilities of the mobile networks around the world, substantially improving the end-user throughputs, sector capacity and reducing the user plane latency.

Moreover, due to the emergence and popularity of the Internet Protocol (IP) as the protocol of choice for all the types of traffic, LTE is designed to be a flat all-IP network, from the handset, through the radio access, across the packet core and into the services layer. The all-IP network provides operators with economic benefits from the simplified network's operations (lower costs) and the new services created with IP's inherent flexibility and utility (improved revenues).

From the consumer's point of view, LTE will provide benefits as the support for IP-based traffic with end-to-end Quality of Service (QoS) leading to high-definition streaming of movies, full-screen video chatting and multi-player gaming revolutionizing the wireless experience on smart phones, tablets and other mobile devices, providing an experience that was previously available only in fixed broadband. This will be a wireless experience that people can take with them anywhere and it will be personal instead of being shared with other household members; this improvement on the data service will be extremely beneficial to consumers and enterprise users.

On the other hand, from the point of view of the operators, the LTE radio network products will have a number of features that simplify the building and management of next-generation networks. Plug-and-play features, self-configuration and self-optimization will simplify and reduce the cost of network planning and management. Since LTE supports hand-over and roaming to existing mobile networks, all these devices can have ubiquitous mobile broadband coverage

One of the most interesting features of mobile communications such LTE is that information becomes accessible almost anywhere at speeds that we are used to have at home. Bringing that technology into a bus, a car or into a train will allow us to set up a wi-fi network within that infrastructure for listening to music, to read our emails, watch our favorite TV show, which will make, for example traveling, a lot more amusing. There will be the ability to broadcast not only our location but also our experience while we are traveling, making our journey even more exciting. Thus, the demand of a new quality of experiences is rising and an improvement on the mobile technologies is needed inspiring and motivating new ideas that might improve the way we communicate and the way we access the information available on the Internet. Among these demands appears the improvement of the system capacity for wireless links. It is considered that for achieving such improvement the transmitter and receiver should be closer to each other creating dual benefits of higher-quality and more spatial reuse.

Since in a mobile network all users can be considered as nomadic, the deployment of more infrastructures, typically in the form of microcells, hot-spots, distributed antennas and relays becomes inevitable. However, a less expensive alternative is the recent concept of Femtocell Access Points (FAPs) - also called Home Base Stations – which are data access points installed by home users to get better indoor voice and data coverage that provide coverage into a small area of 10 to 30 meters. For the deployment of the LTE systems the FAPs become a crucial, critical and challenging issue, regarding to the technical and business arguments that it could represent and the way they could be integrated effectively into the LTE architecture.

1.2 LTE Design Requirements and Targets

As exposed above, with the aim of enhancing the UTRAN, the development of LTE technology began with the establishment of requirements and targets for Evolved UTRAN (E-UTRAN) indeed, these main targets are the following [1]

- 100 Mbit/s for downlink, 50 Mbit/s for uplink in the 20 MHz bandwidth. Meaning a spectral efficiency of 5 bit/s/Hz and 2.5 bit/s/Hz respectively.
- User plane latency (one way) should not exceed 5ms. Round Trip (10ms)
- The average user throughput should be 3-4x higher in the downlink direction and 2-3x in the uplink direction (per MHz). Also the cell-edge user throughput (5th percentile of the all users) is specified as 2-3x higher for both directions.

- Mobility Requirements - LTE should be designed for low terminal speeds, 0-15 km/h, but still for speed up to 120 km/h should provide high performance. The maximum allowed speed of the user terminal is set to 350 km/h.
- Detach Time - The longest interruption in the radio link when making handover between different radio-access technologies is 500ms for non-real-time services and 300ms for real-time.
- Spectrum flexibility: 1.25 to 20 MHz bandwidth
- Enhanced Multimedia Broadcast Multicast Services (E-MBMS)
- Improved support for end-to-end QoS.

1.3 The General LTE/SAE Architecture

With the aim of facilitating the uptake of mass-market IP-based services and come out with a flat "All-IP" architecture, and in order to improve the network performance by reducing latency and also looking for reducing operator's expenditures by simplifying the changes on the network; LTE in parallel with the packet core networks is evolving to the flat System Architecture Evolution (SAE) where some new nodes are introduced into the 3GPP mobile network.

In the figure 1-1 the overall architecture of LTE is illustrated. The following sections are a general description of both the Radio Access network (RAN) and the Evolved Packet Core (EPC) parts of it.

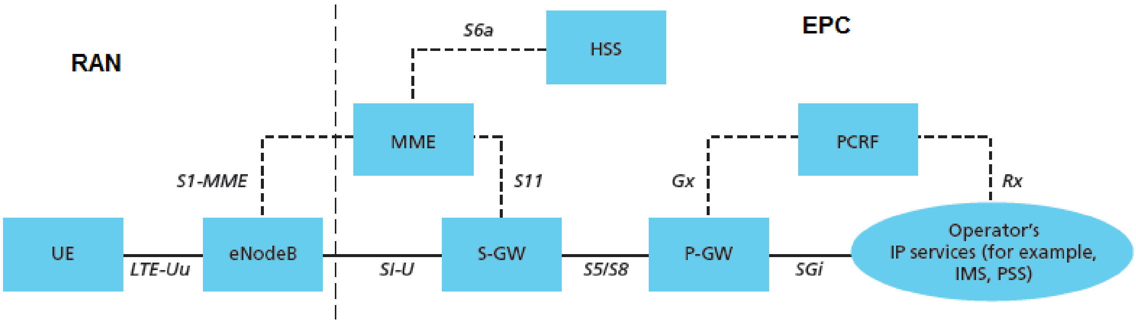


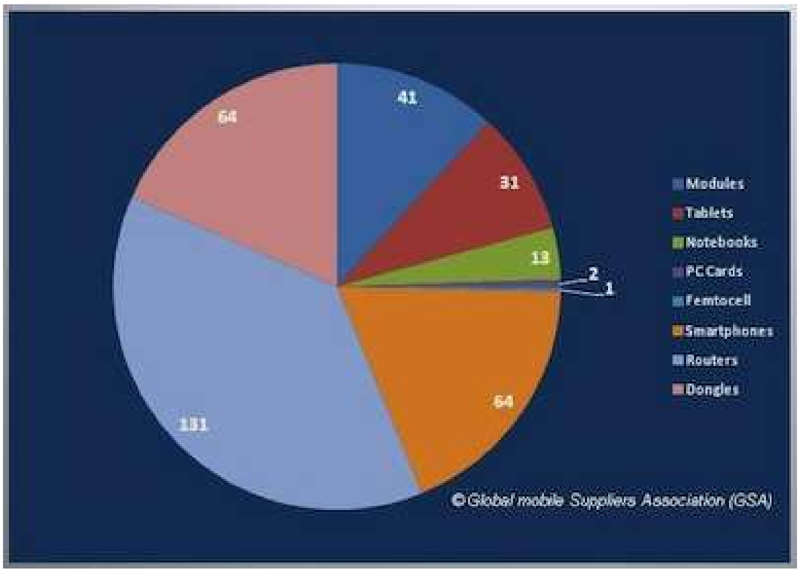
Figure 1-1 Overall LTE/SAE Architecture [2]

1.3.1 Radio Access Network

In a mobile network, the radio access part is the one between the user and the Core Network and therefore it consists of the **User Equipments** (UE) and the base stations or **eNodeBs** (E-UTAN NodeBs).

1.3.1.1 User Equipment (UE)

The UE is the term used to make reference to the devices that consumers use to communicate in a LTE Network. Nowadays, device manufacturers are producing a lot of devices for the next generation on LTE networks, while at the beginning USB modems were designed to provide internet access to laptops, with the fast evolution of the technology there are devices such as smart-phones and Tablets up-taking the market, by the moment this thesis is being written, recent reports from the Global mobile Suppliers Association (GSA) show that around 347 LTE devices have been launched, demonstrating an in increment of around 76% in six months. [3]



©Global mobile Suppliers Association (GSA)

Figure 1-2 LTE Devices (UE): 347 Products Launched [3]

1.3.1.2 E-UTRAN NodeB (eNodeB)

The eNodeB is a base station similar to the NodeB present in 3G architectures, but with integrated RNC functionalities, making this feature one of the main differences between the architectures of LTE and 3GPP 3G networks where RAN consists of separated NodeBs and RNCs. The eNodeB hosts the Physical (PHY), Medium Access Control (MAC), Radio Link Control (RLC), and Packet Data Control Protocol (PDCP) layers and include functionalities like the Radio Resource Management (RRM), IP header compression and encryption, handovers and retransmissions.

1.3.2 Evolved Packet Core (EPC)

Once the UE get access to the resources in the network through to the Radio Access Network, there are many other tasks that should be carried in order to provide operators revenue (charging), authentication for ensuring that the user is a valid user, service setup for end-to-end connection, and so on. These other tasks are provided by the Core Network part of the architecture. The following is a brief description of the main elements that compose this part of the LTE network.

1.3.2.1 Mobile Management Entity (MME)

The MME is the key control-node for accessing the LTE network due to it processes the signaling between UE and the core network. It is responsible for the UE on idle mode, tracking and paging procedure including the retransmissions. At the same time is responsible of the authentication of users, task that is performed by interaction with the Home Subscriber Server. The NAS protocols (Non- Access Stratum) used for signaling are handled at this node.

1.3.2.2 Serving Gateway (S-GW)

The Serving Gateway node routes and forwards the user data packets and serves as the mobility anchor for data bearers. During handover MME commands S-GW to switch data tunnels from one eNodeB to another one. When there are UE on idle mode and the resources in the eNodeB are released the S-GW behaves as a data buffer and requests MME to initiate paging of the UE. It manages and stores UE contexts, e.g. parameters of the IP bearer service, network internal routing information. It also performs replication of the user traffic in case of lawful interception.

1.3.2.3 Packet Data Network Gateway (PDN-GW)

Packet Data Network Gateway is the node that connects the core network with other external data networks such as the Internet becoming the point of exit and entry traffic for the UE. It is the IP point of attachment for the UE so that it performs IP address allocation of the UE. P-GW has capability to provide IP packets filtering. Technologies like WiMAX that are non 3GPP can inter-work with LTE thanks to the P-GW since it acts as a mobility anchor.

1.3.2.4 Home Subscriber Server (HSS)

The role of Home Subscriber Server is providing information about subscribers for authentication and authorization of the users. It is similar to GSM nodes Home Location Register (HLR) and Authentication Centre (AUC).

1.3.2.5 Policy Control and Charging Rules Function (PCRF)

The PCRF is responsible for Policy and Charging Control (PCC) of users and also ensures QoS of the services.

1.3.3 Frequency Bands Flexibility

The aim of the high degree of spectrum flexibility proper of LTE is to allow the deployment of the LTE radio access in diverse spectrum with different characteristics, including different duplex arrangements, different frequency-bands-of-operation, and different sizes of the available spectrum. Therefore LTE is defined to support flexible carrier bandwidths from below 5MHz (1.4MHz) up to 20MHz, in many spectrum bands and for both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) deployments.

Frequency Division Duplex (FDD) as illustrated in Figure 1-3a, implies that downlink and uplink transmission take place in different, sufficiently separated, frequency bands. While Time Division Duplex (TDD), as illustrated Figure 1-3b, implies that downlink and uplink transmission take place in different, non-overlapping time slots. This means that an operator can introduce LTE in both new and existing bands [4]

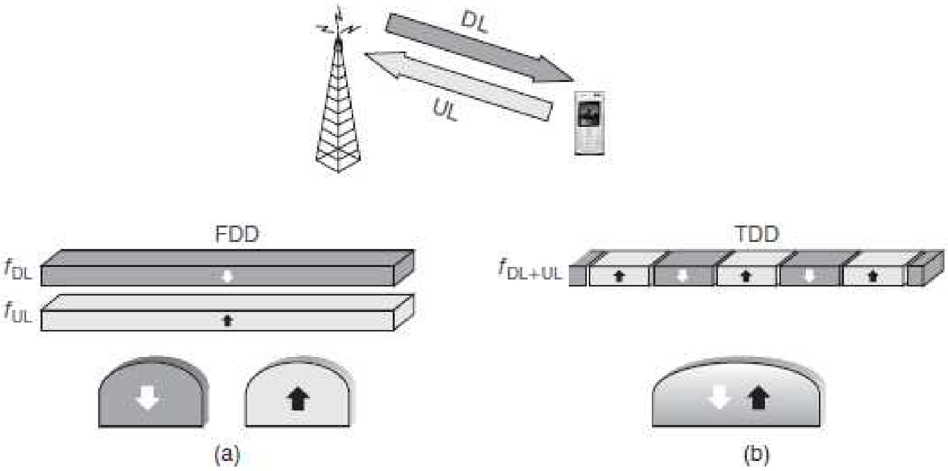


Figure 14.3 FDD vs. TDD. DL: Downlink; UL: Uplink [4]

2. LTE Technology Overview

In this chapter an overview of the Radio Access, Physical Layer (L1), Layer 2 (Medium Access Control, Radio Link Control and Packet Data Convergence Protocol) and Radio Resource Control layer.

2.1 Radio Access Overview

Hybrid-ARQ processing, modulation, multi-antenna processing, and mapping of the signal to the appropriate physical time-frequency resources (using OFDMA for Downlink and SC-DMA for Uplink) are the new modulation, access and transmission schemes that LTE introduces into 3G system enabling its high performance. These new technologies and techniques used will be described in this chapter.

2.1.1 OFDM Access Scheme

OFDM (Orthogonal Frequency Division Multiplexing) is a digital multicarrier modulation widely used in wideband communication systems. Multicarrier means that a large number of closely spaced sub-carriers are used to carry the data that are divided into parallel data streams, one for each sub-carrier. Each sub-carrier is then modulated separately and it is possible to use different modulations for different sub-carriers. These modulations are usually complex multi state modulations like QPSK, 16QAM or 64QAM.

All sub-carriers shall be mutually orthogonal to each other, so they can be placed closely together and inter-carrier guard bands are not required. Simple rectangular pulse of the length T_u is used and rectangular shape in time domain corresponds to a sinc-square-shaped spectrum in frequency domain as illustrated in Figure 2-1.

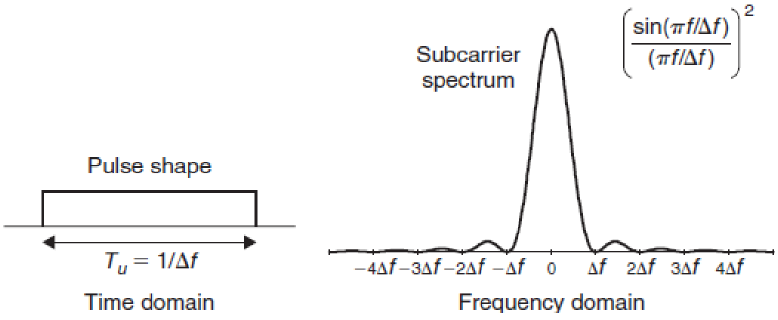


Figure 2-1 Per-subcarrier pulse shape and spectrum for basic OFDM transmission [4]

The orthogonality is reached by separating sub-carriers with spacing $1/T_u$ as illustrated in Figure 2-2. The LTE sub-carrier spacing is set to $\Delta = 15Khz$. Due to orthogonality an OFDM modulator can be implemented by using IFFT (Inverse Fast Fourier Transform) algorithm and demodulator by FFT (Fast Fourier Transform) respectively [4]

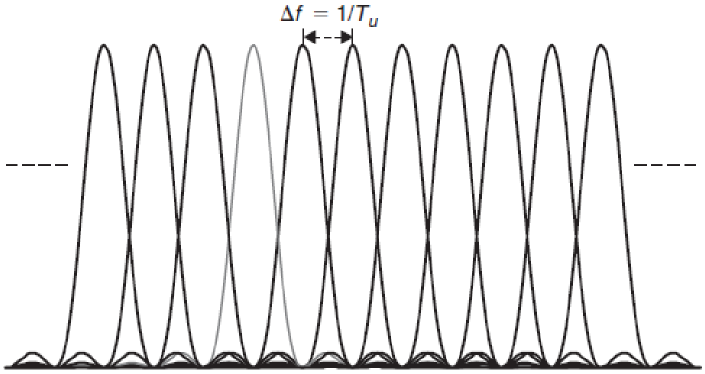


Figure 2-2 OFDM Subcarrier Spacing [4]

The main advantage of OFDMA over conventional single-carrier scheme is its ability to cope with changing channel conditions both in frequency and time. In this case, the receiver is reporting channel conditions back to the transmitter and like this it can choose a proper modulation for each subcarrier frequency. Multiple Access in OFDMA is based on scheduling users both in frequency domain by assigning right number of subcarriers and in time domain by assigning right number of symbols. Apart from LTE other common technologies like ADSL, DVB-T or WiMAX are getting benefits from it.

2.1.2 Single Carrier FDMA Scheme (SC-FDMA)

The uplink transmission scheme is based on Single Carrier Frequency Division Multiple Access (SC-FDMA) due to it has a lower Peak-to-Average Power Ratio (PAPR) compared to OFDM and it is a flexible modulation scheme. Low PAPR means more modest requirements for the power amplifier of UE in sense of cost and power consumption which is highly desirable in a mobile device. In the figure 2-2 the comparison between OFDMA and SC-FDMA in time and frequency domain is illustrated.

SC-FDMA can be viewed as DFT-based (Discrete Fourier Transform) pre-coded version of OFDMA [4] .This pre-coding solves problem with high PAPR in the classic OFDM and allows usage of Frequency Domain Equalization (FDE) to mitigate distortion introduced by multipath propagation. The output of DFT is applied to inputs of the OFDM modulator where unused inputs are set to zero. By changing inputs users can be assigned to a different subcarriers and their number is limited by the DFT size.

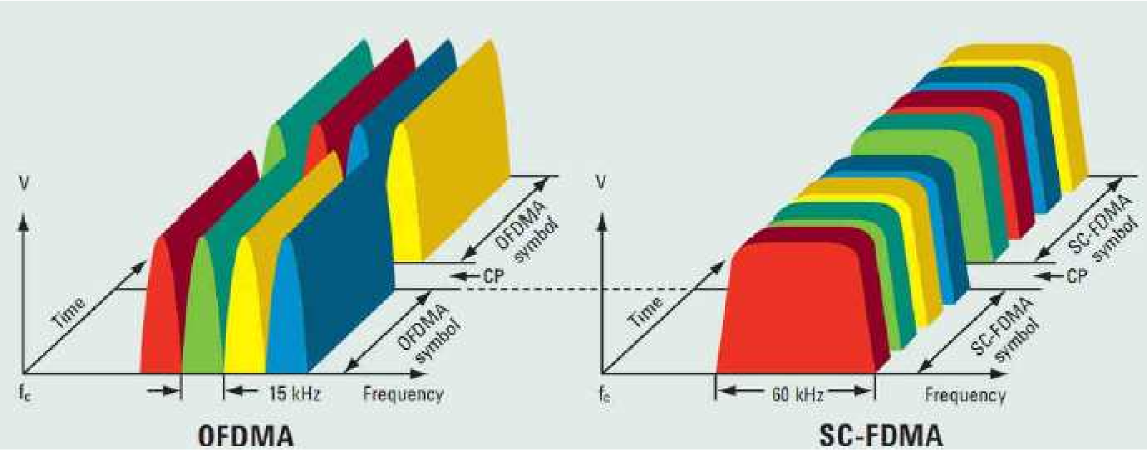


Figure 2-2 Comparison of OFDMA and SC-FDMA on frequency and time domain [5]

2.1.3 Multiple Antenna Technology

The Multiple Input Multiple Output (MIMO) is the key technology used to achieve the aggressive LTE performance targets related to the improvement of the coverage area and the increasing of the throughput. MIMO is based on the use of multiple antennas at both the base station and the UE and covers several techniques including spatial multiplexing and beam forming (also known as pre-coding) [4]. The basic principle in spatial multiplexing consist in transmitting more independent data streams, each fed to own transmitting antenna. The data streams are then received by more receiving antennas creating separated radio paths, as a result, the space dimension is reused or multiplexed.

In beam forming the same signal is emitted from each antenna with appropriate phase and amplitude weighting to achieve desired (directional) transmitting pattern. The directional pattern is established by creating constructive and destructive interference between signals from transmitting antennas.

During the MIMO processing it is really important to know channel characteristics. Therefore each antenna must have its own reference symbols in the transmission scheme. Thus, the receiver is able to differentiate antennas from each other and estimates the channel conditions. The antenna configuration used in an In LTE system could be 2x2 or 4x4.

2.1.4 Hybrid Automatic Repeat Request

Hybrid Automatic Repeat Request (HARQ) is the technique used in LTE to manage the retransmissions, whenever there is an error on a received transport block; it allows a UE to rapidly request retransmission. The standard ARQ detects errors by comparing computed CRC (Cyclic Redundancy Check) at the receiver with the received one. In Hybrid ARQ also additional bits are used to perform also Forward Error Correction (FEC) and not only Error Detection (ED) with CRC. The retransmitted blocks are combined at the UE with the original transmissions. Incremental redundancy is used as the soft combining strategy in LTE.

2.2 Physical Layer

This chapter will be provide a brief description of the Downlink and Uplink procedures of its lowest layer of LTE architecture; the Physical (PHY) Layer.

2.2.1 Downlink

LTE uses OFDMA access scheme in the downlink direction. The following are the descriptions of the transmission scheme and channel structure of physical layer in downlink.

2.2.1.1 Transmission Scheme

In LTE the physical resources are shared and dynamically allocated to the users and then in the LTE radio-interface are used radio frames of length 10 ms divided into ten sub-frames of length 1ms. Each sub-frame is split into two time slots with duration of 0.5 ms. Finally each time slot comprised seven OFDM modulation symbols in the case of the normal length Cyclic Prefix (CP) or six symbols with the extended CP [6]. The general time-domain structure is shown in Figure 2-3.

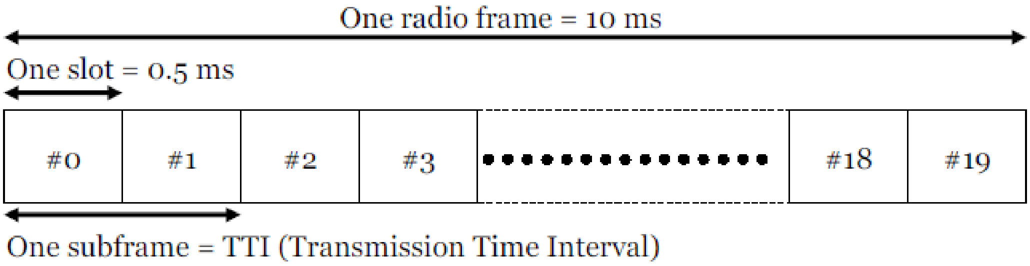


Figure 2-3. LTE FDD frame structure [6]

In the frequency domain, 12 subcarriers are grouped together into a resource block that has duration of one time slot (0.5 ms). Subcarrier spacing in LTE is 15 kHz, thus a resource block occupies a bandwidth of 180 kHz. Each resource block is formed from resource elements, which consists of one subcarrier for duration of one OFDM symbol. Resource block is the smallest unit, which can be scheduled to a user [7]. Figure 2-4 illustrates overall physical structure both in time and frequency domain.

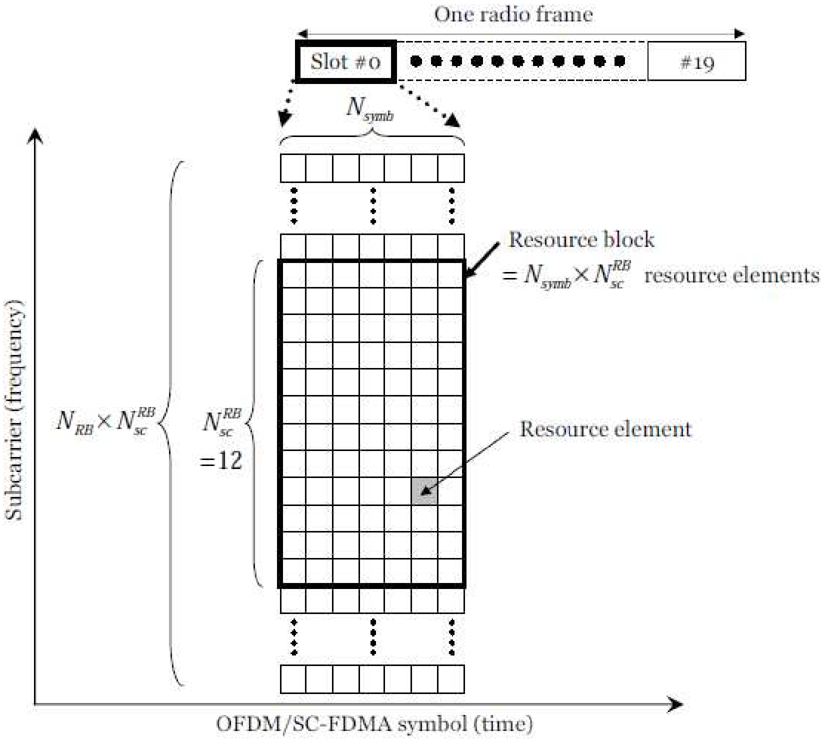


Figure 2-4 Time-frequency physical resource structure [6]

2.2.1.2 Physical Channels and Signals

The data and control signaling for users are transmitted in several physical channels divided by their purpose [7]. Physical channels carry information received from upper layers and physical signals do not carry any user related data, but their information is useful for channel estimation and synchronization. Into the do the downlink frame shown on figure 2-4, all the channels and signals are allocated as illustrated in the figure 2-5.

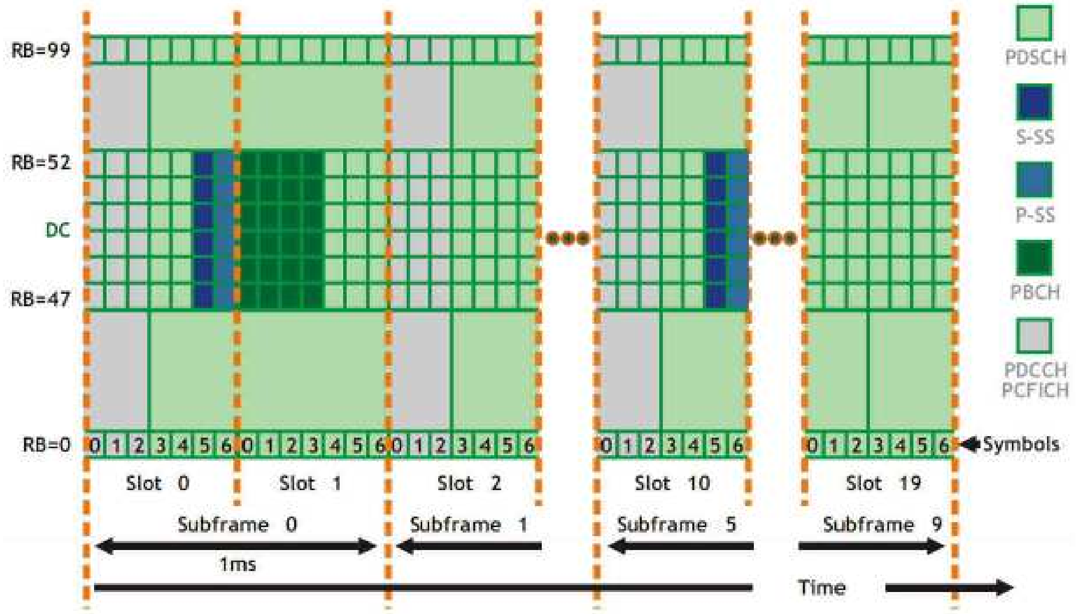


Figure 2-5 Channel and Signal allocation on the downlink frame [8]

The following are the descriptions of the LTE physical channels and signals.

- **Physical Downlink Shared Channel (PDSCH)**: The main downlink data-bearer channel in LTE, used to transport user data. PDSCH allocates the majority of resource blocks in a frame. It is possible to use all supported modulations, QPSK, 16-QAM, and 64-QAM.

- **Physical Broadcast Channel (PBCH)**: carries information for initial access to the cell by UE. Cell-specific information is broadcasted every 40 ms using QPSK modulation.

- **Physical Control Format Indicator Channel (PCFICH)**: informs terminals in a cell about the number of OFDM symbols used for the transmission of control channel in the first time slot of a subframe. The possible values are one, two or three OFDM symbols. The PCFICH uses QPSK modulation.

- **Physical Downlink Control Channel (PDCCH)** The control information indicating resource allocations are transferred through PDCCH channel. There are multiple PDCCH channels in each cell, because every user has its own. This channel again uses QPSK modulation.

- **Physical Hybrid ARQ Indicator Channel (PHICH)**: behaves as the response channel for HARQ mechanism. It carriers ACK/NACK messages to confirm successful reception or requests retransmission of incorrectly received block of data.

- **Physical Multicast Channel (PMCH)** The downlink physical channel for transporting data for MBMS services is PMCH. Multicast information is sent to multiple users simultaneously. PMCH also as PDSCH has multiple modulation options including QPSK, 16-QAM, or 64-QAM.

- **Reference signal (RS)** Reference signal consists from known reference symbol and is intended for channel estimation. The estimation is necessary to provide coherent demodulation of downlink transmission. RS is transmitted in the OFDM symbol 0 and symbol 4 of each time slot every 6 subcarriers. The subcarriers used in the symbol 0 and symbol 4 are shifted between each other, so the channel estimation is possible on every 3 subcarriers (every 45 kHz).

- **Synchronization signals (P-SS and S-SS)** LTE uses two synchronization signals during cell search, Primary Synchronization Signal (P-SS) for time slot synchronization (0.5 ms) and Secondary Synchronization Signal (S-SS) for frame synchronization (10 ms). They are transmitted on six reserved resource blocks around DC on symbol 6 for P-SS and on symbol 5 for S-SS in time slot 0 and 10.

2.2.1.3 Transport Channels DL

The LTE physical channels have associated transport channels. The transport channels are the ‘interface’ between the Medium Access Control (MAC) layer and the physical layer. Data on a transport channel is organized into transport blocks. Each transport block is associated with transport format, which enables MAC layer to transmit at different data rates. LTE has defined these transport channels in downlink: Broadcast Channel (BCH), Paging Channel (PCH), Downlink Shared Channel (DL-SCH), and Multicast Channel (MCH) [4].

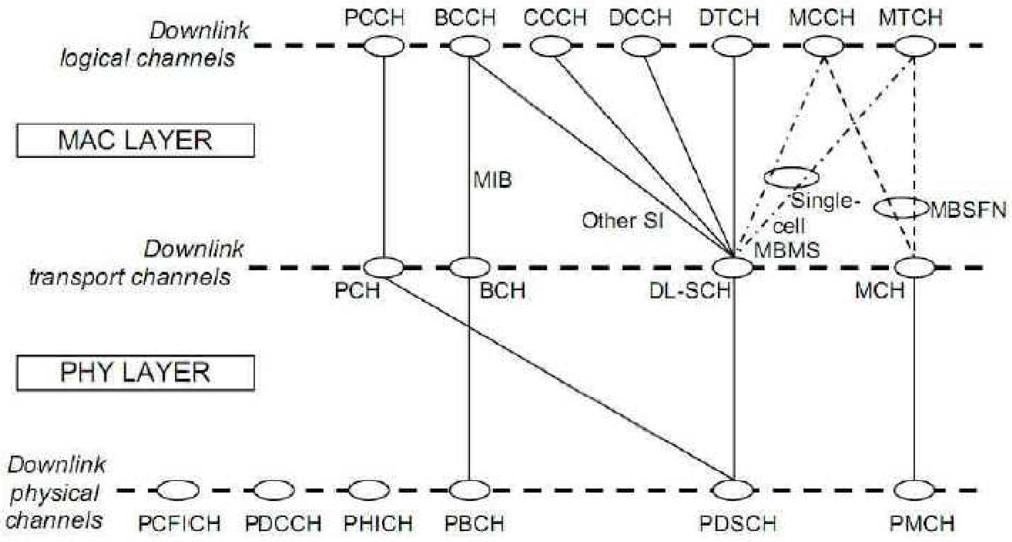


Figure 2-6 Physical, transport, and logical channels mapping in downlink [4]

2.2.2 Uplink

As it has been already described, on the Uplink context the used transmission is based on the SC-FDMA transmission scheme, due to of the low PAPR and orthogonality both in time and frequency domain advantages it has. Also because under this scheme the high level of intra-cell interference associated with code-multiplexed uplink are avoided. Lower intra-cell interference means higher system capacity and better usage of adaptive modulation techniques.

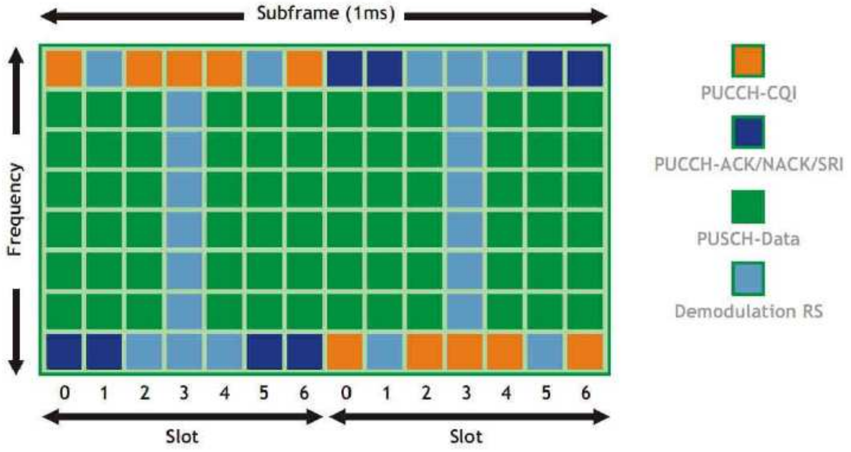


Figure 2-7 Channels and Signal allocation in the Uplink frame [8]

2.2.2.1 Physical Channels and Signals

Both downlink and uplink use the same frame structure shown in Figure 2-3. On the other hand each direction uses its own channels (physical, transport and logical) and reference signals used for coherent demodulation and channel sounding. Therefore also the allocation of resource blocks is different as it can be seen in the figure 2-7. Short description of LTE uplink physical channels and signals is following [7].

- **Physical Uplink Shared Channel (PUSCH)** User data are carried on the PUSCH channel in LTE uplink. Users do not have assigned fixed resources, but allocation of resource blocks utilized by PUSCH is determined in the uplink scheduler. The scheduler needs to know the transmission requirements of each user. The information is provided through MAC layer signaling. The PUSCH may select from all modulations possible in LTE – QPSK, 16-QAM and 64-QAM.

- **Physical Uplink Control Channel (PUCCH):** The uplink control information is carried on the PUCCH channel. It contains channel quality indicator (CQI) used for selection of preferable modulation/coding-rate combination, ACK/NACK responses from UE in HARQ mechanism and uplink scheduling requests. The PUCCH is used only when there are no user data transmitting. In the presence of uplink data, control signaling takes place on the PUSCH. To provide frequency diversity, the PUSCH is assigned resource blocks at the upper part of the spectrum in the first slot of a subframe and the same number of RBs at the lower part in the second slot as illustrated in Figure 2-7.

- **Physical Random Access Channel (PRACH):** When a UE wants to access mobile service (e.g., call originating or paging response), it transmits random access preamble on PRACH channel. There are 64 preamble sequences available, divided into the two subsets. The terminal selects at random one sequence in one of the subsets. As long as there is no other terminal using the same sequence, no collision occurs and eNodeB should detect the access attempt from the UE. The bandwidth of RACH preamble is six resource blocks (1.08 MHz).

- **De Modulation RS (DM RS):** The purpose of DM RS is similar to the reference signal in downlink and it is used for channel estimation needed for coherent demodulation. It has the same bandwidth as regular uplink data transmission. DM RS is placed on the 4th SC-FDMA modulation symbol in each slot. Both types of reference signals in LTE (DM RS and SRS) should have good auto- and crosscorrelation properties, flat frequency domain representation and low cubic metric values. Therefore Constant Amplitude Zero Auro-correlation (CAZAC) Sequences are used.

- **Sounding RS (SRS):** The Sounding Reference Signal is used to estimate uplink channel at eNodeB. Estimated channel parameters are utilized in the uplink scheduling in the frequency domain. The SRS occupies the last SC-FDMA symbol in a subframe and only every other subcarrier. It is configured by cell specific signaling, which set of subframes should apply.

2.2.2.2 Transport Channels UL

There are only two transport channels defined in the LTE uplink. The Random Access Channel (RACH) transfers data for PRACH on the physical layer and the second transport channel, Uplink Shared Channel (UL-SCH), carries all higher layer channels together and is mapped to the physical data channel PUSCH [4]. Overview of channel mapping of uplink is illustrated in Figure 2-8.

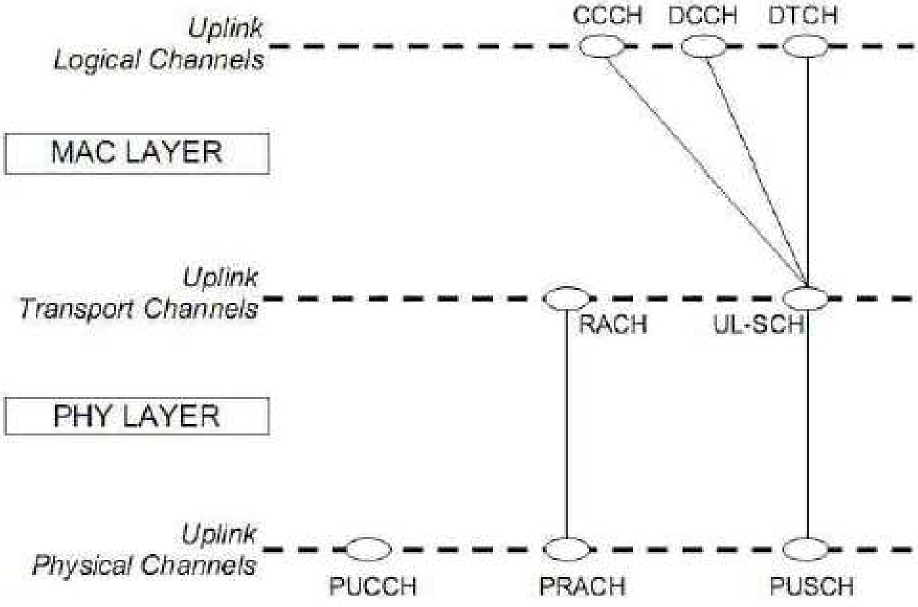


Figure 2-8 Physical, transport and logical channels mapping in uplink [4]

3. Mobility on LTE Networks

The most important features of Mobile systems is the **mobility** of the UE with the aim of providing seamless access to voice and multimedia services with excellent performance and quality of service. The way of achieving such performance is by the implementation and supporting of **handover operations (**from a source cell to a target cell) able to deal with the strict delay requirements proper of mobile networks.

It is specified that LTE networks and systems should support mobility for UE moving at speeds up to 350Km/h or even 500Km/h (e.g., modern trains) [1]. Therefore, taking into account that higher speeds mean more frequent handover operations, the mobility enhancement is a critical aspect especially for real time services.

There are two main handover technologies in wireless communication systems, Hard handover and Soft Handover, LTE standard supports only hard handover i.e. that the switch from one cell to the other happens in a "break-before-make" fashion; (a new wireless link connection with the target eNodeB should be set up after the release of the connection with the source eNodeB) meaning that the UE has connectivity to only one cell at a time. On the other hand, WCDMA networks support both hard and Soft handover, due to the UE may be connected to more than just one cell.

The usual size of cells should be up to 30 km, but even cells up to 100 km should be possible [1]. Of course such an extreme cell sizes expect frequencies below 1 GHz. In comparison, in the GSM system the maximum cell size is determined by the size of timing advance and limits the maximum cell size to 35 km.

3.1 Handover Overview

A handover procedure can be typically divided into four parts: the measurement control, the measurements report, the handover decision and the handover execution [9]. These procedures are depicted in the figure 3-1. Measurement control and measurement reports are considered as handover measurements and in the LTE system these measurements are made in the downlink and processed in the UE by filtering out the effect of fast fading.

Afterward, the processed results are reported in the uplink back to the source eNodeB in a periodic event based manner. Hence the handover is initiated based on the information from the processed handover measurements and if certain criteria are met then the target eNodeB becomes the serving cell performing the network procedures with the assistance of the UE.

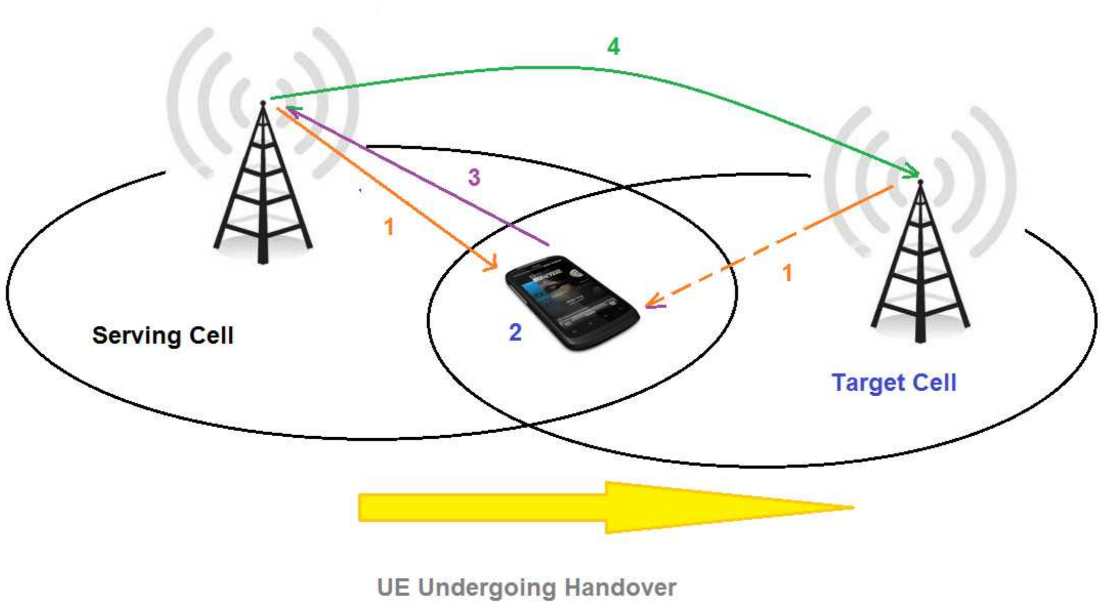


Figure 3-1: The different parts of handover process. 1) Downlink handover measurements, 2) processing of downlink measurements, 3) uplink reporting, 4) handover decision and execution.

The control of handovers is supported by the Radio Resource control thanks to the fact that the major part of signaling between UE and eNodeB in LTE network is processed through RRC protocol. RRC is responsible for maintaining RRC connection, broadcasting system information, paging, establishing of Radio Bearers, mobility control and UE measurement reporting [3]. The following is a brief description of the RRC that in the LTE has a reduced number of messages and RRC states in comparison with the RRC in WCDMA standard.

3.1.1 Radio Resource Control

In LTE standard RRC states were significantly simplified in comparison with WCDMA and only two states exists. The state of UE depends on whether RRC connection has been established or not.

3.1.1.1 RRC_IDLE

The UE is RRC_IDLE state when no user data are transferred to or from the UE. The UE only monitors a paging channel to detect incoming calls, applies broadcasted system information and performs measurements necessary for cell reselection. No Signaling Radio Bearer (SRB) is established, so there is no RRC connection. The UE in RRC_IDLE state can save battery power by applying Discontinuous Reception (DRX). DRX means that UE sleeps most of the time and wakes up periodically to be ready for paging.

3.1.1.2 RRC_CONNECTED

The opposite state is RRC_CONNECTED, when UE is active and receives/transmits user data from/to the network. The UE monitors control channels associated with the data transmission on the shared channel to determine which data are scheduled to the specific UE. The UE also provides channel quality information for the scheduler at the eNodeB. It is also necessary to perform measuring of neighboring cell and reports results back to the eNodeB, which decides about cell reselection.

3.1.2 Measurements and Decision Criterions

The RRC layer provides measurement functions to support the control of UE mobility in the LTE network. The measurements are fully configurable by the network. There is defined several measurement configuration entities. Measurement objects determines on what the measurement should be performed, such as a carrier frequency. A reporting configuration sets which information should be reported by the UE and which criteria triggers report. A measurement identity identifies the measurement, quantity configuration defines the filtering used and finally measurement gaps define time, when no downlink or uplink transmission is scheduled, so the UE can perform measurement [4].

There are many decision criterions on handover technology, the main criterions are as follows: Reference signal power (RSRP); Reference Signal Received Quality (RSRQ); Received Signal Strength Indicator (RSSI); Signal Noise Ratio (SNR); Carrier Interference Ratio (CIR); Signal Interference plus Noise Ratio (SINR). The most widely used criteria is the RSSI.

3.2 Handover Procedure of LTE Systems

In the LTE architecture, the eNodeBs are connected to the MME/SG-GW by the S1 interface whereas X2 interface is interconnecting between the eNodeBs. Figure 3-2 presents a simplified illustration of the E-UTRAN architecture showing the respective interface and interconnections.

The handover within the LTE network, also known as Intra-E-UTRAN handover, can be performed in two different ways depending on the interface they are based on. First, there is X2-based handover, which is utilizing X2 interface between eNodeBs. The LTE has simplified architecture and in this type of handover no control node is used. Only Mobile Management Entity (MME) node is requested to make path switch for data transfer. In case there is no X2 interface between the two eNodeBs (the full mesh network of X2 interfaces between eNodeBs is not expected and possible), the S1-based handover has to be initiated. The S1 interface is between eNodeB and MME (already the core network) and transfers both the control plane and the user plane data.

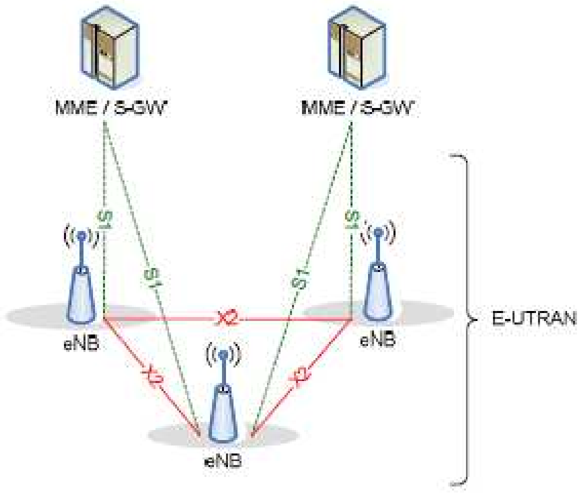


Figure3-2 E-UTRAN Architecture [9]

3.2.1 X2-Based Handover

In LTE systems the eNodeBs are making the decisions without involving the MME due to the active mode mobility managements are distributed. The necessary handover information is exchanged between the eNodeBs via the X2 interface. The MME is notified with handover complete information after a new connection is established between UE and target eNodeB. After the reception of this information, the MME switches the path. This type of handover is the default option in LTE Systems.

The Following are the description of the X2-Based Handover steps. In the figure 3-3 the call flow is depicted

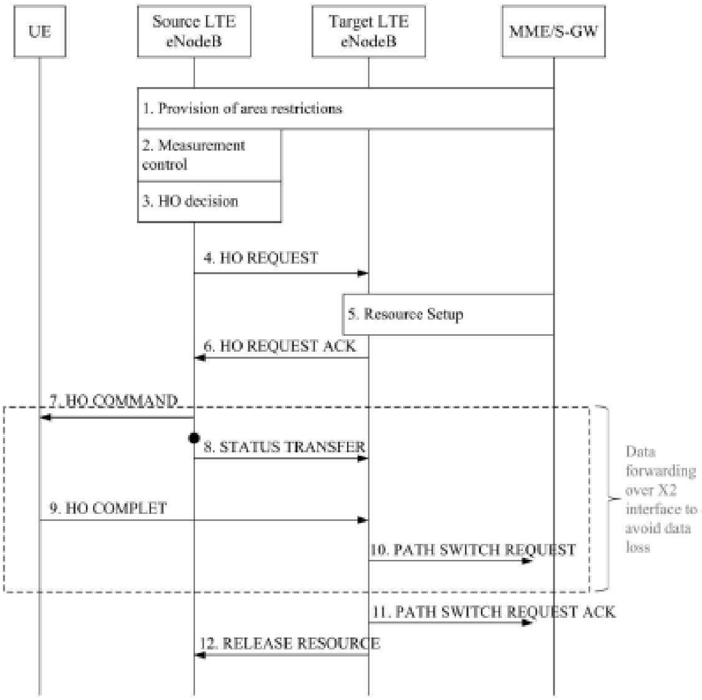


Figure 3-3 X2-based handover procedure without Serving GW relocation [2]

- Step 1: A UE obtains information about roaming restrictions at connection establishment or during last Tracking Area update.

- Step 2: UE is configured to do measurements and reports its results to the source eNodeB.

- Step 3: The handover procedure is triggered by eNodeB based on the measurement report.

- Step 4: The source eNodeB sends HANDOVER REQUEST message to the target eNodeB.

- Step 5: The target eNodeB does admission control and prepares resources (if it has enough capacity to accept the UE)

- Step 6: The Target eNodeB sends back the HANDOVER REQUEST ACKNOWLEDGE message. Then the source eNodeB commands the UE to perform the handover. The data forwarding is initiated as soon as the source eNodeB receives the HANDOVER REQUEST ACKNOWLEDGE to prevent data loss during handover.

- Step 7: After the HANDOVER COMMAND is received, the UE detach from the old cell, synchronize to a new one and performs the random access procedure.

- Step 8: The source eNodeB sends the STATUS TRANSFER message to the target eNodeB with content about the Sequence Number and the Hyper Frame Number, which the target eNodeB should assign to the first packet received from the core network (not from data forwarding). This step provides ability to continue with in sequence delivery.

- Step 9: The UE send the HANDOVER COMPLETE message to the target eNodeB after performing random access.

- Step 10: Then the target eNodeB sends the PATH SWITCH REQUEST to the MME, which sends request for bearer/s modification to the Serving Gateway (S-GW).

- Step 11: The S-GW confirms completion of modifications to the MME and it informs the target eNodeB with the PATH SWITCH REQUEST ACKNOWLEDGE message. Finally the target eNodeB send the RELEASE RESOURCE message to the source eNodeB and the handover is completed.

3.2.2 S1-Based Handover

The S1-Based handover used when the X2-based handover cannot be performed. That happens when two eNodeBs are not connected with the X2 interface or the UE has to change the MME. It means that core network is involved in the handover.

Figure 3-4 illustrates the steps of this type of handover which are basically the same as X2 based handover but the difference appears when source eNodeB tries to reserve resources at the target eNodeB. In this case, S1-based HO the source eNodeB has to first inform the source MME, which then requires the handover at the target MME and then the target MME requests the target eNodeB. The HANDOVER REQUEST ACKNOWLEDGE message is going the same path but in different direction and finally the source eNodeB can command the UE to do the HO.

The source eNodeB sends the STATUS TRANSFER message again through the source MME, the target MME to the target eNodeB. Since The data for the UE cannot be forwarded directly from the source eNodeB to the target eNodeB the indirect data forwarding has to be applied and therefore the indirect tunnel between the source eNodeB and the target eNodeB is established. The UE detach the old cell, synchronize to the new cell and does the random access procedure in the same way as in X2-handover. Only more network nodes have to be informed.

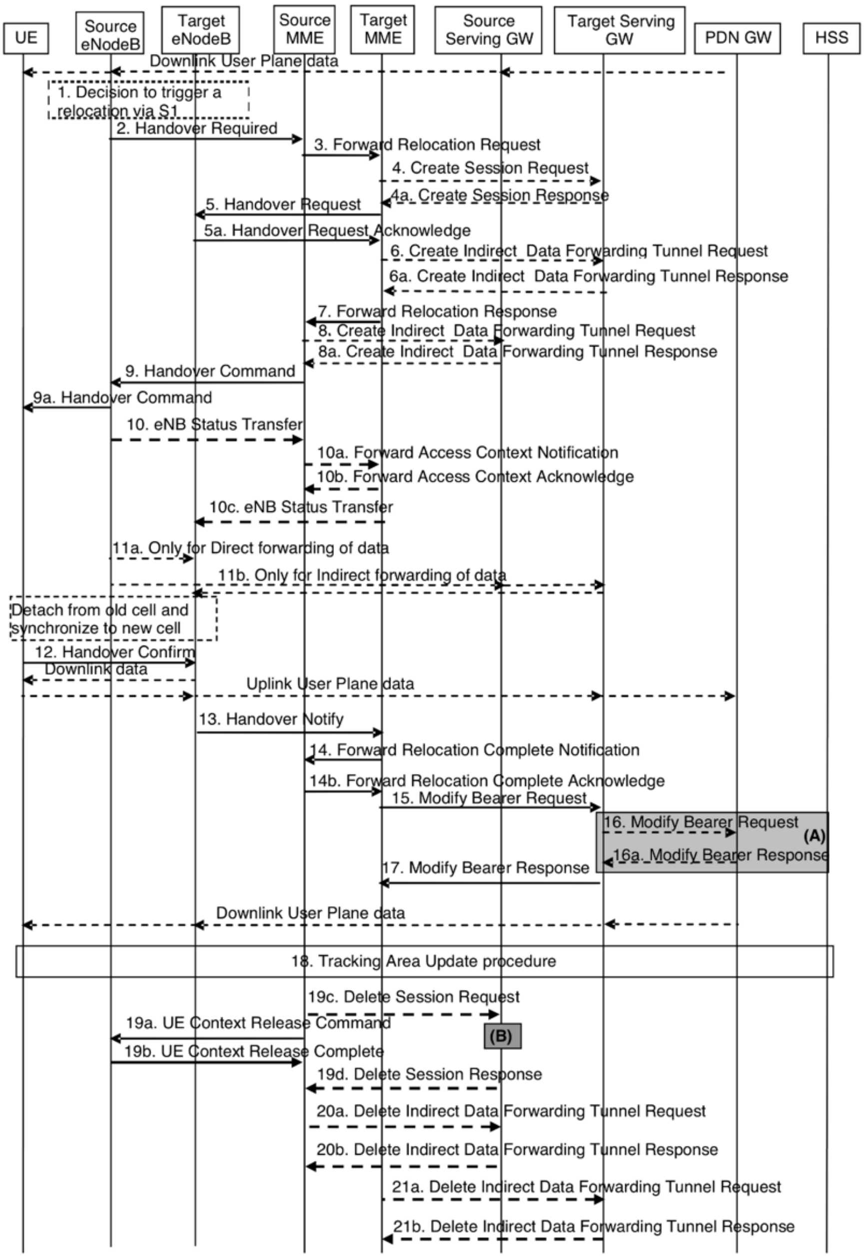


Figure 3-4 S1-based handover procedure

4. LTE Femtocells Systems

One of the main issues for wireless communications is to increase the coverage and capacity of existing cellular networks. Mainly the interest is focused on increasing data rates in and quality of service (QoS) for the indoor coverage/capacity, e.g., residential or enterprise companies, because according to recent surveys a considerable percentage of data services will take place indoors and nowadays, femtocells have come into the spotlight as a solution for that. It was estimated that by 2012 there would have been 70 million FAPs installed around the world and more than 150 million customers. [10]

The Femtocell access points (FAPs) or Home Base Stations (HeNBs) are low-cost, low-power access points deployed by the end-customers that provide indoor coverage of a given wireless cellular standard, e.g. Long Term Evolution (LTE), Wireless Interoperability for Microwave Access (WiMAX), GSM, UMTS. They are connected to the Internet to access the cellular service [11], through a backhaul, e.g. optical fiber, Digital Subscriber Line (DSL).

Further than the low-cost and low-power characteristics, femtocells have many advantages that make them attractive to both users and operators. The mobile users will have a better signal quality due to the proximity between the transmitter and receiver which means that communications will have better reliabilities and throughputs, furthermore, more users will access the same pool of radio resources or use larger modulation and coding schemes. On the other hand, operators benefit from greater network capacity and spectral efficiency. [12]

In the following sections of this chapter, Femtocells will be briefly described on its technical aspects and challenges for future development and integration to existent LTE architecture, after that the LTE Femtocell based architecture will be detailed as an introduction for the different techniques regarding to the handover on this kind of wireless networks.

4.1 Femtocell Networks Overview

Compared to other techniques for increasing system capacity, such as distributed antennas systems and microcells, the key advantage of femtocells is that is very little upfront cost to the service provider, because there is less intervention required from the operator point of view in the terms of installation and support [12]. Since for indoor services, attenuation losses will make high signal quality and hence high data rates very difficult to achieve the installation of short-range and low-power link was proposed as an approach for these location requirements and femtocells are more than suitable for that since they have better coverage and capacity, improved macrocell reliability and cost benefits.

The better coverage and capacity of the femtocells is given by their short transmit-receive distance which means that femtocells can prolong handset battery life and achieve a higher SINR (Signal to Interference plus Noise Ratio) which translates into improved reception – so called *five bar coverage* – and higher capacity. The improvement on the macrocell reliability is related to the fact that all the traffic generated indoors could be absorbed into the femtocell networks over the IP backhaul and then the base station of the macrocell could redirect its resources providing better reception for mobile users. Finally the cost benefits are provided because the deployment of femtocells will reduce the need for adding macrocell towers.

4.1.1 Technical Aspects of Femtocells

The power range of femtocell is between 13 to 20 dBm, and the maximum coverage is about 15 to 50 meters [13]. The benefits attributed to these technical aspects are related to the fact that a lower power will be transmitted and thus interference from neighbor macrocells will be mitigated. Regarding to the reduced distance due to the coverage range, the capacity of femtocells networks can be verified from Shannon's law, which relates the wireless link capacity (in bits per second) in a bandwidth to the SINR.

As exposed previously, the SINR is a function of the transmission powers of the desired and interfering transmitters, path losses, and shadowing during terrestrial propagation. Path losses cause the transmitted signal to decay as:

$$Ad^{\alpha}$$

Where A is a fixed loss, d is the distance between the receiver and the transmitter and α is the path loss exponent, so it can be shown that in order to enhance the reception and signal strength between transmitter and receiver the d and α should be minimized and therefore a higher capacity will be achieved as well.

In addition, since femtocells serve only around one to four users, a larger portion of their resources (transmit power and bandwidth) can be dedicated to each subscriber providing a better Quality of Service (QoS) in comparison with Macrocells that have larger coverage area and hence a larger number of users.

4.2 LTE Femtocell System Architecture

For the femtocell/macrocell network integration, there are many possible options and still the architecture has not been finalized, nevertheless, there is a strong consensus among the 3GPP and NGMN Alliance to keep it as flat as possible following the principles of "All-IP" networks adopted in the LTE Standards. Each option comes with a tradeoff in terms of the scale but the best option depends on the capabilities of the existent operator's network and their future plan regarding to the network expansion. The debate is still going on the evaluation of the need for a signaling aggregation element or whether the evolved packet core (EPC) itself should be able to support femtocells directly. [14]

The LTE femtocell architecture is shown in figure 4-1 which has an element named HeNB GW and a set of S1 interfaces to connect the HeNBs to the EPC. As illustrated, the HeNB GW has the role of ***concentrator element***, in order to expand the S1 interface between the HeNB and the core network and therefore allowing the deployment of more HeNB. The HeNB GW appears as a eNodeB to the MME and as a MME to the HeNBs.

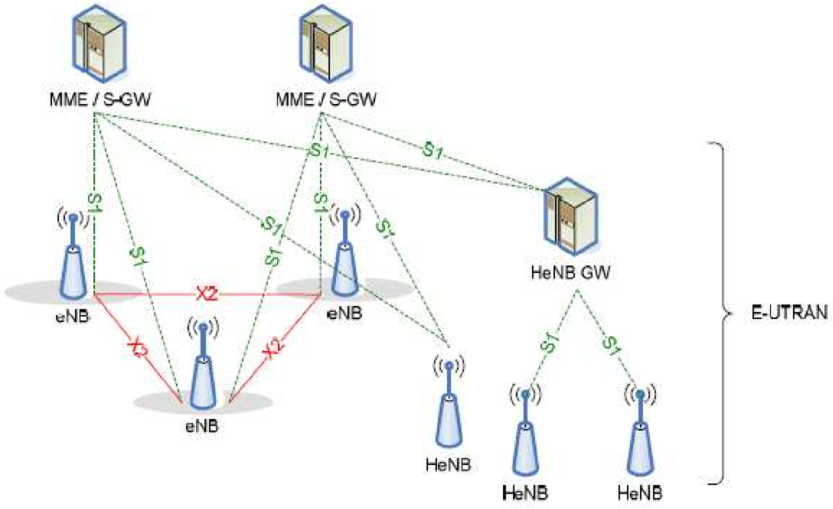


Figure 4-1 Overall E-UTRAN architecture with deployed HeNB GW [14]

The logical architecture of LTE femtocell networks is composed by four main elements as depicted in figure 4-2.

4.2.1 Security Gateway (SeGW)

The security Gateway is responsible of the authentication of the femtocell and it provides the femtocell with access to the HeNB GW. It terminates secure tunneling for TR-069.

4.2.2 Home eNodeB Gateway (HeNB GW)

The HeNB GW appears as an RNC to the existing core network using S1 interface and it supports femtocell registration and UE registration over S1 and terminates S1 from femtocell.

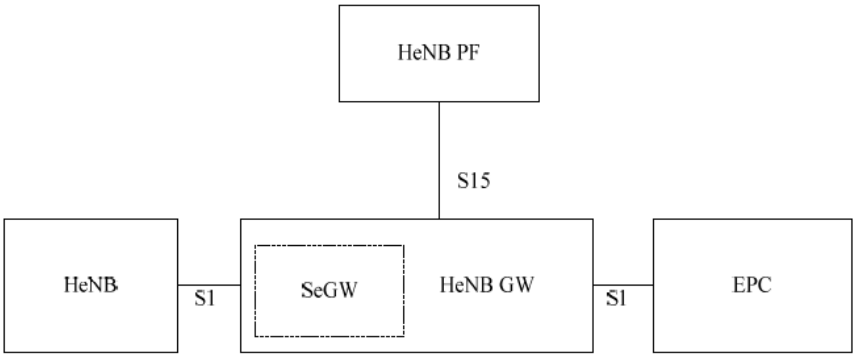


Figure 4-2 Femtocell Logical Architecture [15]

4.2.3 Home eNodeB (HeNB)

The Home eNodeB is the customer Premise equipment that offers the Uu interface to the UE so it is the element that provides RAN connectivity using the S1 interface. It also supports some RNC functions and supports HeNB registration and UE registration over S1.

4.2.4 HeNB Policy Function (HeNB PF)

The HeNB PF is the element of the architecture responsible for making decisions according to the characteristics of HeNB about whether the admission quest can be accepted or rejected. It is able to Interact with other policy entity (e.g. PCRF and BPCF)

5. LTE Macro and Femtocells challenge scenarios

Nowadays, the frequency bands of providers are very limited, for instance at the recent auctions of licenses for long-term evolution (LTE) also higher frequency bands (e.g. 2600 MHz) have been sold, where high-quality network coverage within buildings is difficult to achieve with base stations that are located outside the buildings. Operators are planning to cover areas within buildings by means of femtocells due to the complications they have already with macro and micro cells.

Furthermore, the femtocell architecture is much more different than existing cellular networks and thus, interaction on scenarios with coexistence of LTE Macrocells and Femtocells is one of the main issues for femtocell network deployment. First of all, femtocell have low antenna heights compared to external antennas and then the customer has the free choice of placement incurring in problems such that a poorly placed femtocell could therefore interfere with the rest of the network, rather than providing the desired additional capacity. [16]

Hence, femtocells are definitely an element that has to be taken into account in future network and handover planning in order to mitigate their impact on the existing networks due to handovers to and from femtocells as well as another technical challenges that will be described in the following sections.

5.1 Femtocell Access Methods

Femtocells have three different access methods to indicate which users are allowed to use each femtocell or restrict their usage by certain users. The advantages and drawbacks of these access methods are:

5.1.1 Open access

When using open access, all users, subscribers and nonsubscribers, can access any femtocell. This method may not be preferred by the femtocell owners, since they pay for a device that is to be shared with other operator customers. Open access, however, presents some advantages like the improvement of the overall capacity of the network, due to in practice macrocell users can connect to nearby femtocells in locations where the macrocell coverage is deficient. From an interference viewpoint, this avoids femtocells behaving as interferers since outdoor users can also connect to indoor femtocells. Nevertheless, a disadvantage of this mode is the increased number of handovers and thus signaling.

5.1.2 Closed access

When using closed access, only the subscribers of a femtocell are allowed to establish connections. This mode may be preferred by the femtocell owners, because there is no need to share the resources of the femtocells with other users. Thus, this access method is more likely to be deployed in the home environment; however, this implies that power leaks through windows and doors will be sensed as interference by passing macrocell users, decreasing their signal quality.

5.1.3 Hybrid access

When using the Hybrid Access, only a limited amount of the femtocell resources can be accessed by nonsubscribers. In this way, most of the interference problems of closed access are eliminated while controlling the impact on the femtocell owner.

5.2 Time Synchronization

In order to minimize multi-access interference, network time synchronization is necessary between macrocells and femtocells. Without timing, transmission instants would vary between different cells. This could lead to the uplink period of some cells overlapping with the downlink of others, thus increasing inter-cell interference in the network. [10]

One of the possibilities for achieving time synchronization would be the FAPs equipped with high precision oscillators; however this option is not suitable because FAPs are intended to attain low prices. Therefore, the use of GPS receivers for providing accurate timing over satellite links, has been proposed as a possible solution with the drawback that their performance depends on the availability of GPS coverage inside user premises.

Another solution is the use of the IEEE-1588 Precision Timing Protocol as a feasible method to achieve synchronization However, some modifications are necessary in order for it to perform efficiently over asymmetric backhaul links such as ADSL.

5.3 Physical Cell Identity (PCI)

Physical cell identity (PCI) is used to identify a cell for radio purposes such as handoff procedures. The PCI list is provided so that mobile terminals know which cells to monitor. This represents a challenge in femtocell networks, since FAPs must select their PCIs dynamically after booting or changing their position in order to avoid collision with other macro/femtocells. Furthermore, in extensive femtocell deployments and due to the limited number of PCIs the reuse of PCIs among femtocells in a given area may be unavoidable, thus causing PCI confusion. [10]

5.4 Neighboring Cell List

Femtocells must thus be able to set up their neighboring cell list in a dynamic manner due to they are not fixed as a normal base station and every time they are switched on/off for re-location or movement purposes their neighbors are modified. Therefore, the relationships between femtocells must be handled differently than those between macro and femtocells and new techniques must be developed to allow macro and femtocells to support a larger number of neighboring cells to be handled rapidly. [10]

5.5 Mobility Management

The mobility management is the most critical and challenging scenario where Macro and Femtocells coexist and thus, different handoff management procedures are needed to allow, for example, nonsubscribers to camp for longer periods on nearby femtocells. Furthermore, the implementation of a hierarchical cell structure (HCS) becomes important in order to distinguish between macro- and femtocells. In this way, the signaling across layers can be minimized as well as the neighboring cell list that users scan when performing a handoff.

6. Handover Techniques

One of the key points of femtocell network deployment is the ability of switching between femtocell and macrocell networks in a seamlessly way and this is one of the big challenges that are faced nowadays with LTE for mass deployment scenarios like in case of the Home eNodeBs because femtocells not only provide coverage at the customer premises, but also radiates toward neighboring houses as well as outdoors and they can cause interference and strong degradation of the macrocells' performance. Furthermore, the deployment of new femtocells could also disturb the normal functioning of already existing femtocells. Therefore, in order to reduce the appearance of dead zones within the macrocells and successfully deploy a femtocell network, interference avoidance, randomization, or cancellation techniques are being applied and developed. This is a topic under research and there are many techniques being proposed to improve the performance of both femtocell and LTE networks through the optimization of the handover procedures, in this chapter, the novel techniques proposed will be described.

6.1 Handover based on Users Velocity

In the indoor scenario, we could have a considerable amount of femtocell with its respective coverage area (of few meters) and UEs moving through them. Therefore, it is important to take into account the way the handover indoor and outdoor (with the macrocells) will be performed depending on the velocity the UEs are moving. The reason why this is important is related to the fact that especially for high speed users there could be many unnecessary handovers performed that will result in a reduction in the system capacity and could impact at the same time the user's QoS level. Moreover, conventional handover methods cannot meet this current need and cannot promise a good enough handover performance for multiservice under different mobility in macrocell and femtocell coexistence scenarios.

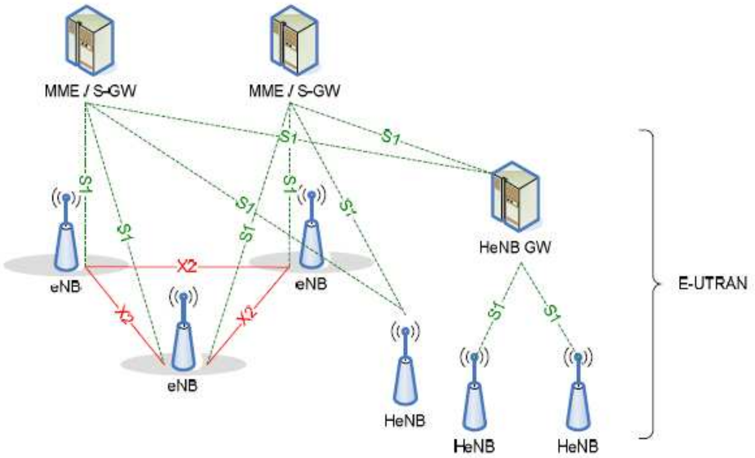


Figure 6-1 Overall E-UTRAN architecture with deployed HeNB GW [14]

This method proposes the call flow based on the typical handover parts (measurements, processing, reporting and decision) and it is based on the architecture shown in Figure 6-1, where the handover between eNodeBs is performed without EPC involvement, i.e. preparation of the information is directly exchanged only between the eNodeBs using X2 interface. This method also assumes that only registered users can access the HeNBs. (Closed Access Method)

6.1.1 Inbound Mobility for Home eNodeB

Due to the fact that there are thousands of possible targets HeNBs, the inbound handover for Home eNodeB is the most challenging issue for LTE femtocell networks. As it was explained before the UE belongs to a subscriber group (CSG) cell served by a CSG Home eNodeB and only UE belonging to the CSG are allowed to access and receive service from the CSG femtocell. This authentication process takes place during the preparation phase of handover, thus macrocell to femtocell handover is more complex than existing handover between LTE macrocells. The Fig. 6-2 shows the basic handover scenario from macrocell to femtocell (Intra-MME/Serving Gateway).

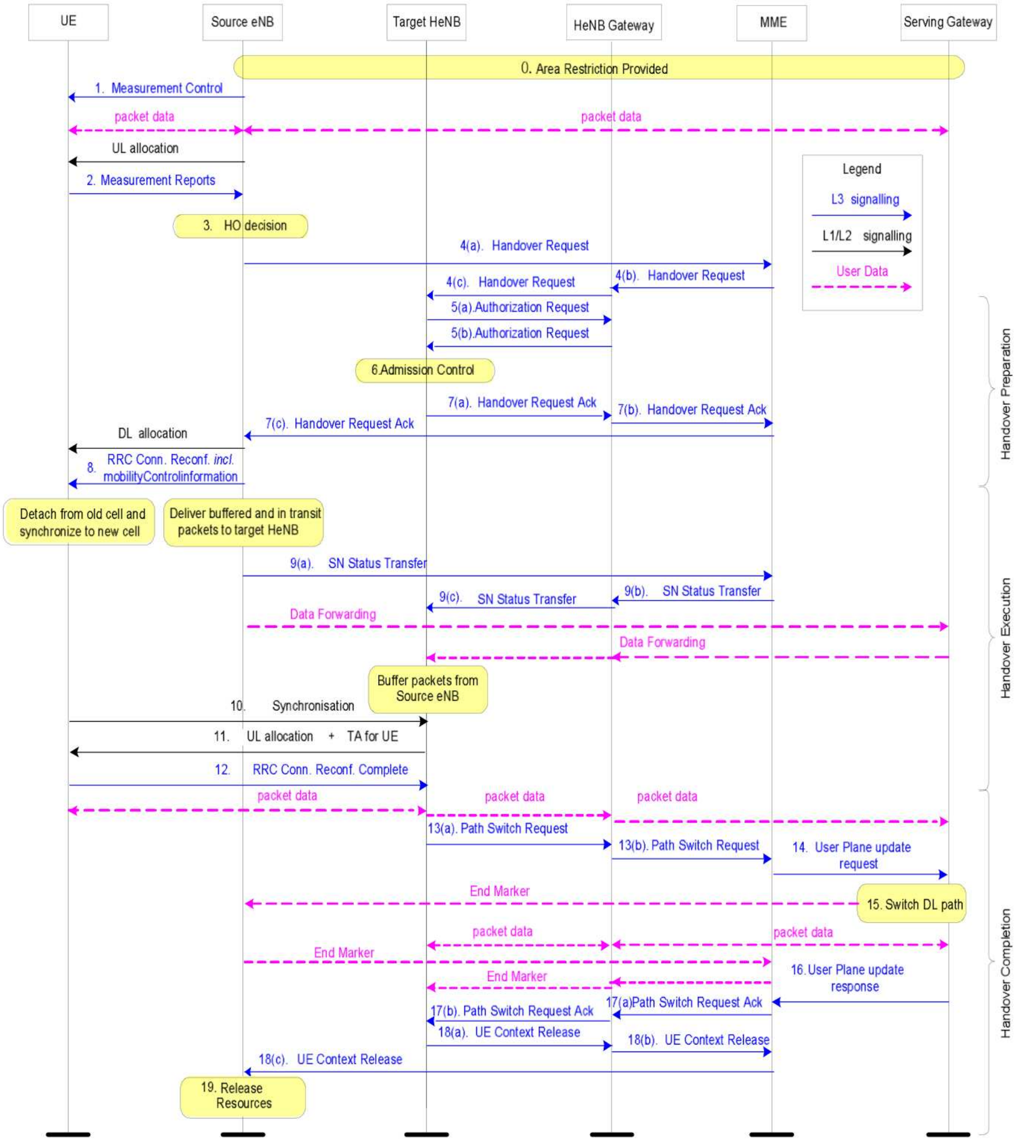


Figure 6-2 Handover from Macrocell to Femtocell (Intra-MME/Serving Gateway) [14]

6.1.2 Outbound Mobility for Home eNodeB

The outbound handover (from femtocell to Macrocell) is not so complex as the inbound handover because whenever a user move out of femtocell network, the eNodeBs' signal strength may be stronger than Home eNodeB networks in the neighbor cell list and therefore the selection of target cell is easier. The Figure 6-3 shows the call flow for the outbound handover.

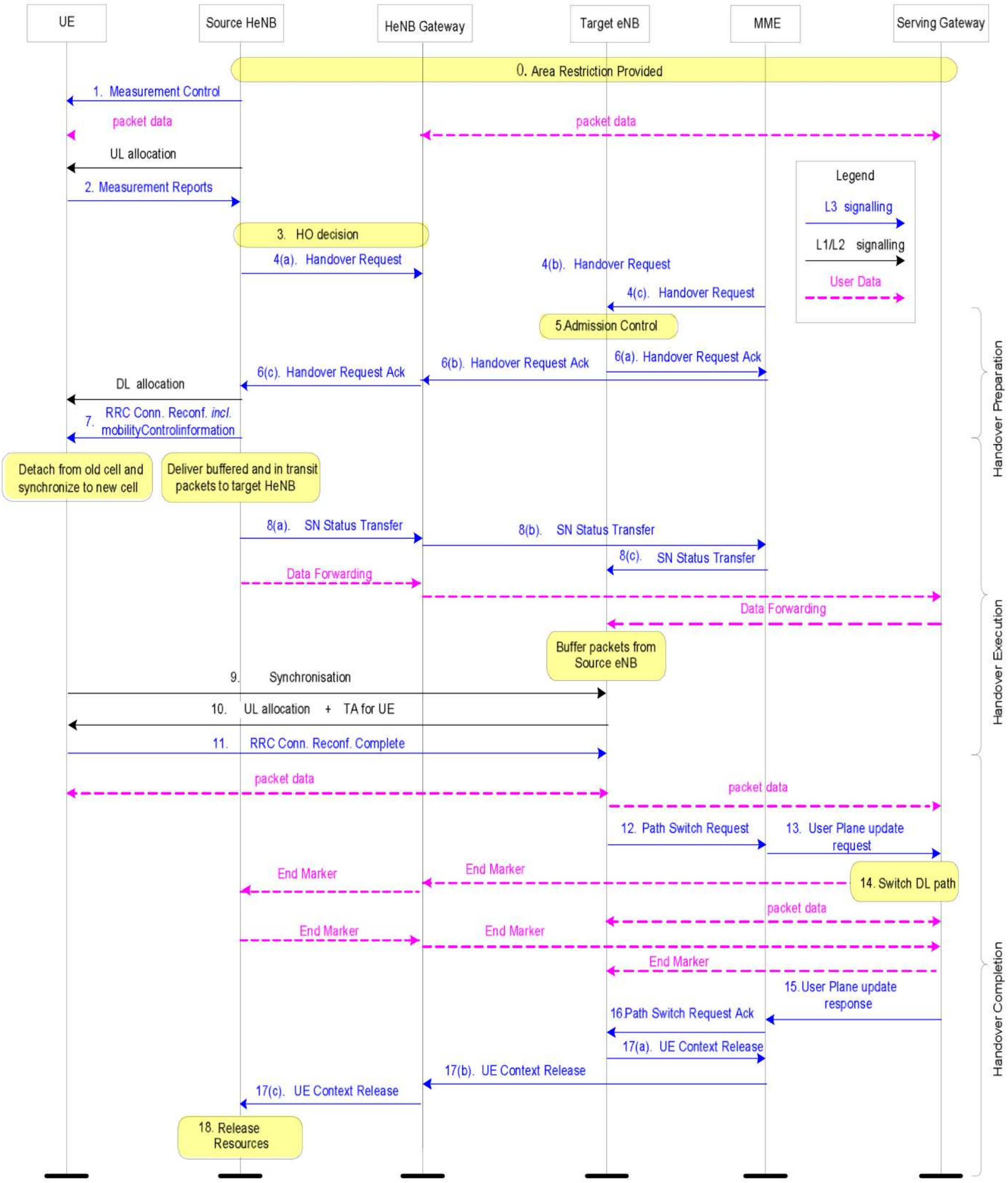


Figure 6-3 Handover from Femtocell to Macrocell (Intra-MME/Serving Gateway) [14]

6.1.3 Handover Optimization Algorithm based on UE velocity

Considering the fact that femtocells' coverage is small, users with a high velocity will cross the femtocell in a short time, and taking into account the users' QoS, those high speed users may not require the execution of handover especially for the non-real-time services because for such applications delay and packet loss can be tolerated to some extent; however, the long interruption of handover is really harmful for delay and packet loss sensitive real-time applications such as VoIP, IPTv and online games.

Then, with this technique the UE are classified according to their speed in 3 groups as follows in order to avoid the so called “unnecessary” handovers.

- Low Mobile state: from 0 to 15Km/h (Slow walk, stationary)
- Medium mobile state: from 15 to 30 km/h (riding a bike)
- High mobile state: above 30 km/h, (driving a car)

The detailed pseudo code of the UE’s state depending on the speed is described as follows:

```
1   Inizialization
2   Calculate Velocity
3   If Velocity > 30 Km/h
            NO Handover
4   ELSE IF Velocity > 15 Km/h
            IF real-time application
                    EXECUTE Handover
            ELSE IF non-real-time application
                    NO Handover
5   ELSE
            EXECUTE Handover
6   RETURN
```

Since a femtocell has a low density of UE and low power compared to a macrocell and even more considering that when the handover executed based on the measurement of the RSRP/RSRQ implies that for the UE it will be a little late to pass the femtocell in a short time, this technique integrates the measurement of RSRP/RSRQ value, the maximum capacity and the current load of the cell as an input to perform the handover decision. The following formula is used then for evaluating the best macrocell/femtocell and making the handover decisions:

$$M = \frac{M_o}{\log(e * k + n)} * N * G$$

- The variable M corresponds to the measurement value for the evaluation
- M_o is the value of traditional measurement such as RSRP and RSRQ
- e=2.7182818284590
- n is the number of UEs present on the macrocell or femtocell coverage area
- k is the adjustment factor of different type of the cell
- N is the maximal capacity of macrocell or femtocell,
- G is the G factor which used to adjust the value of M.

The flowchart of the optimized handover algorithm is described in Fig. 6-4

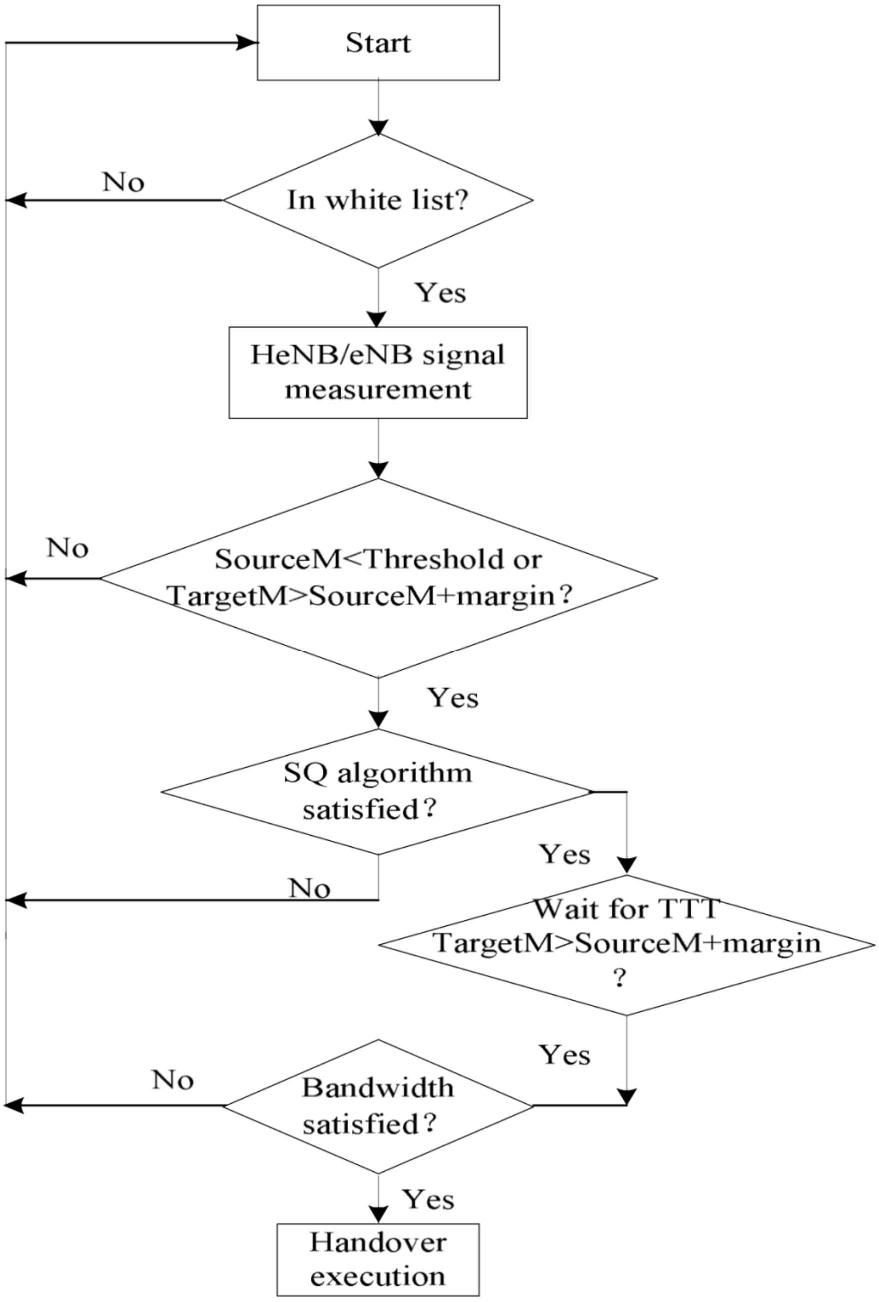


Figure 6-4 Flow Chart of the Optimized Algorithm. [14]

In order to validate the performance of these kinds of algorithms for the managing and optimization of handover execution, there are three main aspects such as rate of unnecessary handovers, number of handovers, system performance, and signaling overhead.

In traditional UMTS femtocell handover algorithm, the high speed users and low speed users can not have the same QoS when performing the femtocell involved handover especially in the handover from macrocell to femtocell. Basically, with the algorithm shown in this chapter, the high speed users' handover are not allowed from macrocell to femtocell while low speed users are allowed. At the same time, these algorithms are making a difference in real-time users and non-real-time users with intermediate speed while traditional handover scheme considers them with the same methods, therefore, this novel algorithm reduces the unnecessary handover especially for the high speed users and non-real-time users.

At the same time, reducing the number of unnecessary handovers will reduce the total number of handover, since the system performance is measured by the number of unnecessary handovers and total number of handovers, the system performance of proposed algorithm could be better than the traditional.

6.2 Handover based on UE residence Time in the Hybrid Access Scenario

This technique includes a Call Admission Control (CAC) mechanism for the hybrid access mode and takes into account two important phases during the handover procedures:

- Handover preparation phase (information gathering, and handover decision)
- Handover execution phase.

During the information gathering phase, the UE collects the information about the handover candidates, and authentications are acquired for security purposes [11]. Afterwards, the best handover candidate is determined during the handover decision and once the best handover candidate is selected, the UE initiates a connection with the new NodeB. For the handover between a macrocell and a femtocell, there is a previous step required: an initial network discovery for the femtocell and initial access information gathering.

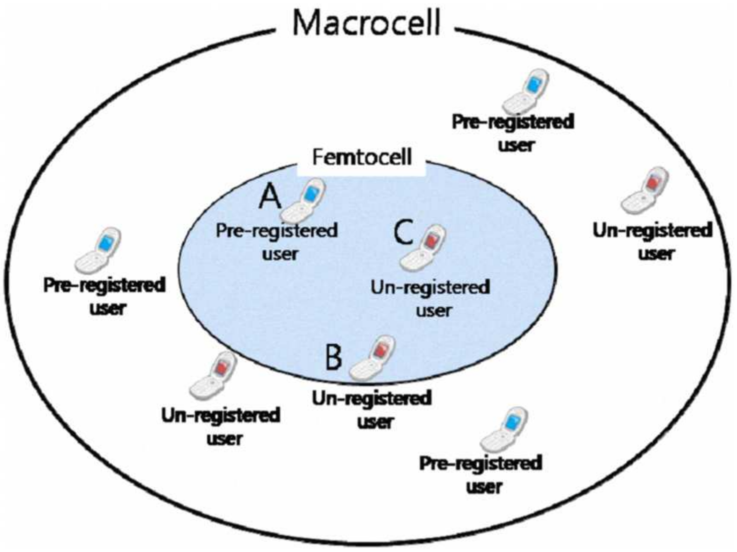


Figure 6-5 Hybrid Access Mode Scenario [11]

The Fig. 6-5 show the hybrid access mode scenario of a femtocell within the macrocell coverage area, as it was explained in the previous chapters, in the hybrid access mode, there are two types of users: pre-registered users and un-registered users. Pre-registered users are those who have the priority to use the femtocell services while Un-registered users are only able to use the femtocell resources and services when there is remaining bandwidth. The hybrid access mode is more flexible than the open access mode and the closed access mode, and allows the number of unnecessary handovers to be reduced.

6.2.1 Femtocell to Macrocell Handover

As it has been exposed before, this kind of handover is not so complex because whenever a UE moves away from a femtocell network, there is no option other than a macrocell network. However, it is very important to maintain a small handover time. Fig. 6-6 shows the handover procedure for the intra MSN handover from femtocell to UMTS-based macrocell.

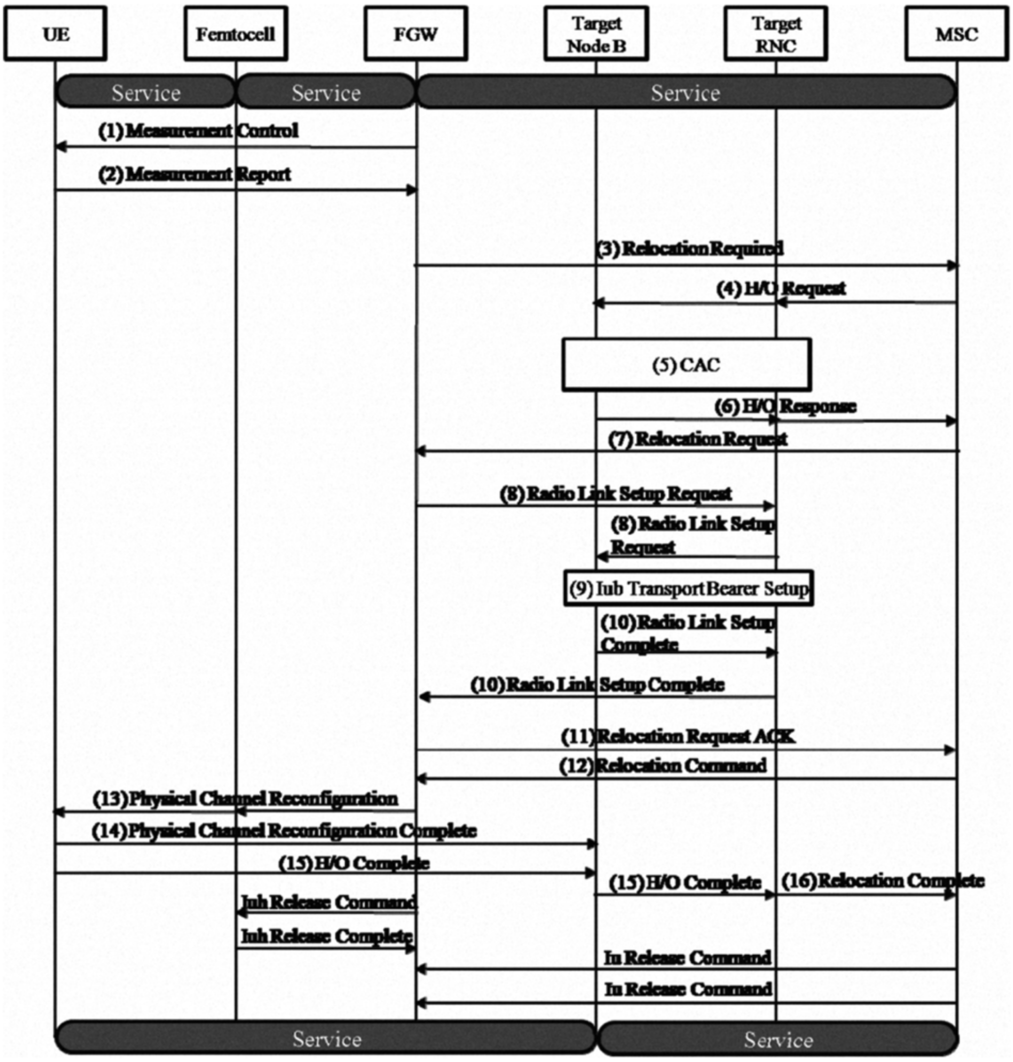


Figure 6-6 Femtocell to Macrocell Handover [11]

6.2.2 Macrocell to Femtocell Handover

Normally, 2G and 3G systems broadcast a neighbor list used by a mobile station attached to the current cell to learn where to search for the potential handover cells. However, in the scenario of mass deployment of femtocell such handoff protocol causes complexity because of the huge number of information needed to build this neighbor list. Moreover, since serving NodeB needs to select an appropriate one from many femtocells the MAC overhead becomes crucial due to the increased size of the neighbor cell list message. Another important factor to take into account in handover is the interference since a UE scans many femtocells.

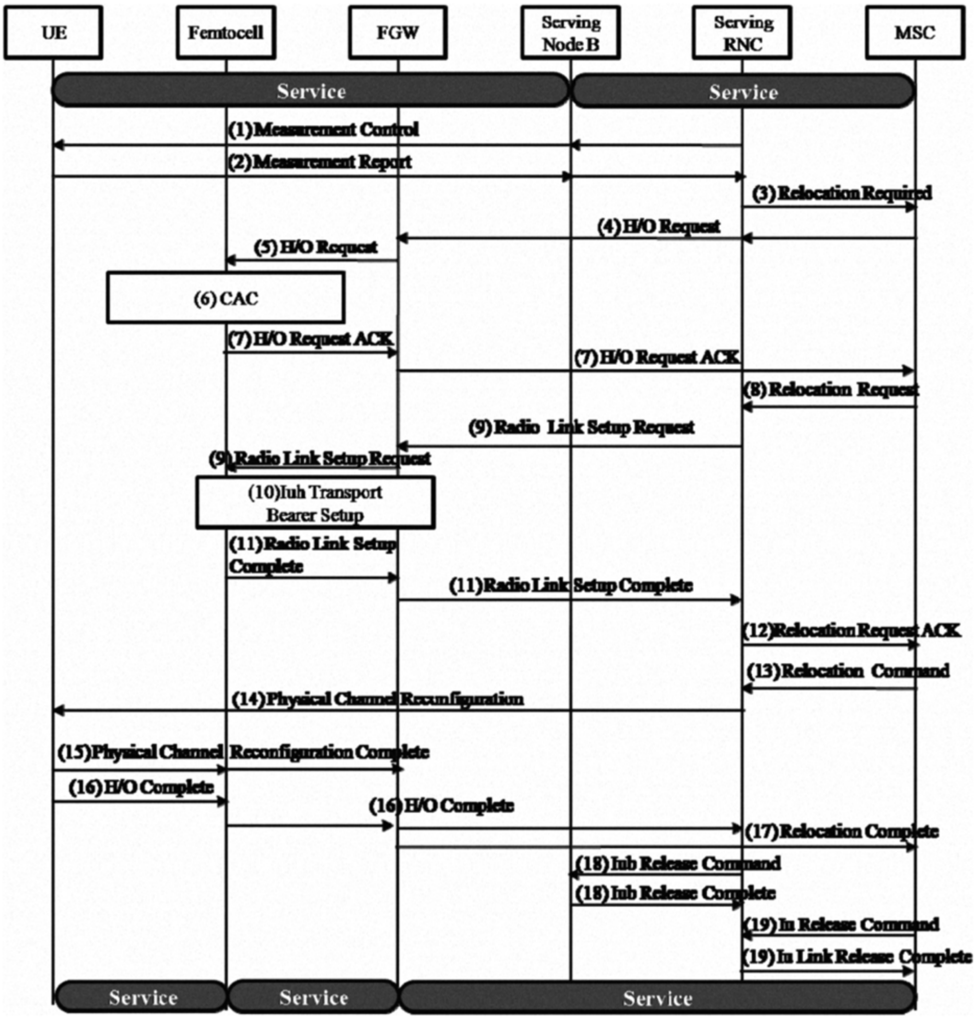


Figure 6-7 Handover from Macrocell to Femtocell [11]

The CAC mechanism proposes that when a femtocell receives handover request from FGW the femtocell makes a decision to allow the handover according to the residence time of a UE in a cell. Parameters as the user type, the received signal level, the duration a UE maintains the signal level above the threshold level, the signal to interference level and the capacity (bandwidth) that one femtocell can accept are taken into consideration.

The threshold is the minimum level required for the handover from macrocell to femtocell. If the received signal level from the femtocell is higher than the threshold, the FGW checks whether the UE is preregistered. 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 (T) during which a signal level is higher than the threshold signal level before continuing to the next handover procedure. Thus the threshold time interval can reduce the number of unnecessary handovers. The figure 6-8 shows the flowchart of the algorithm implemented with this technique.

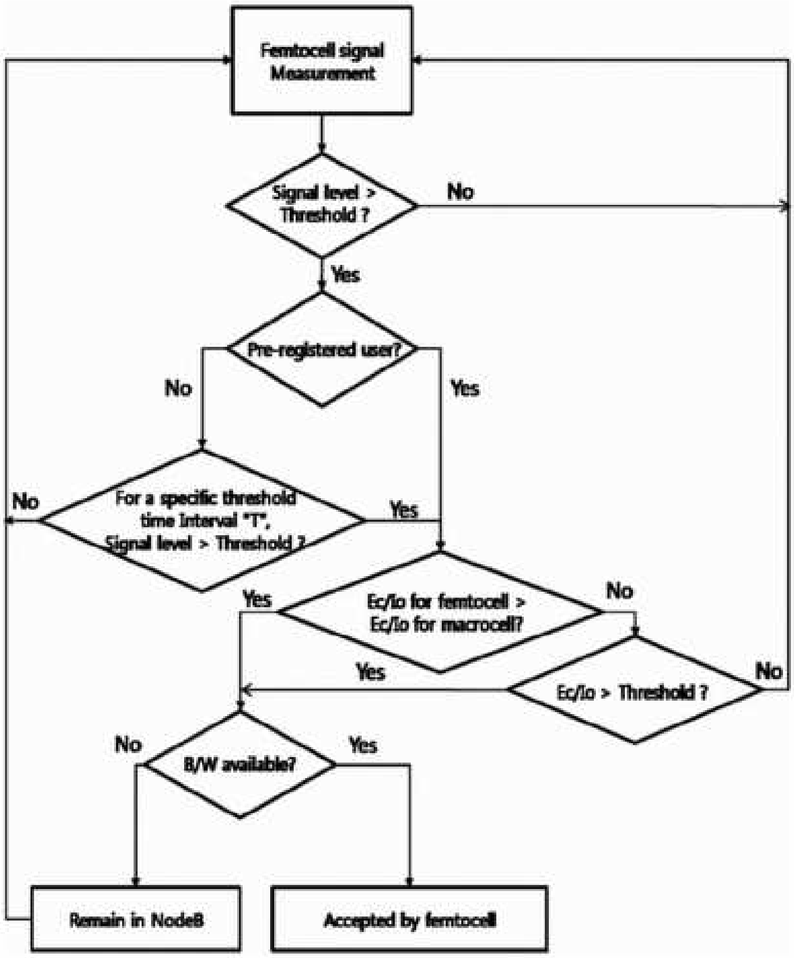


Figure 6-8 Flowchart of the Hybrid Access algorithm [11]

6.3 Double Threshold Algorithm based Handover

For the implementation of this technique some changes on the network architecture are applied: the HeNB GW is no longer the core of the process and the pressure of the HeNB GW is dispersed, and the features of the HeNB are increased. In this case, the handover decision takes places in the HeNB and the target HeNB gets some new added features as the handover initialization, access control, data cache and forwarding.

6.3.1 Inbound Handover

Like in the previous cases, this technique is mostly used for inbound handover (from macrocell to femtocell) since that is the most challenging scenario for the LTE femtocell networks because of the existence of a large number of possible HeNB targets and because under this scenario there are a lot of frequent and unnecessary handovers that on a big scale turn out to be an critical issue causing the reduction of QoS and affecting the system capacity.

Once again, considering that a UE is provided for communicating with a serving HeNB, where the UE belongs to a closed subscriber group CSG cell served by a CSG home eNodeB, during the handover procedure the serving NodeB needs to select the appropriate femtocell target from a very large group of them including another factors as interference in order to make a better selection, therefore, with this technique the femtocell receives handover request from the HeNB GW and then makes the decision to allow the handover according to a Double Threshold Algorithm and CAC mechanism (explained in the previous section)

A high speed UE causes two unnecessary handovers: one due to the movement from Macrocell to Femtocell area and again going out from the femtocell coverage area back to the Macrocell and in order to reduce this unnecessary handovers the Double Threshold Algorithm technique is used set up an asymmetric handover mechanism in which two signal level are used to make comparisons and decision during the handover.

The procedure is like follows: when the UE moves from the source cell to the target one, the signal level of the source cell is compared with the first threshold level (Threshold1) and the signal level of the target cell with the second threshold level (Threshold2). It is defined that:

$$Threshold1 < Threshold2$$

Where the *Threshold1* is the minimum level required for the handover from macrocell to femtocell and the *Threshold2* is the optimized level to improve the handover performance.

Understanding the *Threshold1* as the minimum signal level needed to handover a UE from a source to a target cell, if the signal level of the source cell is lower than the *Threshold1* there is no handover execution. Therefore, the handover will be executed when the signal level is higher than the *Threshold2*.

The reason why unnecessary handovers are reduced is because all source signal level is compared with *Threshold1* and all target signal level is compared with *Threshold2*. Once the handover is finished, the source cell becomes the target one and the target becomes the source and there's no need to make any change to the algorithm at this point to reduce the probability of frequent and unnecessary handovers.

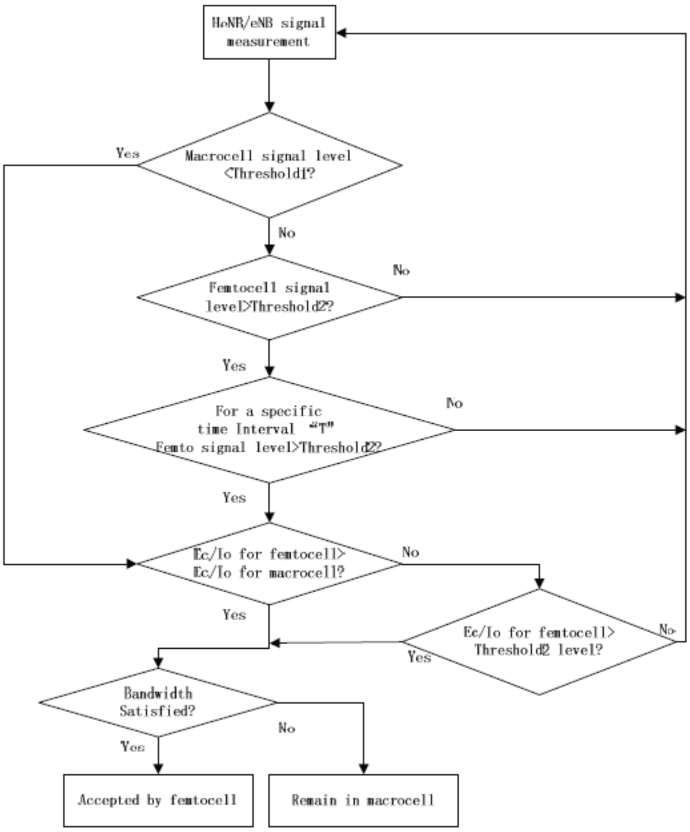


Figure 6-9 Flowchart of the Algorithm of DTA and CAC [17]

Basically, the algorithm considers:

- Received Signal Level
- Period of Time the UE maintains the signal level above the threshold level
- Signal interference level and capacity (bandwidth) that a femtocell can accept
- Threshold value

In the following figure the performance of this technique is shown

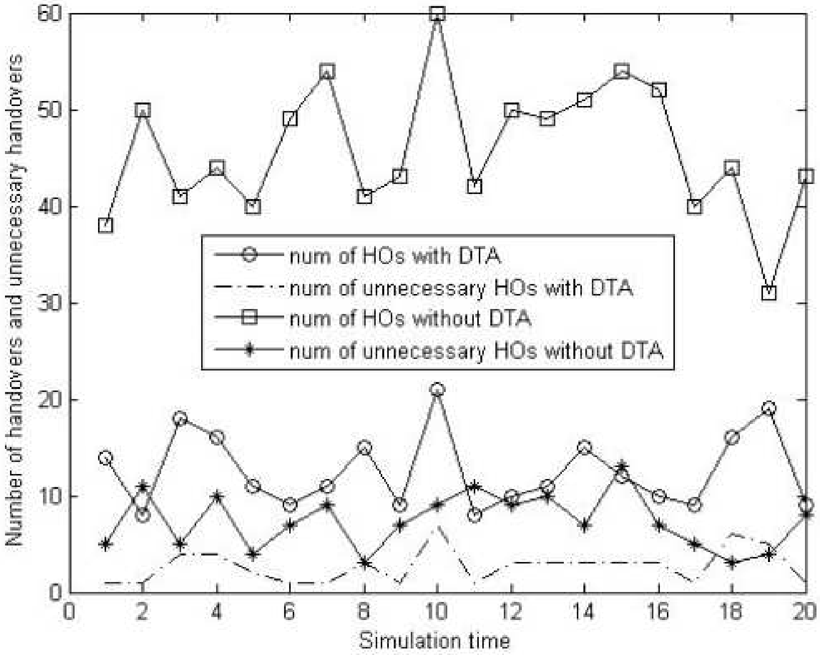


Figure 6-10 Performance Evaluation of the DTA CAC technique [17]

It is possible to see the number of handovers and unnecessary handovers with and without the Double Threshold Algorithm. In the simulations executed for obtaining the results, a handover is considered as unnecessary when the UE moves from macrocell(femtocell) to femtocell(macrocell) and within 60 seconds it moves back to the original state or if it terminates the call with 10 seconds. It can be seen as well the way the unnecessary handovers are considerably reduced with the implementation of DTA.

6.4 Handover based on Location Prediction of UE

Considering the indoor environments where femtocells will be deployed and where people mainly move along aisle between rooms with a relatively low velocity, this technique exploits the next mobility prediction algorithm to identify temporary femtocell UE so that the number of unnecessary handovers can be significantly reduced.

The mobility/location prediction algorithm is applied by dividing the femtocell area and its surroundings into grid shaped sub-areas (like in figure 6-11) using positioning technology which is recently used for location based data services [18] and can be summarized as follows:

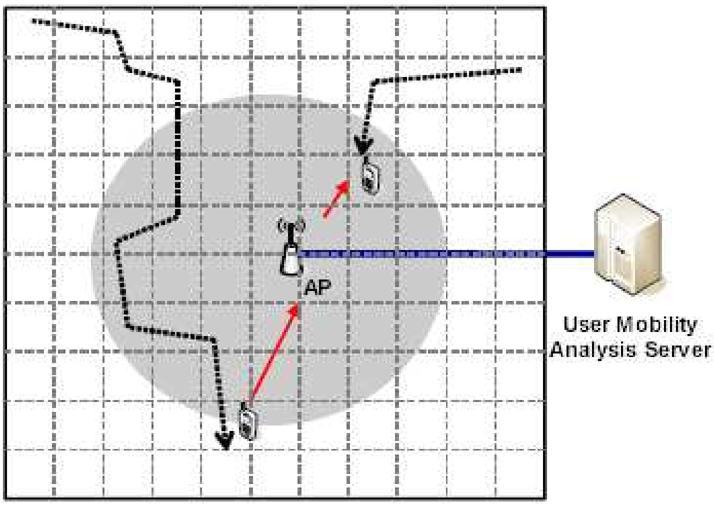


Figure 6-11 Femtocell area and its surroundings where the algorithm is applied [18]

- Each mobile terminal transmits its sub-area movement history to the User Mobility Analysis Server periodically.
- The server collects the histories and mines the mobility patterns. Then, mobility rules are extracted.
- When a mobile terminal comes in the boundary of the femtocell and predefined handover conditions are satisfied, the mobile terminal predicts its next consecutive movements based on its current trajectory and mobility rules which are broadcasted by the femtocell base station. If the next consecutive movement sequences are included within the coverage of femtocell in enough length, it eventually performs handover process.

Through the movement pattern analysis based on sequential pattern mining among these sub-areas, it is possible to predict next sub-area movement patterns when a mobile user approaches the femtocell. The idea consists on keeping macrocell connection rather than conducting macro → femto handover when the mobile user may be a temporary femtocell visitor based on next movement pattern analysis.

6.4.1 Mobility Pattern: Location Prediction Algorithm

In the system scenario shown in the figure 6.11, each mobile terminal is able to recognize its precise position with an error tolerance of 5 meters by using indoor localization technique such as Wi-Fi, Sensor, Audio Tuner [18]. At the same time, each mobile terminal saves its consecutive movement histories and periodically reports them to the user mobility analysis server. Therefore, if a mobile terminal stops and stays in a sub-area for a long time, for instance more than one minute, it is possible to assume that its history ends there and a new movement history record is started.

It means that a *temporary femtocell visitor* using mathematical notations is defined and a new handover decision criterion to prevent unnecessary handover is introduced with this technique. Firstly, threshold time T_{th} is defined to identify temporary femtocell visitor; it can be set differently depending on the administration policy of each femtocell. If user that was switched (handover performed) stays in the femtocell for more than T_{th}, it can be assumed that it is appropriate femtocell user (appropriate handover). In the other hand, if user that was switched stays in the femtocell less than T_{th}, it becomes temporary femtocell visitor (unnecessary handover). Thus, the criterion of macro → femto handover is defined as follows:

$$S_f > S_{th} \text{ and } T_c > T_{th}$$

Where:

- Sf denotes the received signal strength of femtocell
- Sth denotes the predefined threshold value
- Tc is cell residence time of user.

Meanwhile, the user mobility analysis server gathers the movement histories of mobile users and mines the mobility patterns from the histories by using generalized mobility pattern mining algorithm proposed in [19], the server extracts mobility rules which describe the movement trends of users among the sub-areas from the mined mobility patterns and those rules are periodically delivered to the femtocell base station. Algorithms 1 and 2 show the pseudo code of the mobility pattern mining and rule generation algorithm performed by the mobility analysis server.

Algorithm 1 UserMobilityPatternMining(H, $SPmin$, G)

H: All the history of users in the database server

$SPmin$: Minimum support value

G: Surrounding sub-area graph

```
$S_1 \leftarrow$the candidate sub-area patterns which have a length of one
$k = 1$
$UMP = \phi$
$R = \phi$ //Initially the set is empty
while $S_k \neq \phi$ do
    // $S_k$ is the candidate length-k sub-area patterns
    for all $s \in S_k$ do
        for all $history\ h \in H$ do
            if $s$ is a subsequence of $h$ then
                $s.count = s.count + s.suppInc$ //increment the support value
            end if
        end for
    end for
    //choose the candidates which have enough support value
    $L_k = \{s | s \in S_k, s.count \geq SPmin\}$
    $UMP = UMP \cup L_k$ //add these large patterns to set of UMP
    //Generate next length-(k+1) candidate patterns
    for all $P \in L_k$, $P =< p_1, p_2, \ldots, p_k >$ do
        $V = \{v | v$ is the neighbor of $p_k\}$
        for all $v$ do
            //generate a candidate sub-area patterns
            $S' =< p_1, p_2, \ldots, p_k, v >$
            $S_{k+1} = S_{k+1} \cup S'$
        end for
    end for
    $k = k + 1$
end while
return $UMP$
```

Algorithm 2 GenerationOfMobilityRules($CFmin$, UMP)

$CFmin$: Minimum confidence percentage

UMP: User mobility patterns

```
for all $C \in UMP$, $C =< c_1, c_2, \ldots, c_j >$, where $j > 1$ do
    for all $i$ from 1 to $j$-1 do
        //derive all the possible mobility rules
        $head =< c_1, c_2, \ldots, c_i >$
        $tail =< c_{i+1}, c_{i+2}, \ldots, c_j >$
        $rule = head \rightarrow tail$
        //calculate the confidence value
        $rule.confidence = (C.count/head.count) \cdot 100$
        if $rule.confidence \geq CFmin$ then
            $R = R \cup rule$
        end if
    end for
end for
return $R$
```

Once the mobility rules are generated, each femtocell access point (FAP) periodically receives the set of mobility rules overlapped with its coverage area. These mobility rules are broadcasted through control channels. Thus, the mobile terminal is able to get the mobility rules of each femtocell and then predict its next consecutive movement by comparing current trajectory and the received mobility rules. This prediction technique can be exploited for handover decision. If the prediction result reveals that the terminal stays in the femtocell less than T_{th}, the terminal keeps the connection to the macrocell so that unnecessary handovers are effectively avoided. The figure 6-12 shows an overview of the protocol deployed on this handover technique.

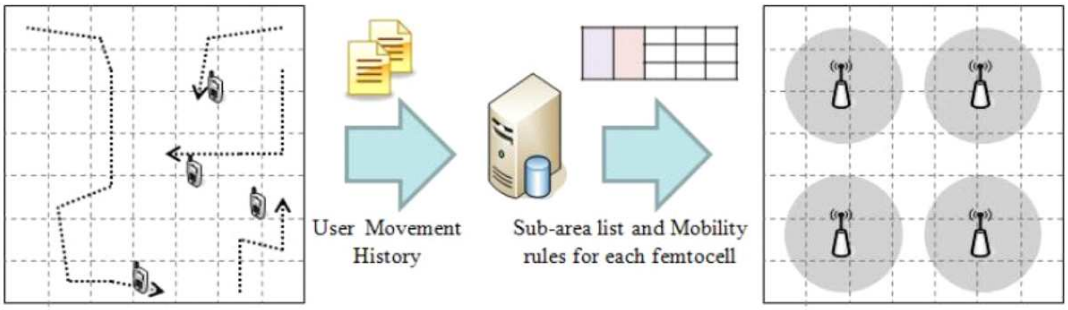


Figure 6-12. Overall System Protocol [18]

6.4.2 Smart Handover Decision Algorithm

Apart from the location algorithm implemented, this technique proposes a handover decision algorithm that basically works as follows: when the mobile terminal moves into the femtocell area, it firstly checks the equation:

$$S_f > S_{th} \text{ and } T_c > T_{th}$$

as the criterion of handover during signal scanning periods. If the received signal strength of femtocell *Sf* is higher than pre-determined threshold *Sth*, the mobile terminal gets the information about the sub-area map and user mobility rules from the control channel.

At this point, the mobile terminal will attempt to predict its next n-consecutive movements among subareas by comparing its actual movement history and received mobility rules. Handover occurs only if the predicted next n-movements are within the femtocell area. In other words, the decision algorithm recognizes that the user is not a temporary femtocell visitor if his next movement sequence in the femtocell is longer than pre-determined parameter n which is obtained from:

$$n = \frac{v \times T_{th}}{s}$$

Where:

- v is the velocity of mobile terminal
- s is the length of edge of a square shaped sub-area.

Therefore, a rounded-off integer n means the minimum number of next consecutive sub-areas which must belongs to the femtocell in the future, for staying in femtocell longer than T_{th}.

The movement prediction is done by applying mobility rules to current movement history of the user. Supposing that the user has followed a path U = <s1, s2, . . ., s_i> up to now, and the handover criterion is satisfied at sub-area s_i. The mobile terminal checks if the head part of rule is contained in U and ended with s_i. If it is satisfied, the tail of the mobility rule becomes a candidate of next possible coming path. Each possible coming path has a probability value which is the sum of confidence and support value of the mobility rule.

The next step corresponds to the handover decision. For each candidate coming path, if at least n-consecutive sub-areas are included in the femtocell area, which is called in-femto paths, the corresponding probability value is summed up to a value A, otherwise, summed up to a value B. Finally, if A is greater than B, handover is performed. In other words, the system assumes that the terminal will stay in femtocell longer than T_{th} if the sum of probabilities of in-femto paths is greater than that of out-femto paths. The pseudo code of the algorithm is presented in Algorithm 3. [18]

Algorithm 3 SmartHandoverDecision(U, R, n, G, F)

U: Current trajectory of the user, $U =< s_1, s_2, \ldots, s_i >$

R: Set of mobility rules from control channel

F: In-femto sub-area list from control channel

n: Minimum number of coming sub-areas

G: Surrounding sub-area graph

```
$k = 0$
for all rule $r :< a_1, a_2, \ldots, a_j > \rightarrow < a_{j+1}, a_{j+2}, \ldots, a_x \in R$ do
    if $< a_1, a_2, \ldots, a_j >$ is contained by $U =< s_1, s_2, \ldots, s_i >$ and $a_j = s_i$ then
        //Add the rule into the coming path array
        $ComingPaths[k] = (r.confidence + r.support, a_{j+1}, a_{j+2}, \ldots, a_x)$
        $k = k + 1$
    end if
end for
$Index = 0$
$A, B = 0$
if $ComingPath.length == 0$ then
    $Handover = 1$
else
    while $Index < ComingPaths.length$ do
        $inFemto = 0$
        if $ComingPaths[Index].length < n + 1$ then
            if all of next sub-area $\in F$ then
                $A = A + ComingPaths[Index]$
            else
                $B = B + ComingPaths[Index]$
            end if
        else
            for all $i$, $1 \leq i \leq ComingPaths[Index].length$ do
                if $ComingPaths[Index][i] \in F$ and it is consecutive then
                    $inFemto = inFemto + 1$
                end if
            end for
            if $inFemto \geq n$ then
                $A = A + ComingPaths[Index]$
            else
                $B = B + ComingPaths[Index]$
            end if
        end if
    end while
end if
//Make a decision
if $A \geq B$ then
    $Handover = 1$
else
    $Handover = 0$
end if
```

6.5 Handover using OFDMA Femtocells

Understanding that LTE network architecture has two clearly separated tiers - the macrocell tier and the femtocell tier - this handover technique aims to avoid the cross-tier interference in two-tier networks made up of Orthogonal Frequency Division Multiple Access (OFDMA) macrocells and femtocells; based on the use of Intra-cell Handovers (IHOs), making possible that either a macrocell or a femtocell can reassign its sub-channel or power allocation upon the detection of cross-tier interference or electromagnetic interference between macro and femtocells.

The electromagnetic interference or cross-tier interference is defined as the decline in signal quality of macrocell UE in the UL or DL due to the presence of femtocell users sharing the same spectrum and vice versa. In order to avoid cross-tier interference and an inefficient use of the bandwidth, a co-channel deployment of both macrocells and femtocells is more likely to occur increasing the reuse of the carriers and decreasing the expenses of the operators. [20]

6.5.1 UE Measurements Reports in Two-Tier Networks

In two-tier networks, the UE makes continuous measurements of the Received Signal Strength (RSS) of the pilot channels belonging to the neighbor cells while the serving cell periodically broadcasts the Neighboring Cell List (NCL) of cells and pilot channels that the UEs must measure.

The UE periodically measures the parameters and reports back the results to its serving cell, which then decides whether to start a new cell re-selection or HO procedure or take no action. Apart from the neighbor macrocells information, the NCL of two-tier networks should contain information regarding to the open access femtocells which means that the non-subscribed UE must report back not only the RSS from the macrocells around but also from the open access femtocells. In the other hand, subscribed UEs perform an autonomous search to detect CSG femtocells [20]. Signal quality in the terms of SINR is reported by the UEs using the Channel Quality Indicator (CQI) (at most every 2ms in LTE). This CQI is used by the Medium Access Control (MAC) layer to perform channel-dependent scheduling, but it can also be used to trigger a HO when the SINR reported by the UE is low.

6.5.2 Intra-cell Handover (IHO)

The IHO is a special case of HO, in which the source and target cell are the same, and simply the aim is to change one channel that might be interfered or faded with a new clearer or less faded channel, in other words, to idea is to get rid of the interfered or faded channel using a new channel in better conditions. The proposed approach in this technique intends to perform an IHO when a non-subscriber that is connected to a macrocell suffers from cross-tier interference due to the presence of a nearby femtocell.

The intra-cell HO works as follows: When the SINR of a non-subscriber UE connected to macrocell in sub-channel k is smaller than a given threshold, the serving macrocell requests a measurement report from non-subscriber UE indicating the RSS of the serving macrocell and the RSS of its neighboring cells. Thereafter, macrocell Mm compares its RSS with the other reported RSS values. Then, macrocell triggers an IHO only if condition (1) is verified

$$RSS_{m,y}^{k} < RSS_{j,y}^{k} + \Delta Q_{IHO} \qquad (1)$$

Where:

- $RSS_{m,y}^{k}$ corresponds to the RSS from the serving macrocells in the k sub-channel
- $RSS_{j,y}^{k}$ corresponds to the RSS from the neighboring femtocells in the k sub-channel
- ΔQ_{IHO} is an interference protection margin.

Therefore, if a femtocell verifies the condition (1), it is considered as a cross-tier interferer of non-subscriber UE in sub-channel k, and then an IHO is performed. It is important to mention that the IHO procedure can be carried out either in the serving macrocell or in all interfering femtocells. However, in order to minimize the signaling overhead, it is always preferred to perform an IHO in the serving macrocell than in all interfering femtocells but at the same time this is not always possible due to traffic load or interference conditions in the serving macrocell.

6.5.2.1 Macrocell IHO

An IHO is launched in a serving macrocell only if there is at least a free sub-channel to which a nonsubscriber UE can be re-allocated to and if the interference suffered by that sub-channel is smaller than the one suffered by the currently assigned sub-channel *k*. If there is more than one available sub-channel in the macrocell, the non-subscriber UE is switched to a new sub-channel, preferably the one that suffers the least interference. This sub-channel is selected by macrocell according to the CQI that is periodically reported by the non-subscriber UE. However, if there is no sub-channel fulfilling these requirements, the IHO is not performed in macrocell but in all interfering femtocells.

6.5.2.2 Femtocell IHO

In this case, the macrocell establishes communication with all interfering femtocells and casts an IHO in all of them. It is important to take into account that the IHO procedure differs according to the availability of sub-channels in the interfering femtocell.

When there are available sub-channels in the femtocell, a sub-channel ***switching process*** is executed, while when there are no available sub-channels, a distributed ***power control*** is applied. The ***Switching process*** is performed when there is at least one available sub-channel in the interfering femtocell so that the femtocell subscriber -currently connected to sub-channel k-, can be transferred to the free sub-channel available. In this way, sub-channel k is liberated, avoiding thus cross-tier interference to non-subscriber UE.

In the other hand, the distributed ***power control*** is performed if there is no availability of free sub-channels in the interfering femtocell, then, one option would be to disconnect the registered UEs from sub-channel k for a period of time (TIHO) in order to avoid cross-tier interference towards non-subscriber UE. However, this approach, also known as "forbidding" results in a reduction of the throughput of the femtocell, which is not desirable.

Therefore, instead of disconnecting UEs, the power transmitted by the femtocell in the sub-channel *k* is reduced for a period of time TIHO. In this way, cross-tier interference towards non-subscriber UEs is mitigated, while the throughput of femtocell is enhanced compared to that of the forbidding approach. The aim of distributed power control is to set the power with which all interfering femtocells transmit in sub-channel k, to a value that ensures a given signal quality to non-subscriber UEs.

6.6 Handover based on Backbone Characteristics and UE Residence Time

The FAPs are typically connected to the Internet via a backbone of lower quality (for instance, XDSL) with parameters that fluctuate significantly in time. [21]. This technique considers this parameter (FAPs' backbone quality) during handover decision and also exploits some estimation and prediction techniques getting rid of the fact that the radius of femtocells is very small assuming at the same time, that the handover will be performed for low speed users.

6.6.1 Backbone Delay and Capacity

The performance of the handover is influenced by two backbone parameters: ***delay and capacity***, the following conditions must be fulfilled before performing handover to a target FAP:

- The ***packet delay*** from the FAP to the destination target should be ***less or equal*** to the maximum acceptable delay of the specific service currently experienced by the UE.
- In the other hand, the ***backbone capacity***, should be at least equal to the sum of all requests from all services experienced by the current UE.

Each FAP has information about its backbone quality as it uses to schedule users' data through backbone. Information on quality must be delivered to the MBS, takes control over handover decision. The reporting of backbone quality (available capacity and packet delay) can be included in control information for coordination of MBSs and FAPs. [21]

The transmission of information on backbone quality can be either triggered by a handover request or periodically. The drawback of handover triggered once is the additional delaying of handover due to delivering information on backbone status to the MBS. However, the overhead is negligible since only few additional bits are transmitted per a handover. Contrary, the periodic reporting does not delay handover but it increases overhead.

6.6.2 UE Residence Time Estimation

The UE Residence Time in a Femtocell, (denoted as Time in Cell, T_c) is defined as the time when the FAP provides higher channel quality (S_f) than channel of MBS (S_m). The definition of the Time in cell is depicted in the figure 6-13.

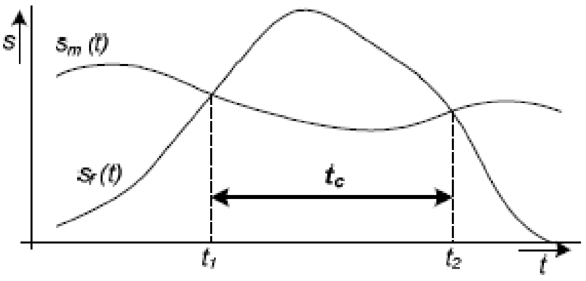


Figure 6-13 Definition of the Time in Cell for FAPs [21]

Regarding to the derivation of the lower and upper limits of the Time in Cell, the scenario of the single direct street is used; the scheme is represented in figure 6-14:

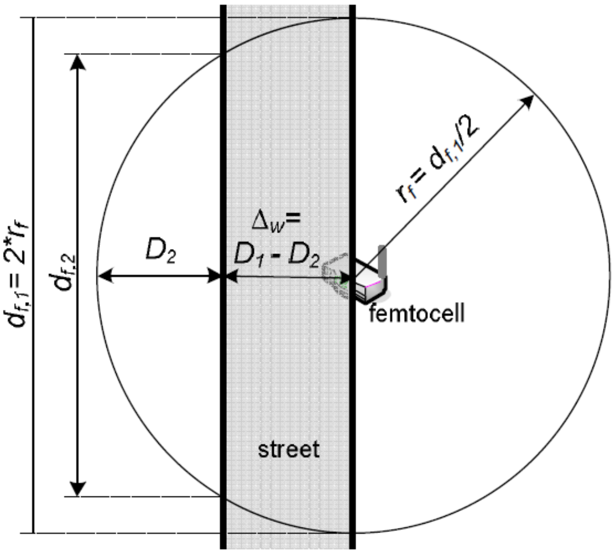


Figure 6-14 Single Direct Street scenario

Defining the distance covered by a *j-th* user in a femtocell as:

$$d_{f,j} = d_{f,avg} \pm \Delta_{d,j}$$

Where:

- $d_{f,avg}$ is average distance covered by all users in the FAP's area,
- $\Delta_{d,j}$ represents distance deviation of j-th user.

And defining the speed of *j-th* user as:

$$v_j = v_{j,avg} \pm \Delta_{v,j}$$

Where:

- $v_{j,avg}$ is the average speed of pedestrians and
- $\Delta_{v,j}$ stands for the speed variation of j-th user.

Due to only pedestrians are admitted to FAPs, the mean speed of users is normally distributed along 1.34 ms^{-1} with deviation of 0.37ms^{-1} [21] . Then the speed of the j-th user is in the interval:

$$v_j = \langle 1.34 - 0.37; 1.34 + 0.37 \rangle ms^{-1}$$

Therefore, the average Time in Cell t_c can be calculated as:

$$t_{c,j,avg} = d_{f,avg} / v_{j,avg}$$

According to the estimations done, the real Time in Cell of an individual user is limited from the lower boundary to:

$$t_{c,min} = \left(d_{f,avg} - \Delta_{d,j}\right) / \left(v_{j,avg} + \Delta_{v,j,max}\right) = \left(d_{f,avg} - \Delta_{d,j}\right) / 1.71$$

This equation corresponds to a movement of the fastest pedestrian along the shortest path. The $t_{c,min}$ depends on the position of a street in relation to the FAP's radius. The street is of the width Δw and its borders are in distances D2 and D1 from the cell edge.

Assuming the direct movement on the street, $t_{c,min}$ corresponds to the user's movement along the direct path, which is in distance D2 from the cell edge. The distance $d_{f,2}$ covered by the user in the femtocell along the path distanced D2 from the cell edge is determined as:

$$d_{f,2} = 2\sqrt{r_f^2 - (r_f - D_2)^2}$$

And like this the tc,min as a function of D2 will be:

$$t_{c,min} = d_{f,2} / \left(v_{j,avg} + \Delta_{v,j,max}\right) = 2\sqrt{r_f^2 - (r_f - D_2)^2} / 1.71$$

The upper bound for t_c can be derived analogically. Then, the $t_{c,max}$ corresponds to a movement of the slowest user along the longest path. In this case, the trajectory covered by a user following the path distanced D1 from the cell edge is equal to:

$$d_{f,1} = 2r_f$$

Then, $t_{c,max}$ is derived as follows:

$$t_{c,max} = \left(d_{f,avg} + \Delta_{d,j}\right) / \left(v_{j,avg} - \Delta_{v,j,max}\right) = 2r_f / 0.97$$

6.6.3 Enhancement Handover Algorithm

The algorithm proposed under this technique considers backbone quality and Time in Cell parameter. Once the conventional handover criteria are met, the requirements on backbone are compared with the parameters provided by the FAP. Subsequently, typical Time in Cell (t_c) for the FAP is compared with a threshold. This treshold should be set up according to the FAP's load and according to user's services. Increasing the threshold lowers the amount of performed handovers. Only fulfillment of all conditions leads to handover initiation. If any of these criteria is not satisfied, handover is not performed. [21]

6.7 Auto-Configuration and Self-Optimization Strategies

The fact that Femtocell Access Points are in practice user deployed, means that the operator does not have any more control over, amongst other things, the location in which femtocells are deployed. This can be problematic because a femtocell can be deployed in an inappropriate location, for example next to a window facing a sidewalk which causes a lot of its radio signals to leak outside the home. This at the same time may cause undesired interactions with the macrocells, resulting in excessive handover performance.

Therefore, it becomes very important for the femtocell to able to automatically adjust its coverage area such that it does not leak outside into public areas, but at the same time provide adequate coverage in the home, in short, the FAPs must be capable of sensing the air interface and tuning their own parameters according to changes in the network or channel.

6.7.1 Cognitive Radio Phase

The cognitive radio stage allows the FAPs to be aware of the presence of neighboring macro or femtocells as well as their respective spectrum allocations. During this stage, the FAPs perform a sensing procedure in which is able to learn about the state of the network (e.g., architecture and load) and channel conditions (e.g., interference and fading). Therefore, there are different sensing strategies that together with other statistics such as the number of mobility events or packet drop ratio can be used to enhance the reliability of the sensing phase and thus the quality of the femtocell tuning for the proper performing of handover procedures with another femtocells or macrocells avoiding interference.

6.7.1.1 Self-Sensing

There are many ways to acquire perform the cognitive radio stage; one of them is the implementation of the sensing capability into the FAP itself so that the FAPs will sense the air interface and identify which cells and sub-channels are active within their range. This can be done using a network listening mode, similar to a user terminal operating in idle mode and finally use this information to configure itself and perform its resource allocation. This procedure is illustrated in figure 6-15.

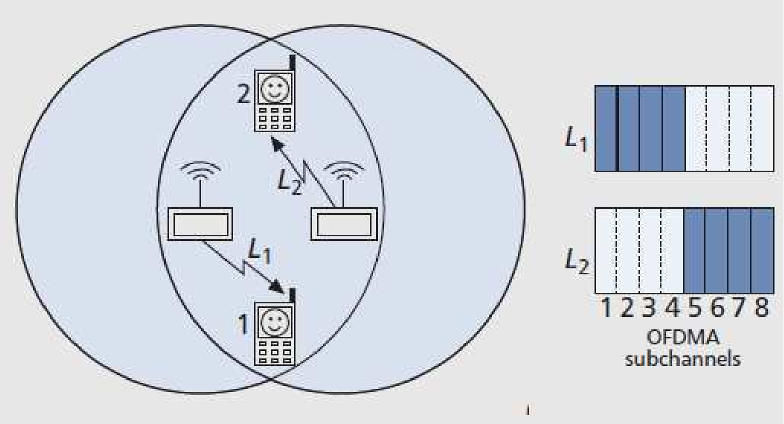


Figure 6-15 FAP Self-Sensing approach [10]

6.7.1.2 Relay-Sensing

A second way to perform the cognitive radio stage is based on the fact that the FAPs could directly exchange information about their sub-channel usage, spectrum needs, and so on. In this way, femtocells can be aware of the present actions and future intentions of their neighboring cells, and act accordingly. These messages can be exchanged through the femtocell gateway, using a direct link between cells (similar to the X2 interface in LTE), but also broadcasting messages or using mobile terminals to relay information. The relay-sensing approach is illustrated in figure 6-16

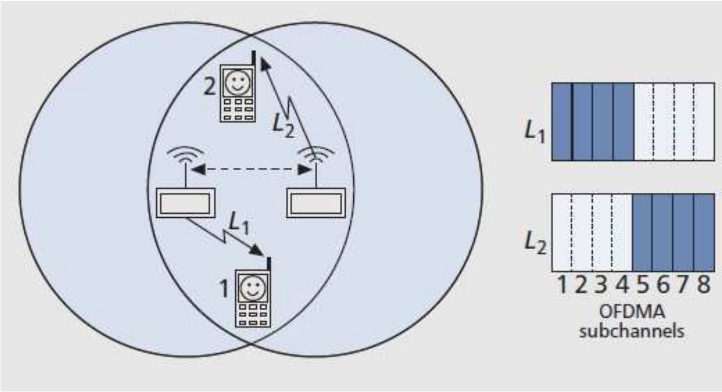


Figure 6-16 Relay-sensing between FAPs [10]

6.7.1.3 Measurement Reports

Unfortunately neither Self-sensing nor Relay-sensing techniques would work in situations where the FAPs are not within the coverage area of other femtocells. As an example, in the figure 6-17, User 3 is located at the cell edge of two overlapping femtocells whose FAPs are not visible to each other. In this situation, such a user might suffer from interference because the femtocells are not able to coordinate their resource allocation as a result of the lack of information obtained during the sensing phase.

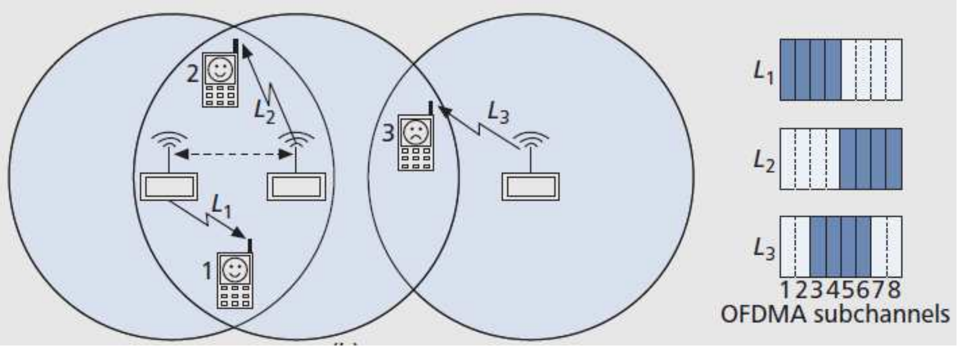


Figure 6-16 Sensing Problem in non-overlapping femtocells [10]

Therefore, in order to solve this issue it would be feasible to forward the user information location to their FAPs and thus mitigate the interference; This could be done by implementing measurement reports. These reports contain information such as the received signal strength and active sub-channels of the serving and strongest neighboring cells (both macro and femtocells) and are periodically performed by users and then sent back to their FAPs. Like this, it could be possible to establish interference relationships between neighboring cells and identify forbidden sub-channels as illustrated in Figure 6-17.

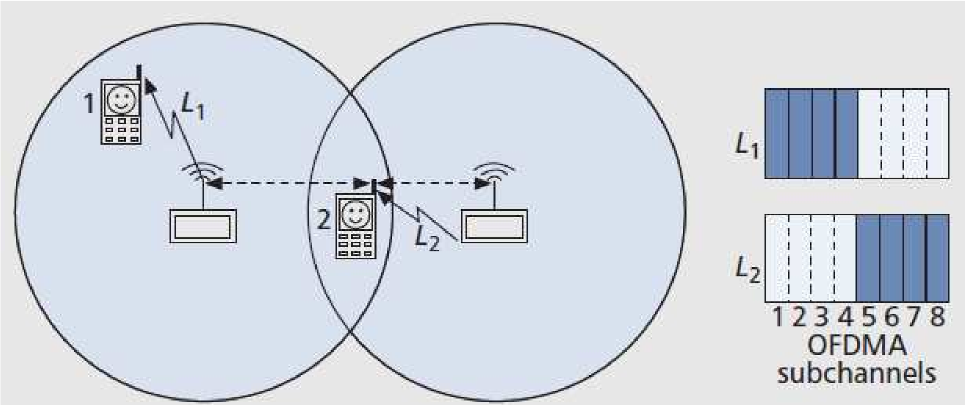


Figure 6-17 Measurement Reports approach

6.7.2 Tuning Phase

There are two concepts to differentiate when referring to the way femtocells achieve the ability of selecting and modifying their parameters in different situations: Auto-Configuration and Self-Optimization. ***Auto-configuration*** makes reference to the an initial configuration provided when the FAP is turned on whereas ***self-optimization*** makes reference to the enhancement of the current FAP configuration during operation, for example based on measurements or statistics collected over time in order to adapt its parameters to the environment. Both of these schemes have the aim of enhance the coverage of the femtocells. [22]

6.7.2.1 Self-Configuration Scheme

Once the femtocell is turned on and registered into the network of the operator, its radio parameters are set to a default configuration over the backhaul where fundamental information as the carrier frequency, location, routing, service area, initial PCI, and neighboring list is provided. Afterwards, the femtocell performs the sensing of the environment throughout the network listening mode. By decoding the control channels, the femtocell is able to synchronize with the external network. Moreover, the femtocell also uses this information to reselect its PCI, and optimize its neighbor list and handoff parameters. In the end, the FAP adapts its power and selects its sub-channels according to the obtained sensing information in order to ensure that it provides the dominant signal in the desired coverage area. [10]

6.7.2.2 Self-Optimization Scheme

Due to radio channel conditions can change rapidly under conditions of shadowing and multipath fading, femtocells must dynamically adapt their radio resources to their environments in order to optimize the performance of the network. Such changes can be detected during the sensing phase (e.g., increase in traffic or interference, decrease in mobility events or dropped calls). Taking into account this information, the FAPs tune their parameters (power or sub-channel assignment) online in order to mitigate interference across cells because the network load and user traffic vary quickly depending on the location and time, and because of the packet nature of the services. [10]

CONCLUSION

The growing popularity of innovative mobile technologies is coming together with trends showing high predominance of data networks over voice networks, challenging requirements and enhanced applications for vendors that are looking for an "always on", high speed, low-latency wireless connectivity. It means that consumer demand for data services is increasing and nowadays, the penetration of smart-phones, tablets and other data devices as well as the launching of 4G/LTE service reflects the high levels of data traffic carried on mobile networks. This trend will need to continue to support demand growth in the future and therefore, due to the attractive data rates, low latency and spectral efficiency characteristics that LTE Systems offer, the deployment of smaller cell sites (e.g. femtocells) is appearing as the solution for meeting this forecasted growth in demand.

Nevertheless, this fast development may have an undesired impact in the current architectures because the femtocells networks are being deployed within the coverage area of existing macrocells and they can cause either strong degradation of the macrocells' performance or also disturb the normal functioning of already existing femtocells. In order to stick to the direction of trend and cope the actual demands; a lot of approaches to reduce the increment of dead zones (interference) within the macrocells and successfully deploy a femtocell network are under currently research and development focusing in the UE mobility. In this document an overview of the novel techniques proposed and implemented is provided; all of them with the aim of improving the performance of handover procedures in scenarios where the macrocells and femtocells will coexist and thus, enhance the mobility of the UE and the throughput of LTE Systems.

As it has been described, the techniques are based on algorithms where parameters such as the user velocity and the residence time of the UE in a Femtocell are determinant for the reducing of unnecessary handovers. Moreover, different approaches can be combined and deployed in different areas taking into account access methods; synchronization, estimation and prediction of UE position that involve at the same time statistic modeling and also approaches that are related with the manufacturing and technical features of the femtocells. There are still many fields to explore due to all the different elements that compose the whole system, meaning that there are many features and concepts from which it would possible to get advantage and start more interesting and innovative approaches.

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List of Abbreviations

3GPP	Third Generation Partnership Project
ACK	Acknowledgement (in ARQ protocols)
ACLR	Adjacent Channel Ratio
AM	Acknowledged Mode
AMPS	Advanced Mobile Phone System
ARIB	Association of Radio Industries and Businesses
ATIS	Alliance for Telecommunication Industry Solutions
AWGN	Additive White Gaussian Noise
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BSR	Buffer Status Report
CAC	Call Admissions Control
CAZAC	Constant Amplitude Zero Auto-correlation
CCCH	Common Control Channel
CQI	Channel Quality Indicator
C-RNTI	Cell Radio Network Temporary Identifier
DANL	Displayed Average Noise Level
DCCH	Dedicated Control Channel
DL-SCH	Downlink Shared Channel
DM RS	DeModulation Reference Signal
DTA	Double Theshold Algoirthm
DTCH	Dedicated Traffic Channel
eNodeB	Evolved NodeB
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex/Duplexing
FAP	Femtocell Access Point
FFT	Fast Fourier Transform
GSM	Global System for Mobile Communication
HeNB	Home eNodeB
HSS	Home Subscriber Server
IMEI	International Mobile Equipment
IMSI	International Mobile Subscriber Identity
IP	Internet Protocol
ISD	Inter-site Distance
LTE	Long Term Evolution
MAC	Medium Access Control
MBMS	Multimedia Broadcast Multicast Service
MCCH	Multicast Control Channel
MCH	Multicast Channel

MIB Master	Information Block
MIMO	Multiple Input, Multiple Output
MME	Mobility Management Entity
MMS	Multimedia Messaging Services
MTCH	Multicast Traffic Channel
NACK	Negative Acknowledgment
NAS	Non-access Stratum (signaling between UE and the core network)
NodeB	The base station in WCDMA systems
OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak-to-Average Power Ratio
PBCH	Physical Broadcast Channel
PCCH	Paging Control Channel
PCFICH	Physical Control Format Indicator Channel
PCH	Paging Channel
PCRF	Policy and Charging Rules Function
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDSCH	Physical Downlink Shared Channel
PDU	Protocol Data Unit
PHICH	Physical Hybrid ARQ Indicator Channel
PMCH	Physical Multicast Channel
PRACH	Physical Random Access Channel
P-SS	Primary Synchronization Signals
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying
RACH	Random Access Channel
RAN	Radio Access Network
RAT	Radio Access Technology
RLC	Radio Link Control
RMS	Root Mean Square
ROHC	Robust Header Compression
RRC	Radio Resource Control
RS	Reference Signal
SAE	System Architecture Evolution
SC-FDMA	Single Carrier Frequency Division Multiple Access
SEM	Spectrum Emission Mask
SFN	System Frame Number
SIB	System Information Block
SLA	Side Lobe Attenuation
SRB0	Signaling Radio Bearer 0

SRB1	Signaling Radio Bearer 1
SRB2	Signaling Radio Bearer 2
SRS	Sounding Reference Signal
S-SS	Secondary Synchronization Signals
S-TMSI	Serving Temporary Mobile Subscriber Identity
TACS	Total Access Communication System
TCP	Transmission Control Protocol
TDD	Time Division Duplex/Duplexing
TM	Transparent Mode
TOI	Third-order Intercept
TTA	Telecommunications Technology Association
TTC	Telecommunication Technology Committee
TTI	Transmission Time Interval
UE	User Equipment
UL-SCH	Uplink Shared Channel
UM	Unacknowledged Mode
UTRAN	Universal Terrestrial Radio Access Network
VoIP	Voice over IP
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access