CHAPTER II

LTE-A KEY TECHNOLOGIES

This chapter presents a brief introduction to the research area along with a description of the problems addressed in this PhD Thesis.

Section 2.1 gives a brief introduction of Long Term Evolution (LTE)-Advanced, overall architecture and LTE physical layer; Section 2.2 provides the concept of home eNodeB (HeNB: base station in UMTS); in section 2.3 Multiple Input Multiple Output (MIMO) is described; the interference mitigation methods are defined in Section 2.4

2.1 LONG TERM EVOLUTION ADVANCED (LTE-A)

LTE is the abbreviation of long term evolution; it means a system as the long term evolution of UMTS from 3G to 4G. LTE project is initiated in 2004, focusing on enhancing Universal Terrestrial Radio Access (UTRA).

2.1.1 Overall Archeticture

The LTE overall architecture consists of cell sites or eNodeB, mobility management entities (MME), and serving gateways (S-GW). The eNBs provide the user interface towards mobile phones and devices, and they are interconnected with each other through X2 interfaces; and they are connected to the backhaul or evolved packet core (EPC) through S1 interfaces.

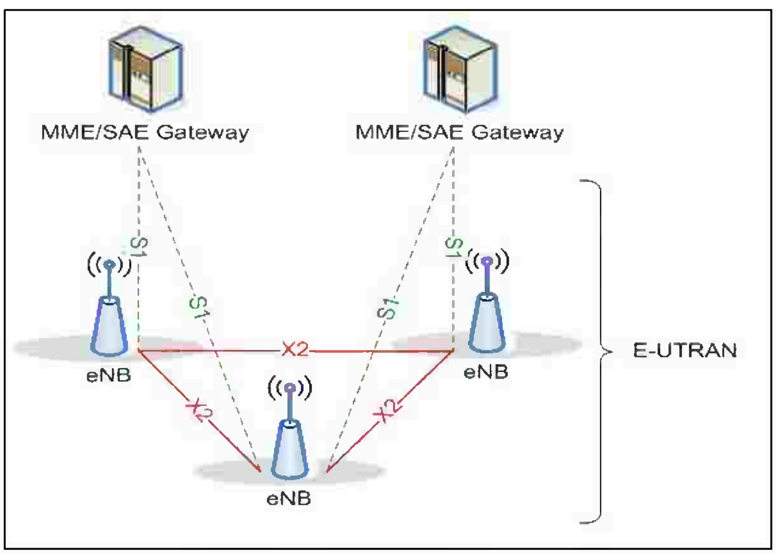


Figure 2.1 LTE Overall Architecture [5]

The S1 interface supports a many-to-many relation between MMEs / Serving Gateways and eNBs [5]. The Evolved Universal Terrestrial Radio Access Network (E-UTRAN) architecture is illustrated in Figure 2.1

2.1.2 LTE Physical Layer

2.1.2.1 Multiplexing Schemes

The capabilities of the evolved node-B (eNB) and the user equipment (UE) are obviously quite different, thus the LTE physical layer downlink and uplink are different002E

2.1.2.1.1 Downlink

Orthogonal Frequency Division Multiplexing (OFDM) is selected as the basic modulation scheme because of its robustness in the presence of severe multipath fading. Orthogonal Frequency Division Multiple Access (OFDMA) is employed as the multiplexing scheme in the downlink.

2.1.2.1.2 Uplink

LTE uplink requirements differ from downlink in several ways. Power consumption is a key consideration for UE terminals. High peak-to-average power ratio (PAPR) and related loss of efficiency with OFDM signaling are major concerns. As a result, an alternative to OFDMA was sought for use in the LTE uplink.

LTE Physical layer uses Single Carrier Frequency Division Multiple Access (SC-FDMA) as the basic transmission scheme for the uplink. SC-FDMA is a modified form of OFDMA. SC-FDMA has similar throughput performance and overall complexity as OFDMA. The principle advantage of SC-FDMA is the lower PAPR than OFDMA.

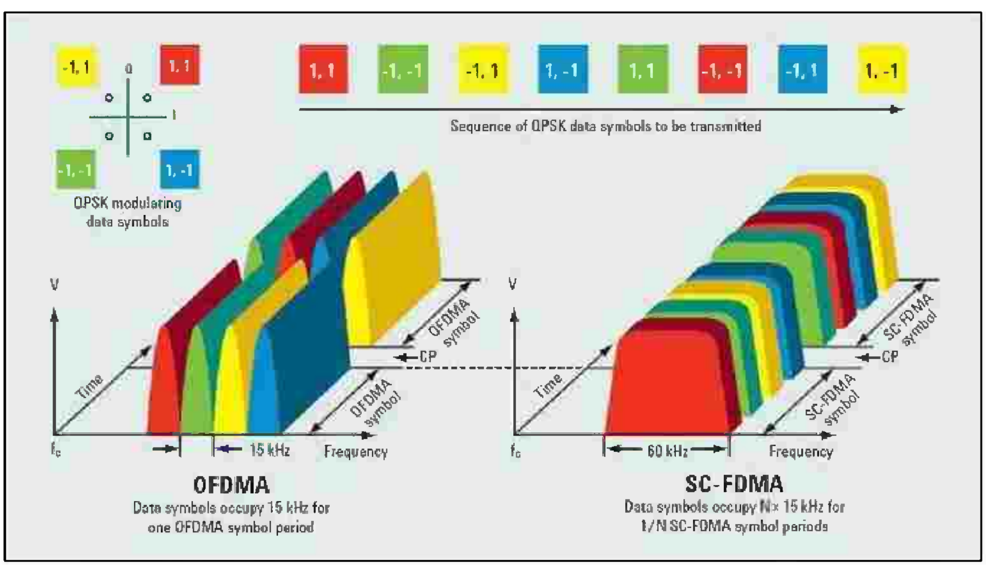


Figure 2.2 Frequency domain representations of downlink and uplink LTE [2].

2.1.2.2 LTE Frame Structure

The radio frame in LTE adopts the 0.5 ms slot structure and uses the 2 slot (1 subframe) allocation period, with duration of 10 ms (i.e. 10 subframes) per frame. In addition, for every subframe, each slot consists of either 6 or 7 Orthogonal Frequency Division Multiplexing (OFDM) symbols for the DL depending on whether extend or short cyclic prefix is used, with a Transmission Time Interval (TTI) of 1 ms. Multiple UEs can share the available resources within each TTI. With two types of frame structure, FDD Figure 2.3 illustrates an example of the LTE frame structure.

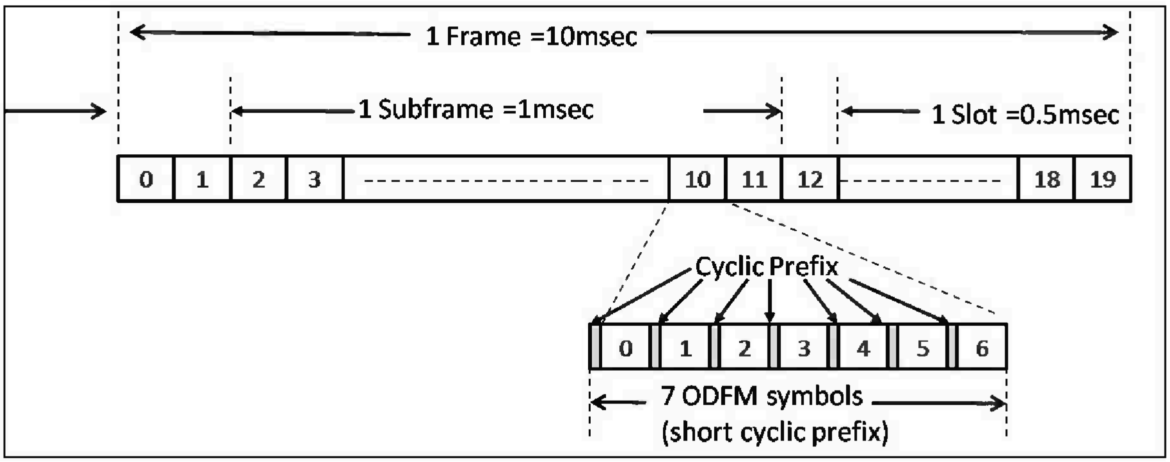


Figure 2.3 LTE Frame Structure Type 1(For FDD) [6]

2.1.2.3 Downlink Physical Resource Block

In LTE, physical resource block (PRB) is the smallest element of resource allocation assigned by the base station scheduler. A PRB is defined as a resource of 180 kHz in the frequency domain and 0.5 ms (1 time slot) in time domain. Since the subcarrier spacing is 15 kHz, each PRB consists of 12 subcarriers in frequency domain as shown in figure 2.4.

It is a straightforward to see that each RB has 12x7 = 84 resource elements in the case of normal cyclic prefix and 12x6 = 72 resource elements in the case of extended cyclic prefix.
The resource grid refers to a number of resource blocks in the available bandwidth. Each entry of the resource block is called a Resource Element (RE) which represents one ODFM subcarrier during one OFDM symbol interval [7].

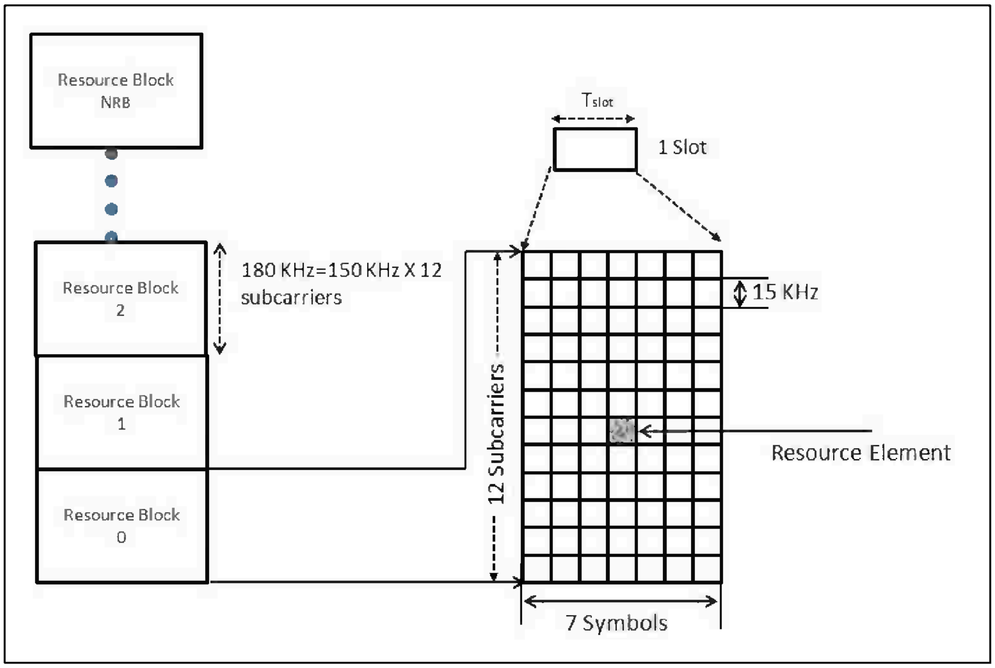


Figure 2.4 Physical Resource Block (PRB) [6]

The number of RB in a resource grid varies according to the size of the bandwidth. The OFDM subcarrier spacing is 15 kHz. The table 2.1 shows the LTE bandwidth and resource configuration.

Table 2.1 LTE Bandwidth and Resource Blocks specifications

Bandwidth (MHz)	1.4	3	5	10	15	20
Number of Resource Block	6	15	25	50	75	100
Number of occupied subcarrier	72	180	300	600	900	1200
IFFT/FFT size	128	256	512	1024	1035	2048
Subscriber spacing (KHz)	15					

2.1.2.4 Cyclic Prefix (CP)

The main advantage of an OFDM signal is that it can be demodulated without any interference between the subcarriers due to the orthogonality between them. However, considering a time dispersive channel, the orthogonality between the subcarriers will, at least, be partly lost. This loss of orthogonality in the time dispersive channel is due to the fact that the demodulator correlation interval of one path will overlap with the symbol boundary of another path.

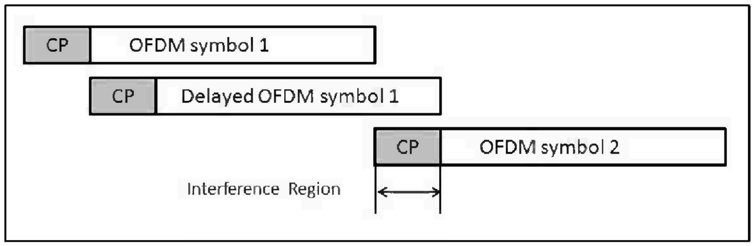


Figure 2.5 Cyclic Prefix [2]

Cyclic-prefix insertion implies that the last part of the OFDM symbol is copied and inserted at the beginning of the OFDM symbol as shown in Figure 2.5, so cyclic-prefix basically increases the length of the OFDM symbol which in turn reduces the OFDM symbol rate, normal and extended cyclic prefix configuration are shown in table 2.2.

Table 2.2 Cyclic Prefix Configuration [6]

Configuration	Subcarrier spacing	Number of Subcarrier	Number of Symbols
Normal Cyclic Prefix	15 KHz	12	7
Extended Cyclic Prefix	15 KHz	12	6
	7.5KHz	24	3

2.1.2.5 Reference Signal (RS)

To allow for coherent demodulation at the user equipment, reference symbols (or pilot symbols) are inserted in the OFDM time-frequency grid to allow for channel estimation. Downlink reference symbols are inserted within the first and third last OFDM symbol of each slot with a frequency domain spacing of six sub-carriers (this corresponds to the fifth and fourth OFDM symbols of the slot in case of normal and extended cyclic prefix, respectively) as shown in Figure 2.6 for an LTE system with one antenna in normal CP mode [8].

Three types of downlink RSs are defined:
- ✓ Cell specific reference signal.
- ✓ Multimedia Broadcast Single Frequency Network (MBSFN) reference signal.
- ✓ UE specific reference signal.

For uplink, there are two types of reference signals for uplink in LTE:
- ✓ Demodulation Reference Signals (DM-RS)
- ✓ Sounding Reference Signal (SRS)

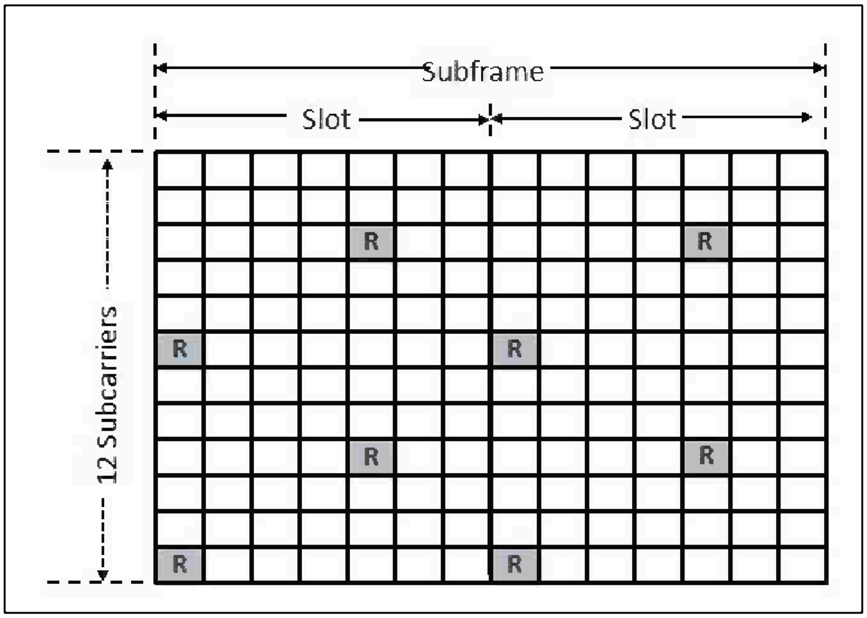


Figure 2.6 LTE Reference Signal (RS) [8]

2.1.2.6 LTE Physical Channel

A downlink physical channel corresponds to a set of resource element (RE) carrying information originating from higher layers and its interface are defined in [6], [9]. The following downlink and uplink physical channels are defined in table 2.3, and 2.4 respectively.

Table 2.3 Downlink Physical Channel and Signals [8]

Primary and Secondary Synchronization Signal	Provide acquisition of cell timing and identity during cell search
Downlink Reference Signal	Cell search, initial acquisition, coherent demodulation, channel estimation
Physical Broadcast Channel (PBCH)	Provides essential system information e.g. system bandwidth
Physical Control Format Indicator Channel (PCFICH)	Indicates format of PDCCH.
Physical Downlink Control Channel (PDCCH)	Carries control information (DCI : Downlink Control Information)
Physical Downlink Shared Channel (PDSCH)	Carries data (user data, system information)
Physical Hybrid ARQ Indicator Channel (PHICH)	Carries ACK/NACK (HI = HARQ indicator) for uplink data packets
Physical Multicast Channel (PMCH)	Carries MBMS user data

Table 2.4 Uplink Physical Channel and Signals [8]

Physical Uplink Shared Channel (PUSCH)	Carries user data
Physical Uplink Control Channel Carries (PUCCH)	control information (UCI = Uplink Control Information)
Physical Random Access Channel (PRACH)	Preamble transmission for initial access
Demodulation Reference Signal (DRS)	Enables channel estimation and data demodulation
Sounding Reference Signal (SRS)	Enables uplink channel quality evaluation

2.1.2.7 LTE Transmission Mode (TM)

Each PDSCH transmission mode defines a specific set of physical layer procedures and configurations based on which the transport blocks are processed and the complex valued baseband signals for transmission on the antenna ports are generated.

There are 10 transmission modes that have been defined for LTE/LTE Advanced as stated in table 2.5

Table 2.5 LTE Transmission Modes [1]

Transmission mode	Description
1	Single transmit antenna
2	Transmit diversity
3	Open loop spatial multiplexing with cyclic delay diversity (CDD)
4	Closed loop spatial multiplexing
5	Multi-user MIMO layer
6	Closed loop spatial multiplexing using a single transmission
7	Beamforming
8	Dual-layer beamforming
9	Non codebook based precoding supporting up to eight layers
10	Coordinated multipoint (COMP) operation

2.2 FEMTOCELL (HOME ENODEB)

Femtocells are low power radio cells, providing wireless voice and broadband services to customers primarily in the home environment. Femtocells usually have an output power less than 0.1 Watt.

Home eNodeB (HeNB) were first introduced in 3rd Generation Partnership Project (3GPP) Release 8, signaling that it had become a mainstream wireless access technology [10]. Femtocells promise improved indoor coverage and increased throughput for mobile data services while off-loading traffic from expensive macro radio access networks onto the low cost public Internet.

Femtocells, also known as home eNodeB, are cellular network access points that connect standard mobile devices to a mobile operator's network using residential DSL, cable broadband connections, optical fibers or wireless last-mile technologies. It can provide indoor coverage for places where macrocell cannot, in addition, It can offload traffic from the macrocell layer and improve macrocell capacity (in the case of using macrocell to provide indoor coverage, more power from the base station will be needed to compensate for high penetration loss, resulting in a decrease in macrocell capacity)[11].

Femtocells access mode defines which user is allowed to use each femtocell. Three difference access types are defined [12]:

- **Closed Access**:

  Closed access mode femtocell is known as the closed subscriber group (CSG) cell in 3GPP and is the only featured access mode in release 8. The CSG cell may be widely used in individual home deployment. In this scenario, the owner of the femtocell does not want to share the femtocell due to the limited source of the backhaul or due to some security concerns. The access control should always be performed whenever a UE is trying to camp on the femtocell. Any UE that is not in the CSG will be rejected by the femtocell. The disadvantage of this type leads to high cross interference.

- **Open Access**

  As a new access mode in 3GPP release 9, the open access mode femtocell operates as a normal cell, i.e. non-CSG cell. The operator may deploy an open access mode femtocell to fill some indoor blind spots and some public hot-spots to serve all the users as macrocell. The mobile network doesn't need to perform any specific UE access control for such a femtocell, but disadvantage of this mode is increased of signaling overhead.

- **Hybrid Access**

- Information about hybrid/semi-open access can be found in [13]. This access feature will be available in 3GPP release 9. A hybrid mode means that the femtocell can provide a combination of both open and closed access modes at the same time. The hybrid access femtocell is a cell that not only has a CSG ID, but also allows UEs that are not members of that CSG to camp thereon. In this access mode, these UEs may only be authorized a limited QoS service and have lower priority compared with the UEs in the CSG.

Figure 2.7 shows the HeNB architecture which consist of two main parts, the security gateway (SEGW) and HNB gateway (HNB-GW). SEGW provides HNB with access to HNB management system (HMS) and HNB gateway, in addition to authentication of HNB, HNB-GW support HNB and UE registration [14],[15].

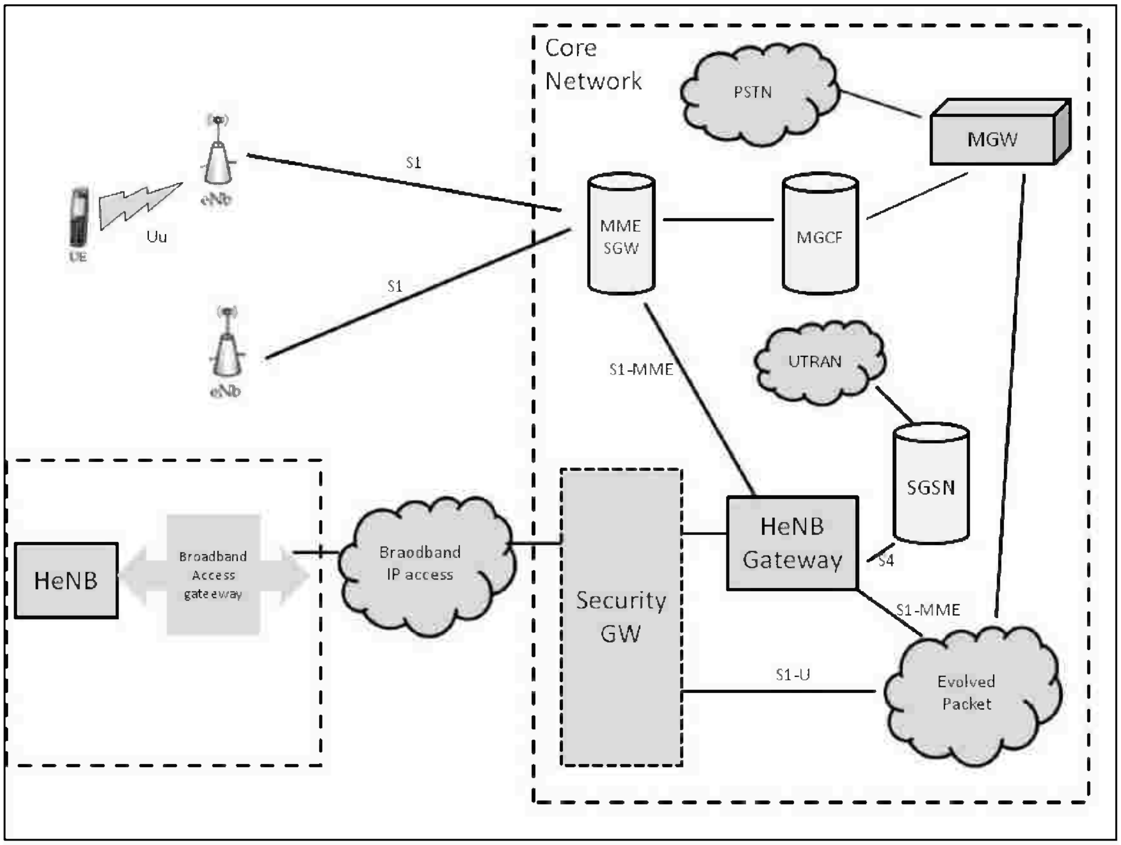


Figure 2.7 Femtocell architecture [10]

2.3 MULTIPLE INPUT MULTIPLE OUTPUT

Multiple Input Multiple Output (MIMO) systems form an essential part of LTE in order to achieve the ambitious requirements for throughput and spectral efficiency [16]. MIMO refers to the use of multiple antennas at the transmitter and receiver side. For the LTE downlink, a 2x2 configuration for MIMO is assumed as baseline configuration, i.e. two transmit antennas at the base station and two receive antennas at the terminal side as shown in figure 2.8.

There are two functionality modes of MIMO. Different gains can be achieved depending on which MIMO mode is used. The Spatial Multiplexing mode allows transmitting different streams of data simultaneously on the same resource blocks by exploiting the spatial dimension of the radio channel so that the data rate or capacity is increased [16]. The other one is the Transmit Diversity mode. It is used to exploit diversity and increase the robustness of data transmission. Each transmit antenna transmits essentially the same stream of data, so the receiver gets replicas of the same signal. This increases the signal to noise ratio at the receiver side and thus the robustness of data transmission especially in fading scenarios.

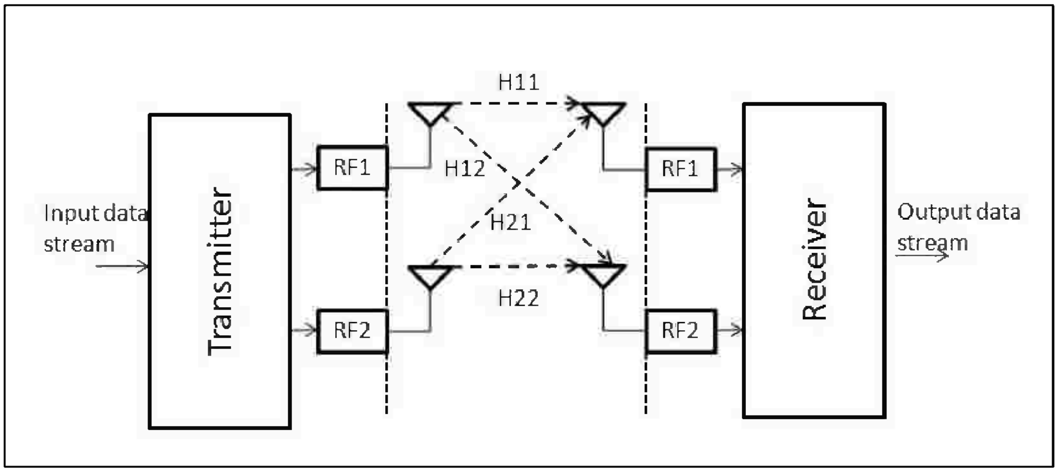


Figure 2.8 LTE-A Downlink 2x2 MIMO [16]

2.4 CONVENTIONAL INTERFERENCE MANAGEMENT METHODS

2.4.1 Enhanced Inter Cell Interference Coordination (eICIC)

Interference cancellation and mitigation techniques have been investigated and deployed with varying degrees of success in terrestrial mobile networks for more than 20 years [17].

ICIC was introduced in 3GPP Release 8 as an optional method to solve inter-cell intra frequency interference. The main idea of ICIC is to divide each cell into two sections, the cell center and the cell edge, and then allocate different subcarriers to users in different locations. Theoretically, it is impossible for subscribers at the edge of two neighboring cells to use the same frequency, and, in that way, the possibility of interference between two neighboring cells is reduced. ICIC techniques can be classified into hard frequency reuse, fractional frequency reuse and soft frequency reuse. The transmission power of each portion of the spectrum is also controlled to prevent cell edges and neighboring cells from being affected.

The eICIC proposal in LTE standards serves two important purposes: allow for time sharing of spectrum resources (for downlink transmissions) between macros and femtos so as to mitigate interference to macro in the downlink, and, allow for flexibility in UE association so that macros are neither underutilized nor overloaded.

The enhanced Inter Cell Interference Coordination (eICIC) in heterogeneous networks is an efficient inter cell interference scheme compared to ICIC in LTE release 8 and 9 which that ICIC only consider data channels and didn't focus in interference between control channels [18], but in LTE-A release 10 solve this problem by three major categories according to [19]:

- Frequency domain techniques
- Power control techniques.
- Time domain techniques.

2.4.1.1 Frequency Domain Techniques

The main frequency domain method for interference cancelation is based on carrier aggregation (CA), which is one of the most important features of LTE-A (3GPP Release 10). CA enables UEs to be connected to several carriers simultaneously. Besides that, a terminal supporting CA can be configured by higher layer signaling to enable cross-carrier scheduling on certain component carriers. This implies that a terminal receiving a DL assignment on one component carrier (CC) may receive associated data on another CC; in other words, a node can schedule its control information on a CC and its data information on another CC. One of the main motivations for introducing cross-carrier scheduling was to enhance operations in HetNets in a multi-carrier deployment [20].

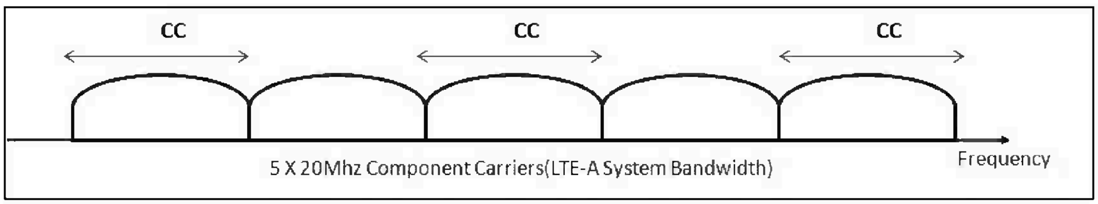


Figure 2.9 Illustration of component carriers using carrier aggregation [2]

2.4.1.2 Time Domain Techniques

When the sub-frames of the macro station and low power nodes are aligned, their control and data channels overlap with each other. The basic idea with time domain eICIC in order to coordinate inter-cell interference and protect control channels is that an aggressor layer creates protected sub-frames for a victim layer by reducing its transmission activity in certain sub-frames. Whereby, transmissions of the victim users are scheduled in time domain resources where the interference from other nodes is mitigated. In macro femto scenario, the femtocell can mute all downlink transmissions to its UEs in certain subframes termed almost blank subframes (ABS) [21].

These subframes are called “almost blank” because a femto can still transmit some broadcast signals over these subframes [22]. Since these broadcast signals only occupy a small fraction of the OFDMA subcarriers, the overall interference a femto causes to a macro is much less during these ABS periods. Thus, the macro can transmit to its UEs at a much higher data rate during ABS periods. Note that, a macro is also allowed to transmit to its UEs during non-ABS periods. This could provide good enough performance to UEs very close to the macro.

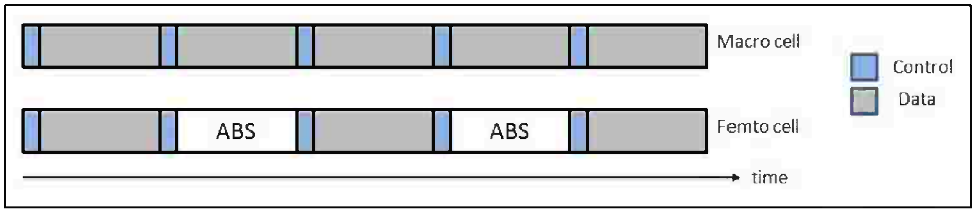


Figure 2.10 Almost Blank Subframe (eICIC time domain techniques)

2.4.1.3 Power Control Techniques

Home eNB (HeNB) typically sets its own transmit power by measuring surrounding RF conditions of macro cells to mitigate interference to macro UE (MUE) and maintain good HeNB indoor coverage for the Home UEs (HUE). However, there may be a significant difference between the RF conditions measured by the HeNB and those experienced by the MUEs or HUEs [23]. Even in an indoor environment, the HeNB and the HUEs may measure significantly different RF conditions in some cases such as between different rooms, or between different floors. In the case the MUE is located at the close proximity of the house or located indoor, the HeNB transmit power is set to a relatively lower value because the signal level from MNB is relatively low [24].

To limit the impact interference of femtocell on existing heterogeneous network, it desired to limit transmission power control of CSG HeNBs; we used method which described in [25]. It doesn't need complicated backhaul negotiation among HeNBs. The femtocell transmission power can be written as:

$$P_{TX} = \max\left(P_{TXmin} , \min (P_{TXmax} , P_{RX} + PL - \lambda)\right) \quad (2.1)$$

Where P_{TX} is HeNB transmission power, P_{TXmin} , P_{TXmax} are the minimum and maximum transmission powers, respectively. P_{RX} is the power received from the strongest macro (MNB), PL is the assumed pathloss in dB, and λ is the target minimum C/I value in dB. The target is to minimize interference to macro network, while the pathloss determines the desired HeNB coverage; it should be set to maximum pathloss for any link between HeNB and its HUE in same apartment [26].

2.4.2 Coordinated Multipoint Transmission (COMP)

Coordinated multi-point (CoMP) transmission/reception is considered for LTE-Advanced as a tool to improve the coverage of high data rates, the cell-edge throughput and/or to increase system throughput in both high load and low load scenarios [27], [28].

2.4.2.1 The COMP Archetecture

CoMP coordinates base station antennae deployed at a number of sites which are in feasible proximity to one another. The 3GPP Technical report on further advancements of E-UTRA physical layer aspects offers two major categories in CoMP scheme which are namely Coordinated Scheduling/Beamforming (CS/CB) and Joint Processing (JP) [29].

The eNBs should be in coordination to reduce the inter-cell interference in the system for both uplink and downlink. The LTE requires the information of radio resource allocation related to the reference UE to be available at all base stations in coordination cluster. Therefore the latency of the links should be very low so that the necessary coordination information can be exchanged in a very short time frame. There are two kinds of architectures described in [30], each of which can be combined with any of the transmission schemes mentioned above

2.4.2.1.1 Centralized Architecture

A central unit is required to gather the information of all the UEs in the area covered by the base stations, eNBs in this case. This unit is also responsible for signal processing operations such as pre-coding and user scheduling. Moreover, what is crucial in centralized approach is the requirement of tight time synchronization among eNBs. The communication links between the central unit and the eNBs are the main challenges of this architecture. The links have to support low latency data transmission and the protocols should be well designed for information exchange.

2.4.2.1.2 Distributed Architecture

Distributed architecture is another method to establish the coordination among eNBs, lessening the requirements of centralized approach. Assuming that all eNBs are identical in terms of scheduling and the channel information within the entire coordination set, cooperation does not need the wireless communication links between the nodes any longer. Thereby, the signaling protocol drawback and infrastructure load related to these links are minimized.

The process to be followed in a distributed CoMP system is described as follows. The channels from all nodes are estimated by the users as is in centralized design. Then the scheduling is independently executed after these estimations are sent back to the cooperating nodes.

The main disadvantage of distributed architecture is the reduction in the efficiency of CoMP algorithm when the eNBs are not cooperating via a wired backhaul. Another drawback can be stated as the difficulty in error handling on different feedback links.

2.4.2.2 The COMP Scheme

3GPP envisages different possible CoMP schemes in LTE Advanced for both downlink and uplink. In the downlink, cooperative scheduling / beamforming and joint processing are the two CoMP transmission techniques envisioned. In the first scheme, there is only one eNB transmitting data to the UE; however, in the second scheme the UE receives data from two or more eNBs simultaneously. In the uplink, coordinated scheduling is the only method presented [31].

2.4.2.2.1 Coordinated Scheduling/ Beamorming

The data at the terminal is received from one of the base stations and coordination takes place among a set of base stations in order to control and coordinate the interference at the terminal. The coordinated scheduling is achieved by silencing the base stations with critical interference towards the victim UE and only allows transmission from serving BS. In other words, mobile station MS1 receives the intended data from only one base station(BS), say BS1; however, another base station, say BS2, selects its own UEs in such a way that it causes little interference to the MS1 [32].

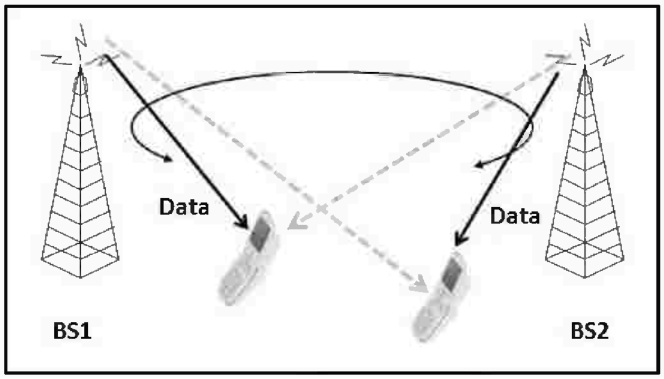
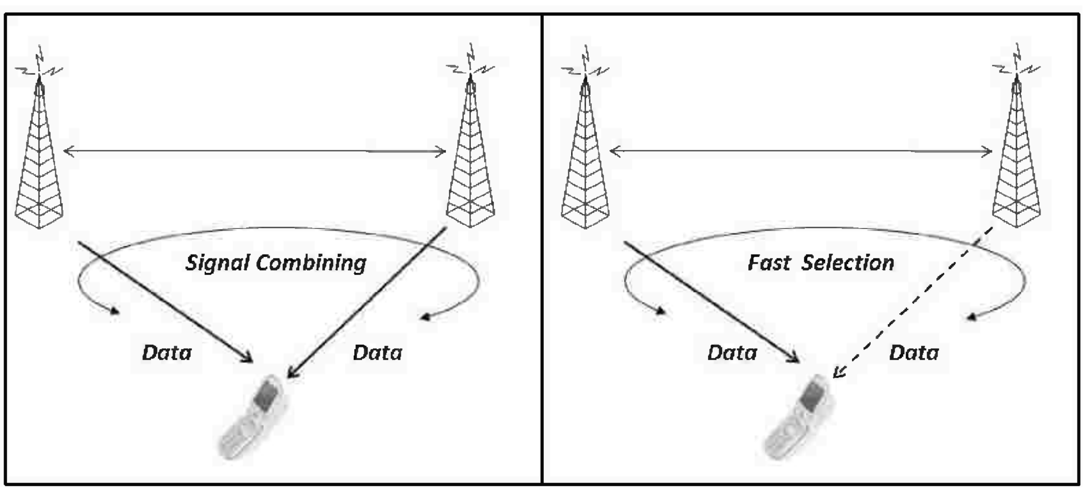


Figure 2.11 Coordinated Scheduling/Beamforming Scheduling [30]

2.4.2.2.2 Joint Processing

As is described in [32] and [33], in Joint Processing (JP), multiple eNBs are responsible for the joint transmission of the data for a particular UE to improve the quality of the received signal and/or to cancel the interference for other terminals. Different cells share the data intended for a particular UE and the data is jointly processed at these cells. Hence, received signals are combined together at the mobile terminal coherently or non-coherently. JP is categorized into two subcategories which are namely, Joint Transmission (JT) and Dynamic Cell Selection (DSC).See figure 2.12.



a) Joint Transmission **b) Dynamic cell selection**

Figure 2.12 Joint Processing Techniques [30]

In DCS, a resource block of the Physical Downlink Shared Channel (PDSCH) is transmitted from one cell among the coordinated cells. This unique cell is dynamically selected by fast scheduling at the central base station, where the minimum path loss is considered. Meanwhile, the other cells do not transmit the resource block so that they do not cause interference to the user. As a result, the mobile terminal obtains the maximum received power and the interference from other users is significantly mitigated.

On the other hand, in JT, multiple cells among a cluster of coordinated cells transmit the same resource block of the PDSCH. JT is accomplished by codebook based precoding in order to reduce overhead of the feedback signal. Basically, in addition to the precoding matrix at each cell, the optimum precoding matrices for inter-cell coordination are chosen such that SINR is maximized at the mobile terminal [33].

The Different modes of CoMP operation in downlink (transmission) are summarized in table 2.6

Table 2.6 Modes of operation in CoMP –transmission (downlink) [33]

Joint Processing		**Coordinated Scheduling /Beamforming**
Joint transmission	**Dynamic cell selection**	
Data available at each transmission point	Data available at each transmission point	Data available at serving cell only
Data transmitted simultaneously from multiple transmission points	Data transmitted from one transmission point at a time	Data transmitted from one transmission point but user scheduling / beamforming decisions are made with coordination among cells