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Interference Management in Long Term Evolution-Advanced System

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Abstract**—**Incorporating Home eNodeB (HeNB) in cellular networks, e.g. Long Term Evolution Advanced (LTE-A), is beneficial for extending coverage and enhancing capacity at low price especially within the non-line-of sight (NLOS) environments such as homes. HeNB or femtocell is a small low powered base station which provides radio coverage to the mobile users in an indoor environment. This deployment results in a heterogeneous network where the available spectrum becomes shared between two layers. Therefore, a problem of Inter Cell Interference (ICI) appears. This issue is the main challenge in LTE-A. To deal with this challenge, various techniques based on frequency, time and power control are proposed. This paper deals with the impact of carrier aggregation and higher order MIMO (Multiple Input Multiple Output) schemes on the LTE-Advanced performance. Simulation results show the advantages of these schemes on the system capacity (4.10^9 b/s/Hz when bandwidth B=100 MHz and when applying MIMO 8x8 for SINR=30 dB), maximum theoretical peak data rate (more than 4 Gbps for B=100 MHz and when MIMO 8x8 is used) and spectral efficiency (15 b/s/Hz and 30b/s/Hz when MIMO 4x4 and MIMO 8x8 are applying respectively for SINR=30 dB).

Keywords**—**LTE-Advanced, carrier aggregation, MIMO, capacity, peak data rate, spectral efficiency.

I. Introduction

LONG Term Evolution (LTE) is one of the most promising candidates for next generation communication standard [1]. The LTE adopts Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier-Frequency Division Multiple Access (SC-FDMA) as multiple access techniques in downlink and uplink respectively and operates with different frequency bands [2]: 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz to achieve higher data rates (50 Mbps in uplink and 100 Mbps in downlink) and enhanced spectral efficiency. But, LTE standard does not fully reach the International Telecommunication Union (ITU) requirements for a 4G system [3]. LTE is widely referred in the scientific community as 3.9G. LTE-Advanced (also known as LTE Release 10) is, however, planned to reach those requirements [4]. Third Generation Partnership Project's aim is to have peak data rates of 1 Gbps in downlink and 500 Mbps in uplink. The spectrum efficiency will then be 15 bit/s/Hz and 30 bit/s/Hz in uplink and downlink respectively [5]. LTE-Advanced was introduced to meet the increasing demand in terms of throughput and coverage. The key components that will make this possible are, among others, carrier aggregation and higher order MIMO (4x4 MIMO in uplink and 8x8 MIMO in downlink) [6].

In this paper, we study the impact of carrier aggregation and higher order MIMO schemes on the LTE-Advanced performance in terms of capacity, throughput and spectral efficiency.

In the following, the paper is organized as follows. The carrier aggregation functionality will be described in Section II. Section III presents enhanced MIMO technique in LTE-Advanced. Simulation results are given in Section IV. Finally, in Section V, we conclude the paper.

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II. Related Works

Inter-cell interference management issues for the femtocells based systems have been actively discussed in LTE and LTE-A [7]-[9].

Fractional Frequency Reuse (FFR) scheme was proposed [7]. In the FFR, frequency band is divided into several sub bands and each one is used in the center or in the edge region of the cell. It reduces interference between macrocells and femtocells by assigning different frequencies or Resource Blocks (RBs). However, FFR is not adapted to the network channel conditions.

Coordinated Multi-Point transmission and reception technique (CoMP) was proposed [8]. CoMP consists of cooperation of transmitters with each other in order to limit interferences. The main objective is to improve coverage and reduce the number of interfered users in the edge region of cells. For this purpose, the base stations communicate between them in order to regulate the use of common radio resources. This interaction between cells can be done directly through the X2 link in LTE/LTE-A systems. But, this technique is characterized by its high cost and its complicity. Almost-Blank Sub-frame (ABSF) is one of the time-domain techniques proposed in the enhanced Inter-Cell Interference Coordination (eICIC) [9]. In ABSF, one way to reduce interference is that the macrocell stops transmitting at a certain sub-frame so that femtocell can transmit information during that period. However, this mechanism is not very spectrum efficient and can affect the macro cellular system performance.

In this work, we study the impact of carrier aggregation and advanced MIMO techniques on the LTE-Advanced performances.

III. Carrier Aggregation

Carrier aggregation is standardized in 3GPP as a part of LTE release 10 [10]. Carrier aggregation is one of the important features of LTE-Advanced. Actually, the most straight forward approach to enhance capacity is to expand bandwidth. Since it is critical to keep backward compatibility with Releases 8 and 9 of mobile networks, consequently, bandwidth increasing in LTE-Advanced is provided through collection of R8/R9 carriers [11]. Each aggregated carrier is named as Component Carrier (CC). This later can have a large of 1.4, 3, 5, 10, 15, or 20 MHz and a greatest of five segments can be collected. Henceforth, the most extreme transmission capacity is 100 MHz [12]. The number of aggregated carriers can be distinctive in downlink (DL) and uplink (UL), but the number of component carrier in UL is never exceeding this in DL [13]. Different carrier aggregation configurations used in LTE-A are discussed in detail [14]:

As mention earlier, up to five segments of different bandwidths up to 20 MHz can be collected allowing for an overall transmission bandwidth of up to 100 MHz. one terminal uses carrier aggregation can receive or transmit simultaneously on multiple component carriers. It should be noted that collected carrier segments do not need to be contiguous in the frequency domain. However, based on the frequency location of the different component carriers, three types of carrier aggregation configurations are distinguished as shown in Fig. 1:

- Intra-band aggregation with frequency-contiguous component carriers: alludes to the transmission on neighboring carriers in the same frequency band. It is easy to implement in User Equipment (UE) since the same power amplifier can be used.
- Intra-band aggregation with non-contiguous component carriers: we speak about this kind of carrier aggregation if multiple CCs belonging to the same band are used in a non-contiguous manner. It is more complex to implement in the UE.
- Inter-band aggregation: suggests that carriers in two or more different frequency bands are aggregated. It requires multiple transceivers in the UE, which increases cost and power utilization.

Carrier aggregation is a frequency domain inter-cell interference coordination method. In fact, user equipment in LTE-Advanced system can use different carriers simultaneously. Carrier aggregation can allow both resource allocations across carriers and scheduler based fast switching between carriers without time consuming handovers; that is to say, a node or a base station can schedule its control information and its data information on two separate carriers.

The concept of carrier aggregation in a heterogeneous LTE-Advanced network is to subdivide the available spectrum into different separate component carriers. For example, in Fig. 2, the available spectrum is divided in two component carriers. The first one (f1) is assigned to macrocell layer and the second component carrier (f2) to femtocell layer as shown in Fig. 2 [21].

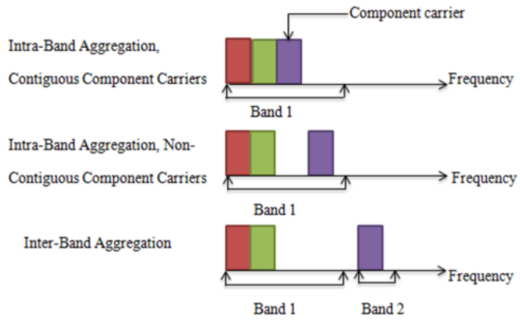

Fig. 1 Types of carrier aggregation

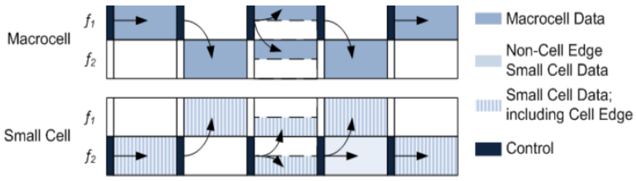

Fig. 2 ICI coordination based on carrier aggregation

Fig. 2 shows that the macrolayer can schedule its control information on (f1) and still schedules its users on both (f1) and (f2), so by scheduling control and data information for both macro and femtolayers on different component carriers interference on control and data can be avoided.

IV. Advanced MIMO

MIMO is used to enhance the overall bit rate by the transmission of two (or more) separate data streams on two (or more) different antennas - using the same resources in both frequency and time, separated only by using different reference signals to be received by two or more antennas [15]. The model of radio interface of the MIMO system contains M_{TX} transmitter antennas and N_{RX} receiver antennas. This model describes the connection between the base station (eNodeB) and the mobile station (UE). In LTE-Advanced, MIMO is one of the fundamental technologies introduced in order to accomplish the 3GPP requirements together with the Carrier Aggregation. In fact, MIMO 8x8 is used in downlink and MIMO 4x4 in uplink [16] as shown in Fig. 3.

In LTE-Advanced standard, the interference channel state is shared between the multiple transmitters. In that case, the transmitters may, for example, coordinate their scheduling decisions and choose conditions that minimize the impact of interference.

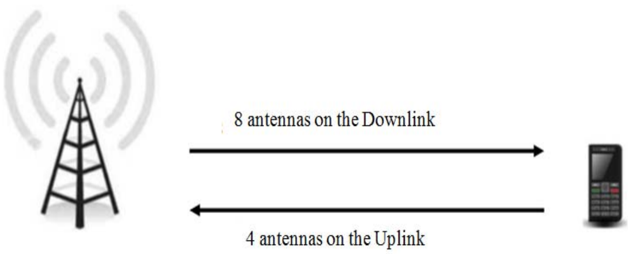

Fig. 3 Advanced MIMO in LTE-Advanced

V. Simulation Results

Carrier aggregation and MIMO configuration are the most important parameters, and these can affect a radio system performance. In fact, bandwidth is an important parameter in the evaluation of a radio system capacity. Indeed, the Shannon's formula can be given by [17]:

$$C = B\log_2(1 + SNR) \quad (1)$$

where: B is the bandwidth, SNR is the Signal to Noise Ratio. It given by [18]:

$$SNR = \frac{S}{N} \quad (2)$$

If we consider the interference contribution that can affect the radio channel's transmission, the SNR ratio will be replaced by a novel ratio named Signal to Interference plus Noise Ratio (SINR). Then, (1) would rewrite as [17]:

$$C = B\log_2(1 + SINR) \quad (3)$$

The SINR ratio for a mobile receiver can be expressed as [17]:

$$SINR = \frac{S}{I + N} \quad (4)$$

where: S is the useful signal power; I is the interference power; N is the noise power.

The evolution of LTE-Advanced system capacity through carrier aggregation is shown in Fig. 4.

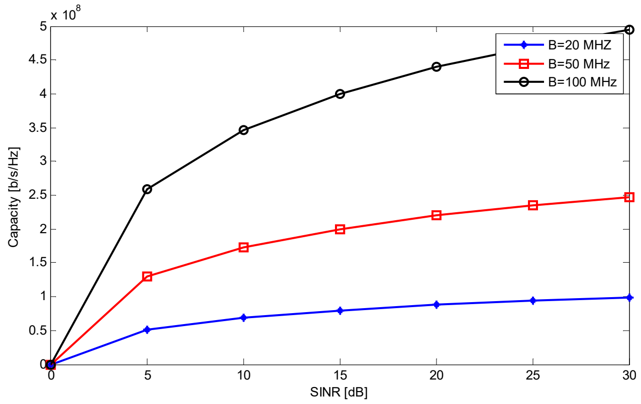

Fig. 4 LTE-Advanced capacity depending on bandwidth

The obtained result shows the importance of carrier aggregation inducing a system capacity improvement. In fact, for example, if SINR=30 dB, the system capacity is multiplied by 5 if the bandwidth increased from B=20 MHz to B=100 MHz. besides, system capacity is multiplied by 2 if the bandwidth value varies from 50 MHz to 100 MHz. Indeed, for SINR= 30dB, system capacity is equal to 10^8 b/s/Hz, $2.5.10^8$ b/s/Hz, and 5.10^8 b/s/Hz if B= 20 MHz, 50 MHz, and 100 MHz, respectively. However, concerning MIMO configuration's impact, results are indicated in Fig. 5.

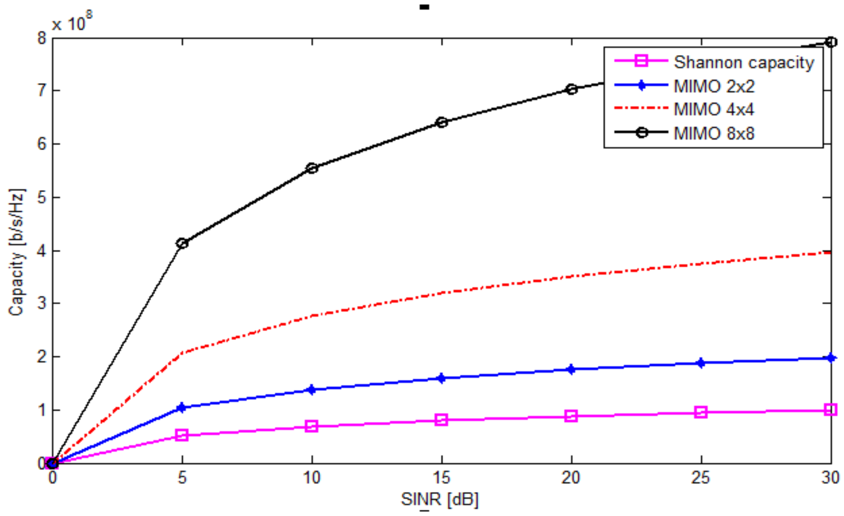

Fig. 5 Impact of MIMO configuration on LTE-Advanced capacity

From this figure, we can clearly conclude the important role of the MIMO scheme for improving a radio system capacity. In fact, with MIMO 2x2 system capacity increases compared to Shannon's capacity. But, this MIMO configuration (2x2) becomes limited compared to MIMO 4x4 and 8x8 configurations which can enhance LTE-Advanced system capacity up to 4.10^8 b/s/Hz and 8.10^8 b/s/Hz respectively for SINR value equal to 30 dB.

Figs. 4 and 5 represent respectively only the impact of carrier aggregation and MIMO schemes on the LTE-Advanced capacity. However, the use of these functionalities and their impact on system capacity will be presented in Fig. 6.

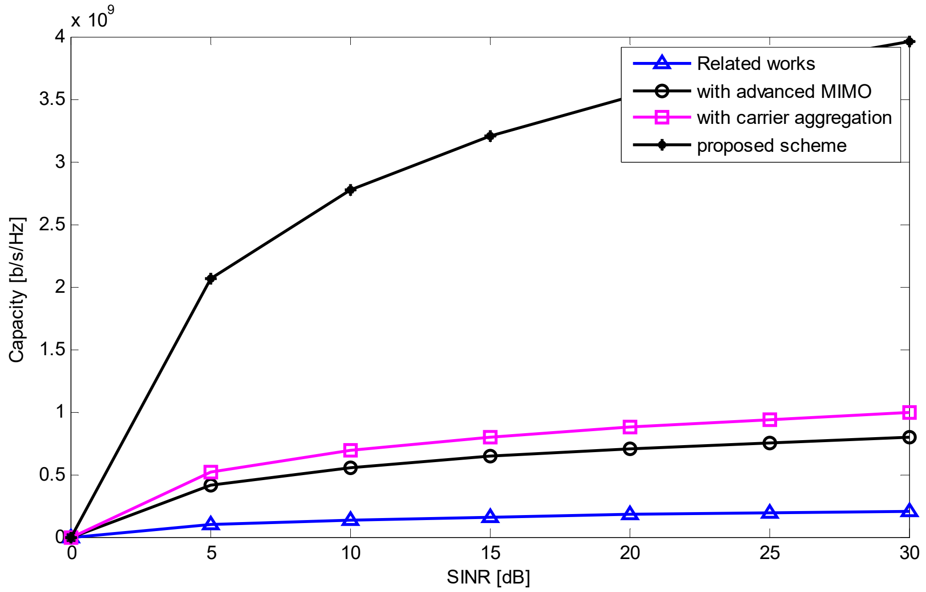

Fig. 6 System capacity enhancement through carrier aggregation and MIMO configuration

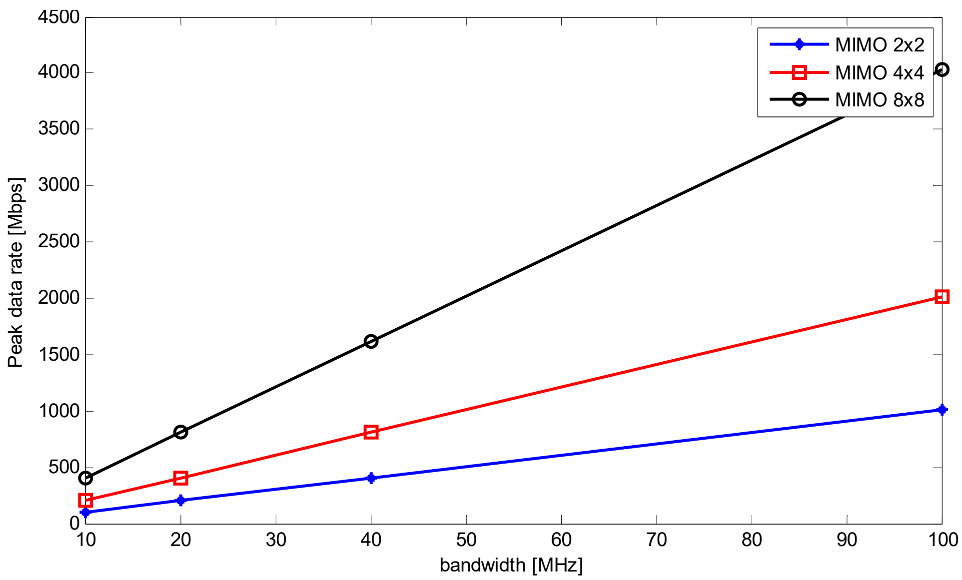

Fig. 7 Peak data rate depending on bandwidth and MIMO configuration

TABLE I
NUMBER OF RB DEPENDING ON BANDWIDTH

Bandwidth (MHz)	1.4	3	5	10	15	20
N_{RB}	6	15	25	50	75	100

The impact of carrier aggregation and MIMO is not only the enhancement of system capacity but also the improvement of throughput. In fact, the achievable user throughput is approximated by [19]:

$$Throughput = N_{RB} Th_{RB_i} \quad (5)$$

where: N_{RB} is the total number of allocated Resource Blocks (RB); Th_{RB_i} is the throughput per RB.

The number of resource blocks is depending to the bandwidth. Table I summarizes the RB number according to the bandwidth value.

The maximum theoretical throughput per RB can be calculated by [19]:

$$Th_{RB_i} = \frac{N_{RB}^{sub} N_{sub}^{sym} N_{sym}^{b}}{T_{RB}} G_{MIMO} \quad (6)$$

where: N_{RB}^{sub} is the number of subcarriers per resource block; N_{sub}^{sym} is the number of symbols per subcarrier; N_{sym}^{b} is the number of bits per symbol; T_{RB} is the resource block slot duration; G_{MIMO} is the maximum achievable capacity gain associated to the use of MIMO scheme.

Fig. 8 shows the variation of maximum theoretical peak data rates depending on both bandwidth and configuration MIMO. From this figure, we can note how carrier aggregation and higher order MIMO have significantly improved the data rate.

In addition to system capacity and throughput enhancement, MIMO technology can increase spectral efficiency. In fact, spectral efficiency is given by [20]:

$$S = \frac{P_d MC_f G_{MIMO}}{B} \quad (7)$$

where: P_d is the peak data rate; MC_f is the modulation and coding scheme average factor; G_{MIMO} is the gain obtained from the MIMO technology; B is the bandwidth.

Fig. 8 presents the evaluation of spectral efficiency when applying MIMO 2x2, MIMO 4x4 and MIMO 8x8.

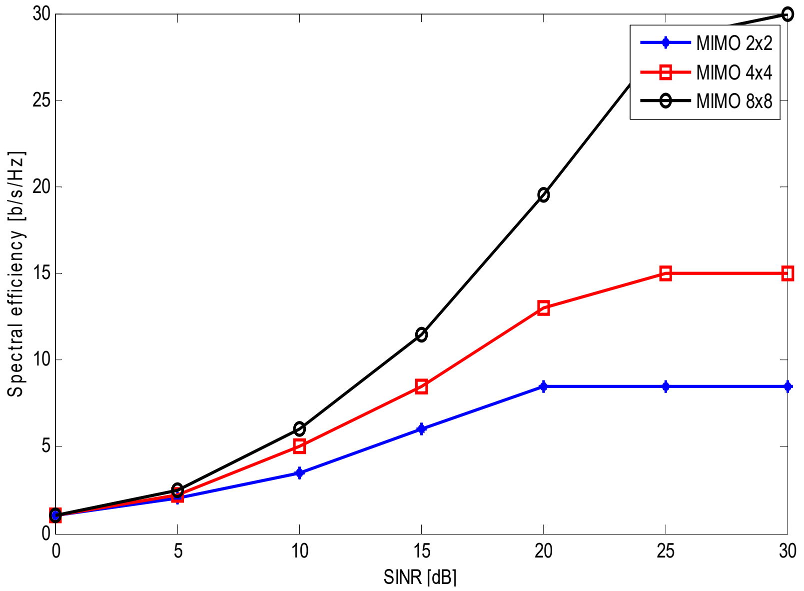

Fig. 8 Spectral efficiency evaluation according to MIMO configuration

Let us note that results obtained for SINR=30 dB. We can clearly conclude that MIMO 4x4 and MIMO 8x8 configurations meet the 3GPP requirements in terms of spectral efficiency.

VI. Conclusion

In this paper, we have present the impact of two technologies integrated in LTE-Advanced system named carrier aggregation and advanced MIMO for interference reduction. The performance of the system that employs carrier aggregation and advanced MIMO was evaluated in terms of capacity, spectral efficiency and peak data rate. In fact, carrier aggregation is developed in LTE-Advanced for increasing bandwidth (up to 100 MHz). Besides, higher order MIMO is applying in LTE-Advanced network up to MIMO 4x4 in uplink and MIMO 8x8 in downlink. These two functionalities can improve system capacity, enhance peak data rate and increase spectral efficiency.

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