On The Impact of MIMO Antennas on Collocation and Coexistence Requirements of LTE Networks in 2.6 GHz Frequency Band

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Abstract

Perhaps one of the most enabling features of Long Term Evolution (LTE) standard and its successors of the third Generation Partnership Project (3GPP) family is the addition of multiple transmission and reception antennas at one transmitting or receiving side or both for improving data throughput and network quality of service (QoS). This paper addresses the impact of employing MIMO in LTE base stations on coexistence requirements of deploying LTE cells in the band 2.6 GHz. Based on the developed coexistence model and simulation results, the adoption of MIMO can dramatically increase separation requirements, and therefore requires more careful site engineering and isolation measures to ensure peaceful coexisted systems.

Keywords: *LTE, MIMO, coexistence, collocation, inter-cell interference, interference threshold*

1. Introduction

Long Term Evolution (LTE) of Universal Mobile Telecommunications System (UMTS) enables operators to provide a high throughput and low latency experience [1]. When deploying LTE networks, various spectral and deployments possibilities are available. Nevertheless, a key concern when deploying a new network is frequency spectrum. It can be the scarcest and most expensive commodity among all radio assets, and can have an enormous impact on network strategy and performance. From LTE standpoint, spectrum allocations have been reported in [2]. Generally, those allocations offer operators wide range of choices depending on their country options and regulations. Chances exist for wireless operators to use different frequency blocks to match their technology business case. They, spectra, can enable various technologies to coexist in the same frequency band. This can yield a coverage advantage at lower frequencies with better transmission characteristics.

One frequency band that has gain great momentum from wireless operators in general and LTE-centric operators in particular is (2500-2690) MHz frequency band [3]. The band, which is also referred to as 2.6 GHz band, has encountered huge global LTE deployments due to its generous spectral choices, as shown in Figure 1 [4]. Due to its enormous deployments worldwide, LTE is by far the fastest growing cellular technology ever known [5].

Main issue encountered when deploying LTE networks is coexistence and/or collocation problem, that is, inter-cell interference between LTE technologies themselves or between LTE and other co-sited technologies, such as UMTS [6]. This has been addressed in quite a lot of literature inputs [4], [7–12]. Nonetheless, as LTE is new emerging technology currently being deployed globally, many radio aspects impacting LTE coexistence/collocation conditions have not yet been covered [13], and MIMO is one of those that their effect on LTE deployments needs to be investigated and modeled [14].

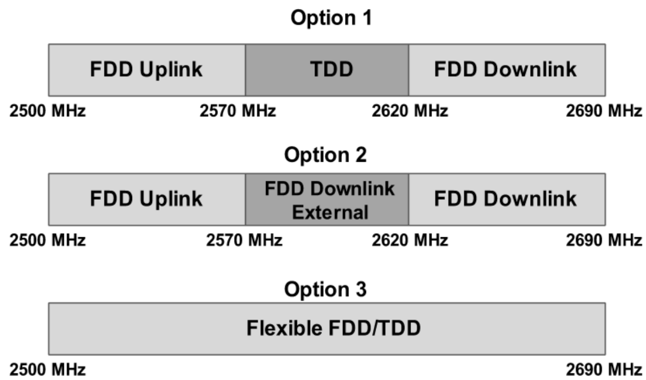

Figure 1. LTE Deployment Choices in 2.6 GHz Band

This paper aims at addressing the impact of employing MIMO in LTE base stations on coexistence and/or collocation requirements. Towards achieving its objectives, this work is organized as follows: Section 2 gives a closer look into LTE inter-cell interference sources and scenarios in the band 2.6 GHz. Section 3 then embarks on the mathematical modeling of inter-cell interference and its associated parameters, including MIMO weighting parameters. Interference protection or threshold criteria in LTE system is then determined in Section 4. LTE systems parameters employed in the present article are explained in details in Section 5, followed by simulation results and discussions of the main characteristics if LTE deployments in 2.6 GHz band in Section 6. A recap of its findings is presented in the conclusions section.

2. Interference Sources and Scenarios

Inter-cell interference usually relates to the ability of a system in one part of the RF spectrum to co-exist with other cells on different channels in the same RF band [15, 16]. In some cases, inter-cell interference may occur between two cells using the same channel(s), or it may occur between two cells in different bands. This work mainly considers cells using different channels in the same RF band, though similar analysis can apply to co-channel scenarios, or scenarios in different bands.

Also, this work focuses mainly on line-of-sight interference, particularly between base stations. Most other inter-system interference scenarios are more statistical in nature, and usually will not come into play unless base to base interference has been reduced or eliminated. And, solving base to base interference may remove other interference scenarios as well.

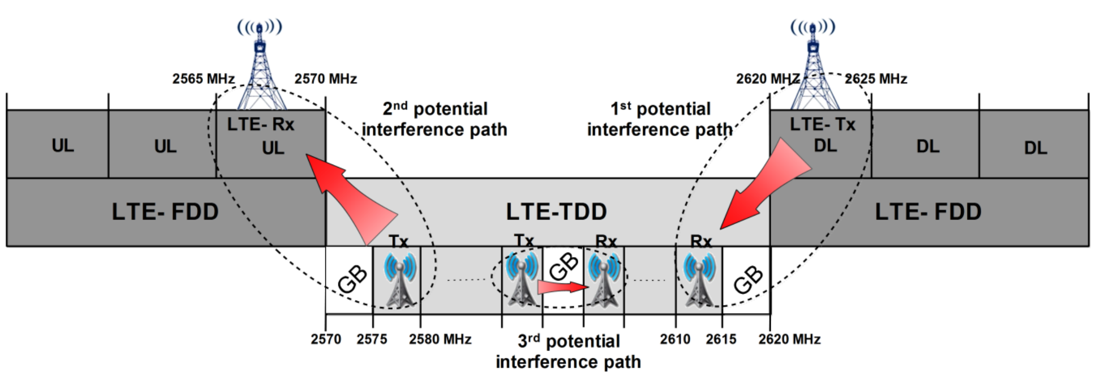

Figure 2. LTE Inter-cell Interference Scenarios within 2.6 GHz Frequency Band

Two main inter-cell interference properties can cause receiver desensitization. These can occur together or separately: Out-of-Band Emissions (OOBE) and receiver overload (such as blocking and inter-modulation).

OOBE is due to the transmission of a signal that extends beyond the intended channel, into the desired channel of a victim receiver. The strongest impact is usually on the immediately contiguous channels, formally referred to as adjacent channel interference (ACI). Nevertheless, some OOBE can occur for larger channel separations [17].

On the other hand, receiver overload includes things such as inter-modulation or blocking that occur within the receiver, due to large signals within the receiver front-end passband. These signals may be in or near the victim receiver's desired channel, but in other cases, they may be anywhere within the front end passband of the victim receiver [18].

3. Inter-cell Interference Modeling

In order to assess the inter-cell interference power incurred between LTE cells, the following analytical model is used:

$$I = P_{Tx} + G_{Tx} + G_{Rx} + 10Log(N) - ACIR - 32.4 - 20Log(f) - 20Log(d) - A_h \qquad (1)$$

Where I is the interference (dBm) transmitted from interfering cell to other victim ones, P is transmission power (dBm) of interfering cell, G_{Tx} and G_{Rx} are interferer transmitter and victim receiver antenna gains (dBi), respectively, N is the number of transmitting antenna elements employed by the interfering transmitter, f is radio frequency (MHz) of interfering transmitter, d is the distance (km) between interfering and victim cells, $ACIR$ and Ah are Adjacent channel interference power ratio and deployment environment clutter loss, respectively. The latter inputs are determined as follows:

Adjacent Channel Interference Ratio ($ACIR$) is the total leakage between two transmissions on adjacent channels, defined from Adjacent Channel Leakage Ratio ($ACLR$) and Adjacent Channel Selectivity (ACS) as follows [19]:

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}} \qquad (2)$$

The A_h is total losses owing to nearby clutter, and given by [20]:

$$A_h = 10.25e^{-d_k}\left[1 - \tanh\left[6\left(\frac{h}{h_a} - 0.625\right)\right]\right] - 0.33 \qquad (3)$$

Where d_k (km) is the terrestrial separation between nearby clutters and interfering antenna, h_a and h are the nominal clutter height and interferer antenna height, respectively, as shown in Table 1 [20].

Table 1. Clutter Heights and Distances

Clutter Category	Clutter Height h_a (m)	Nominal Distance d_k (km)
Rural	4	0.1
Suburban	9	0.025
Urban	20	0.02
Dense urban	25	0.02

Figure 3 illustrates the correlation between clutter loss and antenna height for various environments, where the higher the antenna height is, the lower the clutter loss becomes.

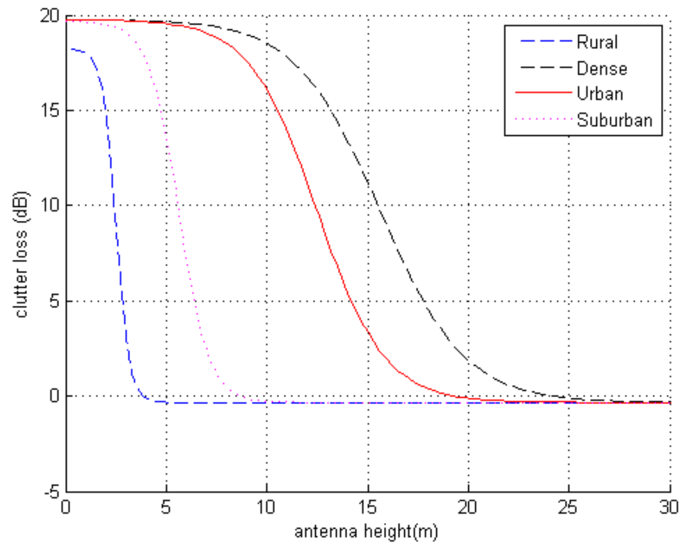

Figure 3. Clutter Losses per Antenna Height for Different Deployment Environments

4. System Degradation and Protection Criteria

System degradation is assessed by the degradation of receiver sensitivity (S). It is defined as the receiver sensitivity degradation due to external interference, and calculated as the noise rise due to the received interference [19]:

$$S = 10Log\left(\frac{10^{\frac{N}{10}} + 10^{\frac{I}{10}}}{10^{\frac{N}{10}}}\right) = 10Log\left(1 + 10^{\frac{I-N}{10}}\right) \quad (4)$$

Where S is degradation of receiver sensitivity (dB), I is the received interference (dBm) as defined in Eq. (1) and N is victim receiver noise floor (dBm), and it is determined as follows:

$$N = N_{thermal} + N_{figure} + 10Log(BW) \quad (5)$$

Where $N_{thermal}$ *and* N_{figure} are victim receiver thermal noise density (= -174 dBm/Hz) and noise figure (dB), respectively, and BW is receiver noise bandwidth (Hz).

For LTE, the following holds true:

$$N = -174\frac{dBm}{Hz} + N_{figure} + 10Log(12 \times 15000\ Hz \times RB) \qquad (6)$$

Where *RB* is number of victim receiver physical resource blocks. It is a system-specific constant, and equals 6, 25, 50, 75 and 100 for receiver bandwidths (1.4, 5, 10, 15 and 20) MHz, respectively.

According to 3GPP [19], LTE system can tolerate no more than 1 dB degradation in receiver sensitivity. Substituting (S=1 dB) into Eq. (4) and solving for (I), gives (I= N−6 dB). This value of I is referred to as the interference threshold (i.e., the received interference level the victim receiver can tolerate), and it is the benchmark we used to evaluate LTE compatibility scenarios.

5. LTE System Characteristics

For better understanding of simulation results, it is quite beneficial to embark on LTE systems parameters employed in this paper, as shown in Table 2. Initially, this work deals with the implication of using multiple antennas transmission system in LTE base station; therefore, antenna numbers of 1, 2 and 4 are considered here. From resource blocks (bandwidth) perspective, this work considers resource blocks numbers of 6, 25, 50 and 100 which corresponds to 1.4, 5, 10 and 20 MHz of victim receiver bandwidths. The interferer bandwidth, on the other hand, is maintained constant throughout simulation, namely 5 MHz.

Table 2. LTE System Simulation Parameters

System parameters		value
Frequency (GHz)		2.6 GHz
number of transmission antennas		1, 2 & 4
eNB transmission power (dBm)		43
eNB antenna gain (dBi)		17
eNB antenna height (m)		15
eNB noise bandwidth (No. of *RB*)		6, 25, 50 & 100
Receiver noise figure		5
ACLR(dB)	@ Co-channel	27.9
	@ offset 3.2 MHz	43
	@ offset 5 MHz	45
	@ offset 7.5 MHz	46.8
	@ offset 12.5 MHz	49
ACS(dB)	@ Co-channel	16
	@ offset 3.2 MHz	31.1
	@ offset 5 MHz	33
	@ offset 7.5 MHz	34.8
	@ offset 12.5 MHz	37

The *ACLR* and *ACS* values in Table 2 are derived using the methodology and spectrum emission masks reported in [8, 17, 19]. The derived values are for: Cochannel, 5 to 1.4 MHz, 5 to 5 MHz, 5 to 10, and 5 to 20 MHz interference scenarios, respectively, in which 1.4, 5, 10 and 20 MHz correspond to victim receiver bandwidths. In fact, these values designate the spectral leakage characteristics of both interfering and receiving sides. Both values are then combined into one comprehensive value, i.e. *ACIR*, as defined in Eq. (2). The offsets in Table 2 refer to carrier-to-carrier frequency separation (or offset). Furthermore, it is worth mentioning that *ACIR* is governed by the lowest value of either *ACLR* or *ACS*.

6. Results and Discussions

This section embarks on system simulation results and discussions. We start with collocation requirements for single and two antennas, we then discuss coexistence requirements for 1, 2 and 4 antennas, showing the impact of multiple antennas in terms of geographical separations along with interference-to-noise power ratios.

6.1. Co-location Scenario

When two LTE cells collocated (or co-sited) in the same geographic area, the effect of adding MIMO on collocation requirements is quite vivid, and additional isolations have to added, as shown in Tables 3 and 4. For both Tables, Eq. (7) is used to find the required isolations for different carrier-to-carrier frequency offsets:

$$Add_{iso} = P_{Tx} + 10Log(N) - L - ACIR - N + 6 \tag{7}$$

Where Add_{iso} is the additional isolation (dB) required for LTE cells to coexist, P_{Tx} is interfering transmitter power (dBm), L is the coupling loss; which is 30 dB [19], *ACIR* is defined in Eq.(1), N is defined in Eq.(5), and 6 is the sharing criterion chosen for this type of study [14].

One can figure out that additional isolations for 2 antennas cells is almost double those for 1 antenna. This is true since each added antenna will add up to the total interference power, as determined in Eq. (7). Also, notice that the bigger the carrier frequency offsets, the less the required isolation.

Table 3. Additional Isolation Requirements (2 antennas used)

System parameter	Carriers offset (MHz)				
	0	3.2	5	7.5	12.5
Transmitter power (dBm)	43				
Coupling loss (dB)	30				
ACIR (dB)	15.7	30.8	32.7	34.5	36.7
Additional isolation (dB)	108.75	99.85	91.7	86.9	81.7

Table 4. Additional Isolation Requirements (1 antenna used)

System parameter	Carriers offset (MHz)				
	0	3.2	5	7.5	12.5
Transmitter power (dBm)	43				
Coupling loss (dB)	30				
ACIR (dB)	15.7	30.8	32.7	34.5	36.7
Additional isolation (dB)	105.74	96.84	88.7	83.9	78.7

6.2. Coexistence Scenario

Figures 4-7 denote the impact of multiple antennas on coexistence requirements of two LTE cells operation in 2.6 GHz frequency band. The requirements are derived with interference threshold of (-6 dB) in mind. From Figures, it can be noted that increasing the number of antenna elements at LTE base station gives rise to increased terrestrial separation.

In Figure 1, separations of 135 km, 187.5 km and 266 km are required for two LTE cells of 1, 2 and 4 antenna elements, respectively, to coexist peacefully. Similarly, other coexistence scenarios behave in the same manner, as in Figure(s) 5-7.

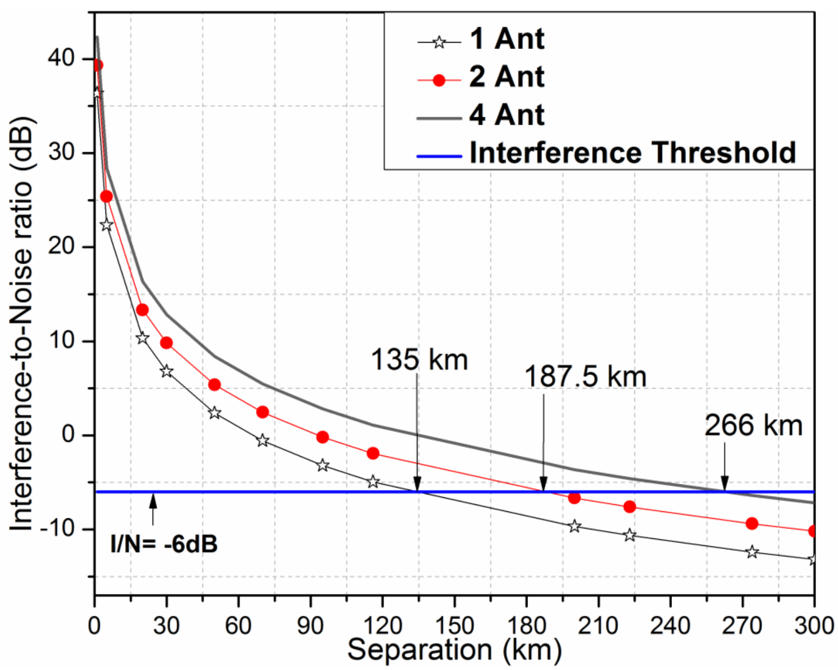

Figure 4. Multiple Antennas Effect on LTE Coexistence Requirements in Band 2.6 GHz (5 to 1.4 MHz interferer to victim bandwidth scenario)

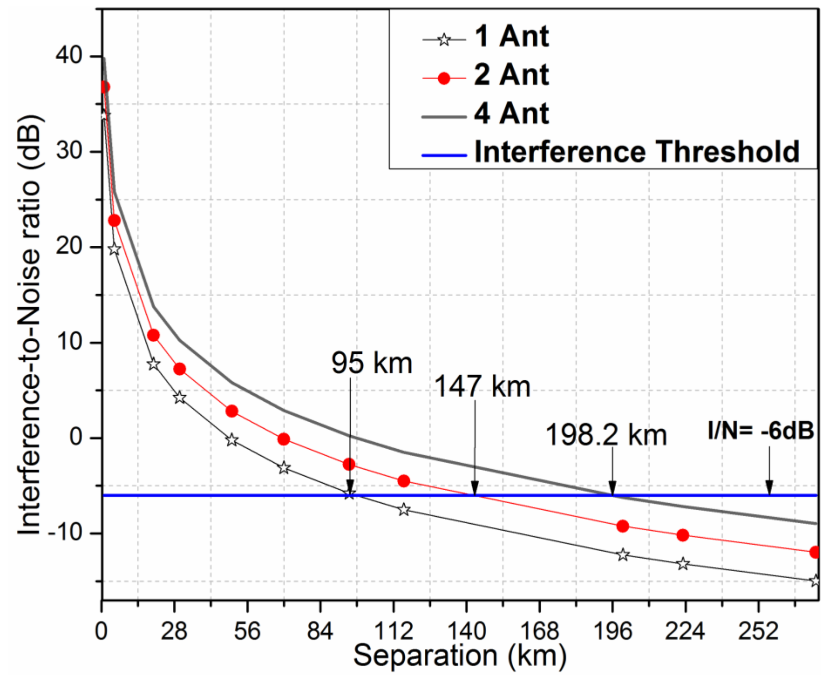

Figure 5. Multiple Antennas Effect on LTE Coexistence Requirements in Band 2.6 GHz (5 to 5 MHz interferer to victim bandwidth scenario)

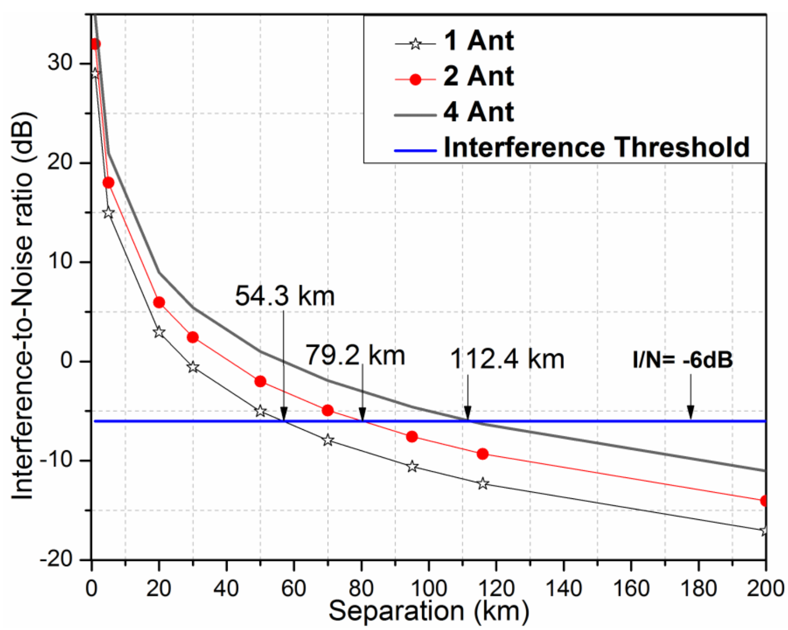

Figure 6. Multiple Antennas Effect on LTE Coexistence Requirements in Band 2.6 GHz (5 to 10 MHz interferer to victim bandwidth scenario)

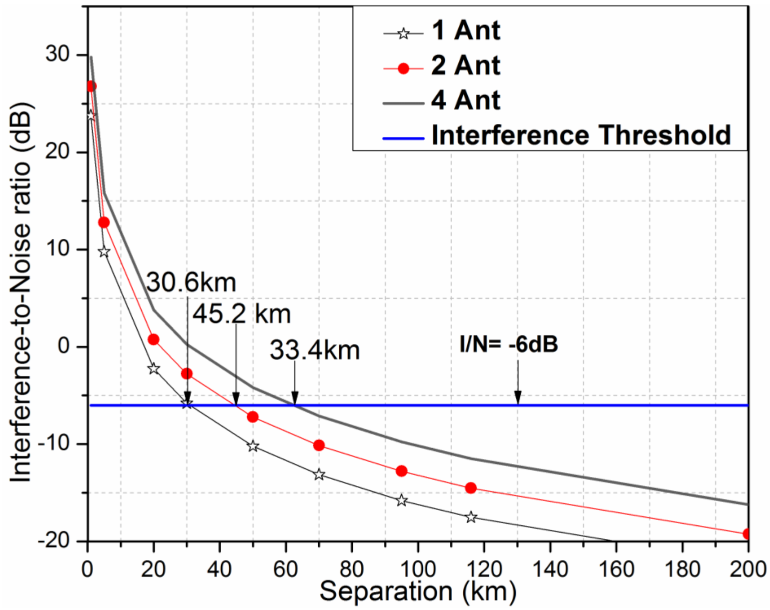

Figure 7. Multiple Antennas Effect on LTE Coexistence Requirements in Band 2.6 GHz (5 to 20 MHz interferer to victim bandwidth scenario)

7. Conclusions

LTE is being deployed in frequency spectra that allow multiple types of access technologies: TDD with different transmit / receive duty cycles for different systems; FDD; and broadcast. This technology blend presents co-existence challenges that differ from previous cellular bands. In this paper, the impact of employing multiple antennas at LTE base stations on inter-cell interference has been analyzed and modeled. Additionally, coexistence and collocation requirements of LTE systems have accordingly investigated and set. It has been shown that MIMO addition will impact isolation requirements by up to $10 \times \text{Log}(N)$ dB, where N is the number of antenna elements used in cells.

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