

COEXISTENCE AND SHARING STUDIES OF COLLOCATED AND NON- COLLOCATED FOURTH GENERATION NETWORKS IN THE 2.6 GHZ BAND

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ABSTRACT

Lots of fourth generation (4G) wireless networks are currently being deployed globally with similar or with dissimilar technologies in various operating bands. In this paper, spectrum sharing and coexistence scenarios of the 4th generation networks in the band (2500-2690) MHz are addressed. Interferences from Long Term Evolution (LTE) to Worldwide Interoperability for Microwave Access (WiMAX) systems and vice versa are carefully investigated. The collocation and coexistence requirements in terms of separation requirements as well as additional isolations are fully addressed. Interference measures of the two systems as functions of adjacent channel interference power ratios are also considered. Finally, the impact of deployment morphologies of the two systems is accounted for by catering for losses due to surrounding clutter.

Keywords: *Coexistence, Collocation, LTE, WiMAX, Isolation requirements, Adjacent Channel Interference Ratio (ACIR)*

1. INTRODUCTION

The 2500-2690 MHz band (or sometimes referred to as 2.6 GHz band) is one of the various bands defined by the International Telecommunication Union (ITU) for operations of International Mobile Telecommunications (IMT) cellular networks [ref]. The ITU definition of the band 2.6 GHz comes in three options to best suit operators' needs, as depicted in Fig.1 [1]. Notably, option 1 is being the target for most wireless operators and, therefore, of the biggest momentum among others [1]. The two most anticipated technologies to be deployed in this band are Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX). These are, nevertheless, based on dissimilar duplex schemes: LTE globally employs Frequency Division Duplex (FDD), whereas WiMAX mostly promotes Time Division Duplex (TDD). This, remarkably, puts forward the key issue of coexistence and collocation.

From the standpoint of relevant literature, there have been plenty of studies addressing coexistence issues of LTE and other systems. In [2-7], coexistence studies of LTE with Global System Mobile (GSM), Universal Mobile Telecommunications System (UMTS), radars, and

LTE networks, respectively, in various duplexing schemes. Coexistence studies of LTE and WiMAX was discussed in [8], [9]. However, for the most part, the main focus of those studies was Quality of Service (QoS) degradations of the disturbed victims and their capacity losses due to the interference of either collocated or non-collocated LTE systems. This paper, however, brings forward necessary isolations requirements when LTE system coexists with WiMAX one in various carrier-to-carrier frequencies offsets and geographical separation choices. The impact of guard bands is also considered.

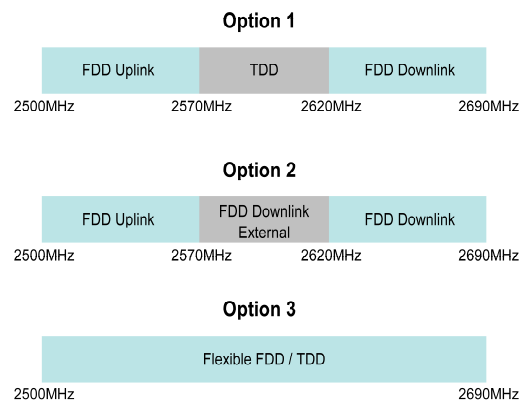


Fig. 1. ITU Options for the 2.6 GHz Band

Towards fulfilling its purposes, this paper is organized in the following way: section 2 embarks on collocation and coexistence- characteristics, differences and deployment merits; interference scenarios and models are covered by sections 3 and 4, respectively, coexistence enabling measure is shown in section 5, and finally; sections 6 through 10 cover analyses, systems descriptions, results, and conclusions, respectively.

2. COLLOCATION AND COEXISTENCE

Co-location, or co-siting, is a comprehensive concept that refers to a so-called multi-station site comprising of several transmitters and receivers located within the bounds of a limited geographical area. The site generally corresponds to a number of antennas that are all mounted on one mast or spread among a small number of closely placed masts.

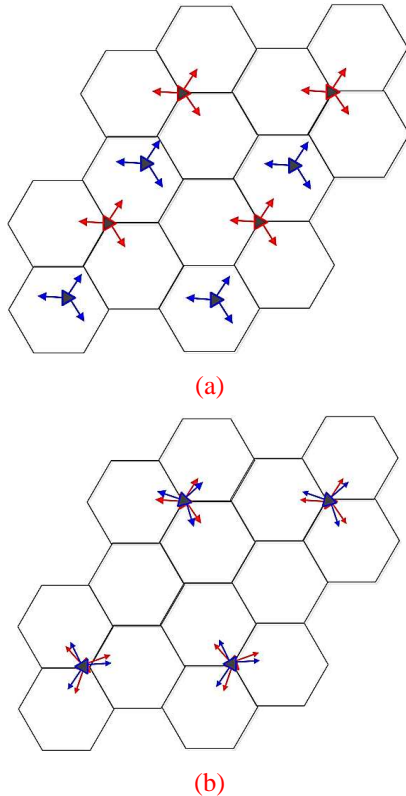


Fig. 2. (a) Co-existence (b) co-location.

Co-existence, on the other hand, is that LTE sites, for instance, and WiMAX sites are in the same geographical area, but not co-located.

The co-location of radio stations may give rise to significant interference if not preceded by pre-studies and careful planning. In spite of the risk of interference, the co-location of radio stations has

some advantages and is occasionally inevitable for the following reasons:

- Operator can reuse the resources of old sites and reduce the cost for building new networks;
- operator can reuse the legacy network drive test and optimization results and take as a reference to new evolving ones;
- the characteristics of certain geographical locations are such that they are perceived as being attractive from a radio coverage point of view, for example locations that are situated high above the surrounding areas that already have existing masts;
- larger radio systems may often be made up of numerous stations that must be co-located
- for reasons such as the achievement of optimal resource utilization, such as road networks, electrical power and maintenance;
- for one reason or another, the licensing agency refuses to grant permission for the new construction of a mast and refers the applicant to use existing masts for the new radio users.

3. INTERFERENCE SOURCES AND SCENARIOS

The collocation and coexistence of more than one base station may give rise to interference between the transmitters and the receivers. The source of the interference experienced by one of those receivers may be one or more of the other receivers or transmitters, which is most common. Generally, intersystem interference between radio stations may be subdivided into two main groups: a) interference between different systems that employ the same radio frequency, i.e. cochannel, and b) interference between different systems that use different radio frequencies, e.g. adjacent channels.

Interference between different systems that utilize the same radio frequency is usually corrected by the governmental agencies whose responsibility it is to assign frequency bands. On the other hand, interference between different networks that operate using different frequencies is the result of deficiencies in radio equipment or is due to the predominance of a high-power signal that interferes with a receiver that expects a signal of a comparatively lower power level. One condition for

the occurrence of interference is the result of, among many other factors, a sort of "collaboration" between the transmitter's and the receiver's secondary characteristics, i.e., other attributes over and above the attributes that were designed into the equipment in order that they fulfill their intended function.

Stated simply, equipment imperfections always exist and may therefore lead to situations in which the transmitted power of frequencies that lie outside of the transmitter's nominal frequency may reach receivers that are sensitive to frequencies that lie outside of their nominal reception frequencies. The collaboration mentioned above refers to a certain amount of correspondence between the "other" frequencies of the transmitter and the "other" sensitivities of the receiver. In this paper, this type of interference will be addressed in terms of Adjacent Channel Interference power Ratio (ACIR), which is the total leakage between two transmissions on adjacent channels. It consists of the following parts: Adjacent Channel Leakage Power Ratio (ACLR) which is the ratio of the filtered mean power centered on the assigned channel frequency to the filtered mean power centered on an adjacent channel frequency, as shown in Fig.2, and Adjacent Channel Selectivity (ACS) which is a measure of the receiver ability to receive a wanted signal at its assigned channel frequency in the presence of an adjacent channel signal, as shown in Fig.2. In linear domain, the ACIR is expressed as follows [10]:

$$ACIR = \frac{ACLR.ACS}{ACLR + ACS} \quad (1)$$

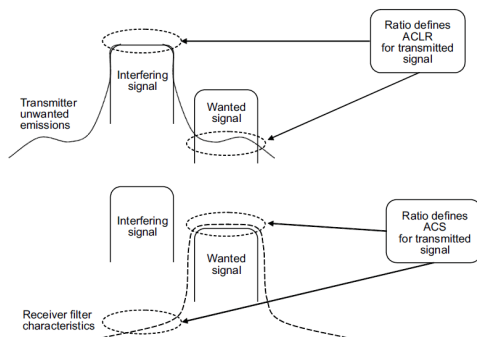


Fig. 3. Descriptions of ACLR and ACS

When two systems are collocated or deployed in the same geographic area, harmful interference that can degrade system performance may occur between them: Base station (BS) - to-base station, BS-to-User equipment (UE), UE-to-BS, and UE-to-UE.

The interference between BS(s) is vastly deterministic, while the interference between the UE(s) or between BS(s) and UE(s) is statistical due to mobility of the UE. Accordingly, this paper only deals with BS-to-BS sharing scenarios.

As shown in Fig. 3, two spectrum sharing scenarios are considered in this paper: LTE (BS)-to- WiMAX (BS) and WiMAX (BS)-to- LTE (BS). Obviously, this is option 1 of ITU's 2.6 GHz band sharing plan (see Fig 1) where an LTE FDD-centric network is (1st) collocated and (2nd) coexisting with other WiMAX TDD-based network. Both systems' parameters are tabulated in Tables 2 & 3, respectively.

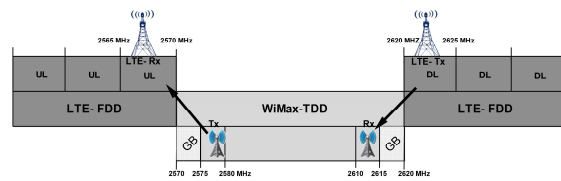


Fig. 4. Interference scenarios between networks.

4. INTERSYSTEM INTERFERENCE MODEL

The intersystem interference power (I) can be expressed as follows:

$$I = P_{Tx} + G_{Tx} + G_{Rx} - ACIR - PL - A_h \quad (2)$$

Where I is interferer transmitter power (dBm), G_{Tx} and G_{Rx} are interferer transmitter and victim receiver antenna gains (dBi), respectively, ACIR is defined in (1), PL is the pathloss (dB) from [11], and A_h is loss (dB) due to protection from local clutter (i.e. clutter loss), and is given by [12], [13]:

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

Where dk (km) is the distance from surrounding clutter to the antenna, h is the transmitter antenna height (m) above local ground level and h_a (m) is the nominal clutter height above local ground level. In [12], clutter losses are estimated for different environments, namely; dense urban, urban, suburban and rural. Clearly, higher antenna heights give rise to corresponding lower clutter losses, as shown in Table 1.

Table 1. Nominal 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 |

5. INTERFERENCE PROTECTION CRITERIA

The term *interference protection criteria* is used extensively in interference-limited scenarios to impart allowed interference levels at the victim receiver input. In general, interference is acceptable if and only if it does not deteriorate the victim receiver performance below a definite threshold [14]. According to the work in [12–14], 1 dB escalation in receiver noise floor caused by unwanted signal of 10 dB below victim receiver noise floor is a sufficient criterion for two systems to coexist, as depicted in Fig.5.

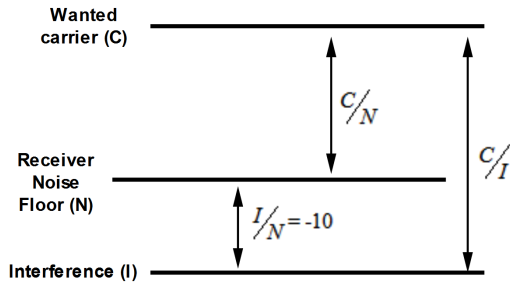


Fig. 5. Interference protection criteria

Consequently, the difference in dB between received interference and victim receiver noise floor must equal -10 dB, as expressed below:

$$I - N \leq -10 \quad (4)$$

Where I is interferer received power (dBm) as expressed in (2) and N is victim receiver thermal noise, and found as follows:

$$N = 10\log(K \times T \times BW) + NF \quad (5)$$

Where K is Boltzmann's constant (J/k), T is the temperature in Kelvin, BW is the receiver noise bandwidth (Hz) and NF is the noise Fig. (dB) of the receiver. Equation (5) can be re-written for an LTE receiver noise bandwidth as follows:

$$-174 + 10\log(12 \times 15000 \times RB) + NF \quad (6)$$

Where RB stands for Resource Blocks per receiver bandwidth, i.e. 6, 15, 25, 50, 75 and 100 resource blocks for receiver bandwidths of 1.4, 3, 5, 10, 15 and 20 MHz, respectively.

6. LTE AND WIMAX SYSTEMS CHARACTERISTICS

To begin with, both LTE and WiMAX systems parameters need to be defined. Tables 2 and 3 list LTE evolved node B (eNodeB) and WiMAX base station specifications, respectively [10], [15]. For comparable performance, the powers, noise Figures, bandwidths, antenna heights and gains of both systems are chosen identical to each other. This is acceptable since both technologies are relatively identical in terms of transmission peculiarities [16], [17].

The 3rd Generation Partnership Project (3GPP) LTE is currently the fastest growing 4G cellular technology in the world [18]. Its underlying PHY layer caters for 300 Mbps data rate in the downlink and 75 Mbps in the uplink. This is fundamentally ascribed to its scalable bandwidth support of (1.4-20) MHz that corresponds to (6-100) Resource Blocks (RB) of transmission entities [19]. Table 2 tabulates LTE parameters used in this study.

Table 2. LTE system parameters

| System parameters | value | |
|-----------------------------------|-------------------------|----|
| Transmission frequency (MHz) | 2622.5 | |
| eNodeB transmission power (dBm) | 43 | |
| Antenna coupling loss (dB) | 30 | |
| eNodeB antenna gain (dBi) | 17 | |
| eNodeB antenna height (m) | 15 | |
| eNodeB noise bandwidth (MHz) | 4.5 | |
| eNodeB receiver sensitivity (dBm) | -102.47 | |
| Receiver noise Fig. | 5 | |
| ACLR(dB) | @ carrier offset 5 MHz | 45 |
| | @ carrier offset 10 MHz | 48 |
| | @ carrier offset 15 MHz | 50 |
| ACS(dB) | @ carrier offset 5 MHz | 33 |
| | @ carrier offset 10 MHz | 36 |
| | @ carrier offset 15 MHz | 38 |

In parallel to LTE, WiMAX features more or less the same transmission characteristics of LTE with little architectural distinctions [20]. Table 3 lists WiMAX transmission parameters employed in this study.

Table 3. WiMAX system parameters

| System parameters | value | |
|-----------------------------------|-------------------------|------|
| Transmission frequency (MHz) | 2577.5 | |
| eNodeB transmission power (dBm) | 43 | |
| Antenna coupling loss (dB) | 30 | |
| eNodeB antenna gain (dBi) | 17 | |
| eNodeB antenna height (m) | 15 | |
| eNodeB noise bandwidth (MHz) | 4.5 | |
| eNodeB receiver sensitivity (dBm) | -102.47 | |
| Receiver noise Fig. | 5 | |
| ACLR(dB) | @ carrier offset 5 MHz | 53.5 |
| | @ carrier offset 10 MHz | 66 |
| | @ carrier offset 15 MHz | 68 |
| ACS(dB) | @ carrier offset 5 MHz | 70 |
| | @ carrier offset 10 MHz | 70 |
| | @ carrier offset 15 MHz | 74.7 |

Table 4. Collocation requirements of LTE-to WiMAX interference scenario

| System parameter | Carriers offset (MHz) | | |
|---------------------------|-----------------------|------|------|
| | 5 | 10 | 15 |
| Transmitter power (dBm) | 43 | | |
| Coupling loss (dB) | 30 | | |
| ACIR (dB) | 45 | 48 | 50 |
| Additional isolation (dB) | 60.5 | 57.5 | 55.5 |

7. RESULTS AND DISCUSSIONS

In this section, collocation and coexistence requirements of LTE system, whose parameters are tabulated in Table 2, with another WiMAX network, whose parameters are listed in Table 3, are fully investigated. Two possible deployment scenarios are addressed here; collocated and coexisted BS(s). Furthermore, additional coexistence requirements for the two different systems to coexist when existing isolation measures are no more viable are discussed in subsection 7.3.

7.1 Results Of Collocated Systems

Table 4 imparts additional isolation requirements when LTE eNodeB is collocated with another WiMAX BS. In this case, LTE eNodeB is the intruder, while WiMAX BS is the interference receiver. Eq. (7) is used to find required isolations for different carrier-to-carrier frequency offsets, i.e. 5, 10 and 15 MHz.

$$Add_{iso} = P_{Tx} - CL - ACIR - N - 10 \quad (7)$$

Where Add_{iso} is the additional isolation (dB) required for LTE eNodeB and WiMAX BS to coexist, P_{Tx} is interfering transmitter power (dBm), CL is the coupling loss; which is 30 dB, $ACIR$ is defined in Eq.(1), N is defined in Eq.(5), and 10 is the sharing criterion chosen for this type of study [14].

Here, it can be seen that 60.5 dB is needed for 5 MHz carrier-to-carrier separation, while isolation of 55.5 dB is enough to meet collocation requirements of 15 MHz carrier-to-carrier offset.

Similarly, additional isolation due to the interference from WiMAX BS to LTE eNodeB are shown in Table 5; where needed isolations become smaller as carrier-to-carrier offsets become bigger. Interestingly, isolation requirements when WiMAX BS is the source of interference (Table 5) are remarkably larger than those when LTE is the interferer (Table 4). This is mainly ascribed to WiMAX's relatively high ACLR values compared to LTE's ones. Additionally, it is worth noting that ACIR values generally tend to follow the lowest of its elements, i.e. ACLR or ACS; LTE's ACLR is the smallest in this case.

Table 5. Collocation requirements of WiMAX-to-LTE interference scenario

| System parameter | Carriers offset (MHz) | | |
|---------------------------|-----------------------|-------|------|
| | 5 | 10 | 15 |
| Transmitter power (dBm) | 43 | | |
| Coupling loss (dB) | 30 | | |
| ACIR(dB) | 33 | 36 | 38 |
| Additional isolation (dB) | 72.5 | 69.47 | 67.5 |

7.2 Results Of Coexisting Systems

Initially, when it comes to coexistence with other evolving or legacy networks, terrestrial separation is operator's first choice. It turns out that careful geographical isolations can be quite cost-efficient solutions without the need to resort to man-made isolation requirements. Nevertheless, certain situations necessitate artificial coexistence solutions as terrestrial ones are unfeasible or impossible to implement due to deployment constraints.

Figure 6 illustrates required separation requirements when WiMAX is the victim of interference from LTE, and Fig.7 when LTE is the victim of WiMAX unwanted emissions.

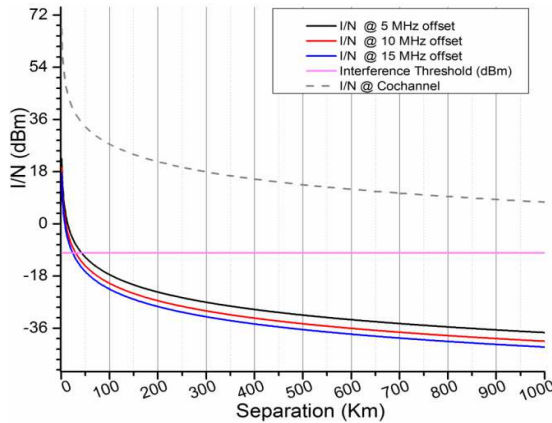


Fig. 6. Separation requirements due to LTE to WiMAX unwanted emissions

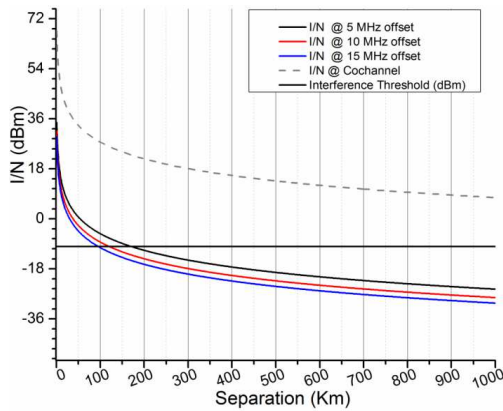


Fig. 7. Separation requirements due to WiMAX to LTE unwanted emissions

As seen in Sec.5, $(I/N = -10)$ is chosen as the coexistence enabling criteria for 4G networks. Interestingly, coexistence requirements applied in the case of (LTE-to-WiMAX) interference scenario are much more relaxed than (WiMAX-to-LTE) interference constraints. This is valid since LTE unwanted emissions are fairly more contained than WiMAX unwanted transmissions transmits. Furthermore, it can be seen from the figures above that 5 MHz of carriers offset between the two systems requires the two to be more separately placed than larger offsets such as; 10 or 15 MHz.

7.3 Results Of Additional Isolations

Over time, capacity and coverage requirements of networks evolve and become more intricate as the number of users increases. In this case, initial isolation requirements (as discussed in subsection 7.2) are no more viable or adequate to keep the network entity from being disturbed by another coexisting one. Such situations require additional isolation constraints for both systems to coexist.

Fig. 8 shows additional isolation requirements when LTE eNodeB coexists with WiMAX BS. Here, these requirements are presented as functions of separation distances between the two relevant base stations, i.e. LTE and WiMAX. As can be seen in Fig.8, the smaller the carrier-to-carrier offset (MHz), the larger the separation required to maintain interference-free deployment. Moreover, the negative values in Fig. (s) 8 and 9 indicate degradation-free coexistence; meaning that systems can be deployed without the need to employ additional segregation measures due to sufficient geographic separations.

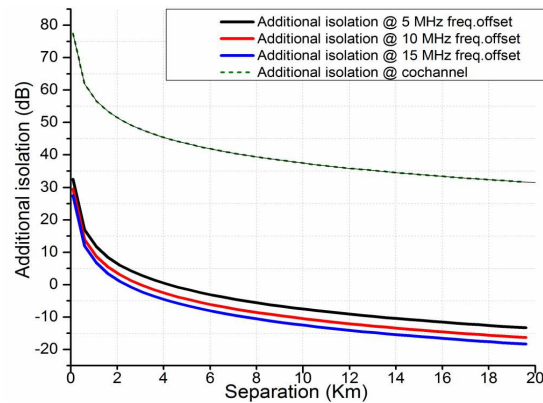


Fig. 8. Additional isolation requirements due to LTE to WiMAX unwanted emissions

Likewise, interference from WiMAX BS to LTE eNodeB is confined by the additional requirements in Fig.9. Notably, those restrictions are little bit more stringent than for LTE ones owing to high WiMAX's ACLR compared to low LTE's ACS levels.

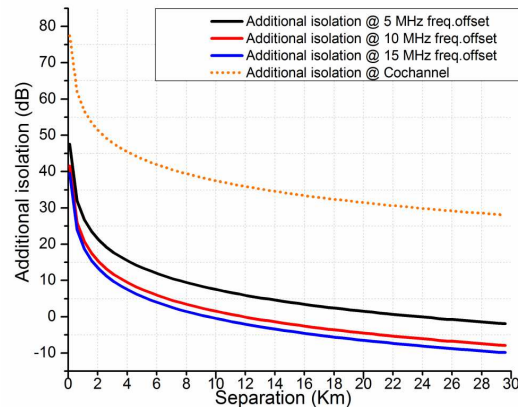


Fig. 9. Additional isolation requirements due to WiMAX to LTE unwanted emissions



8 CONCLUSIONS

System degradation may occur due to interference when LTE systems are collocated or coexisted with different mobile telecommunications systems including LTE. Collocation is when two or more base stations share the same site. Coexistence of deployed base stations means that the base stations have separate sites but share the same geographical area. This document presented terminologies, scenarios and measures required when LTE and WiMAX systems operate in the same geographical area. Based on above exposition, collocated deployment scenarios of the two systems appeared to be the most demanding type of deployment, in terms of interference-free requirements, compared to the coexisting ones. Finally, it has been shown that terrestrial offset is a major coexistence enabling factor along with improved ACLR and ACS values of both intruder and disturbed systems.

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