Digital Television Interference on the LTE System in the 700 MHz Band

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***Abstract*—Today, the coexistence of Long Term Evolution (LTE) systems operating in adjacent channel with Digital Television (DTV) in the 700 MHz band is under investigation. Many countries are using both technologies to provide respectively high capacity broadband connection and terrestrial television broadcasting. However, the interference between the systems may cause direct impact on their co-existence in the 700 MHz band. This work aims to provide a comprehensive study to evaluate the impact of the interference caused by DTV in the LTE system performance. We determine the minimum separation distance to ensure that LTE system can operate without suffering interference from DTV system. Moreover, we use Monte Carlo simulation to assess the impact of interference from different classes of DTV (Special, A, B and C) on LTE system. The results show that interference from Special class DTV may restrain the LTE channel capacity. On the other hand, the results show that the LTE capacity loss provoked by DTV interference may be significantly reduced if the separation distances between DTV tower and LTE base stations are respected.**

Keywords—DTV; LTE; Interference; coexistence.

I. INTRODUCTION

The old fashion analog television (ATV) broadcasting has found the end of its life cycle, e.g., in USA the shutdown happened in 2009. Today, the Digital Television (DTV) took place as the main television broadcast access medium in different parts of the globe. The migration from ATV to DTV has released a wide frequency band (689MHz – 806Mhz) called Digital Dividend (DD), which will be used by the mobile telecommunication operators to expand their services at providing higher capacity and guaranteeing more access to multimedia resources. Today, the DD is available for commercial usage and due to its propagation characteristics is considered an attractive alternative for allocating mobile broadband services (MBs) such as Long Term Evolution (LTE). For this reason, some countries such as Japan and the USA have already allocated the DD for MBs [1]. However, the allocation of MBs such as LTE in the DD band is a major concern for DTV and LTE services providers because such allocation may cause radio frequency interference (RFI) between the services resulting in performance reduction.

Currently, the problems caused by mutual interference between DTV and LTE have been intensively investigated by both sides, i.e. researchers [1][2][3][4] and frequency spectrum regulators from different countries [5][6]. In [1], the authors analyze the DTV interference impact in LTE system considering the Chinese DTV parameters. The results show that the LTE uplink may suffer greater impact of DTV interference. Paper [2] analyzes the coexistence between DTV and 10MHz bandwidth LTE system operating in the DD spectrum. The results show the decrease on the mutual interference in function of Adjacent Channel Interference Ratio (ACIR) and separation distances. In [3] the authors studied the interference that LTE system may cause on DTV and the results show that the DTV suffers less interference in rural environments than in urban environments. In paper [4] the co-channel interference between DTV and LTE systems is analyzed. The results of this study highlight that DTV transmit power and antenna height are key factors when determining the distance to protect LTE system.

Among the cited works, none of them analyzes simultaneously the interference between DTV and LTE systems considering different classes of DTV and different LTE operation bandwidths. In this study, we present a comprehensive analysis of the interference impact caused by DTV of classes Special, A, B and C in LTE system operating in adjacent channels with bandwidths of 5MHz, 10MHz and 20 MHz. In order to quantify the impact of the interference, we analyze the LTE channel capacity loss and the bit error rate (BER), which represents the ratio between the number of bits received in error and the total number of bits transmitted. The BER was computed applying QPSK modulation scheme. The results for the other modulation types, 16-QAM and 64-QAM will be presented in the future works. The investigation is performed through Monte-Carlo simulations. In this paper we intend to answer two questions:

- What is the minimum separation distance required between the systems (DTV and LTE) to operate in adjacent channels with satisfactory levels of performance?
- Does the antenna height of LTE base station matter to minimize the impact of DTV interference?

The remainder of this paper is organized as follows: Section II presents a brief overview of DTV and LTE systems. The math models are presented in Section III. Section IV presents the case study. Section V presents the results and finally, conclusions are presented in Section VI.

II. DIGITAL TELEVISION AND LONG TERM EVOLUTION SYSTEMS

Digital television (DTV) has brought respectively improvements in the quality of signal, i.e., audio and video, and new services such as Internet connection over smart TV that allows interactivity among users and services broadcasters [7].

DTV operates in the same frequency band as analog TV, Very High Frequency (VHF) and Ultra High Frequency (UHF) and depending on the implemented DTV class, i.e., Special class, class A, class B or class C, it may have a maximum coverage radius of 57 km, 42 km, 29km and 18 km, respectively. More details about DTV can be found in [8].

Figure 1 illustrates a DTV system composed by a transmitting tower (DTV-Tx) and user receiver (located at user premises). The antenna broadcasts the signal to all end-users, whereas the end-users, represented by the TV receivers (DTV-Rx), receive the signal transmitted. The distance (d) represents the distance between DTV and LTE towers, while the distance (R) is DTV coverage radius.

The Long Term Evolution (LTE) of Universal Mobile Telecommunication System (UMTS) is one of the latest steps in an advancing series of mobile telecommunications systems [9]. In the DD band, LTE will operate in a frequency range of 698 MHz up to 802 MHz with coverage radius of up to 35 Km [10]. Additionally, LTE system is able to provide maximum capacity of 50 Mbps and 100 Mbps on uplink and downlink, respectively and the LTE transmission bandwidth varies between 1.25 MHz and 20 MHz [11][12].

LTE networks have introduced a set of new technologies to improve the internet services, e.g., Orthogonal Frequency Division Multiple Access (OFDMA), Multiple Input Multiple Output (MIMO) and System Architecture Evolution (SAE). More details about LTE systems can be found in [11][12].

III. MONTE CARLO AND MATH MODELS

In the Monte Carlo (MC) simulation the LTE user equipment (UE) positions are varied according to a uniform distribution. Note that in this analysis the UE represents the LTE transmitter.

In order to assess the impact of DTV interference on LTE system we firstly calculate the maximum LTE capacity/ throughput (C_{max}) considering that the system operates without suffering any kind of external interference. The throughput is determined according to the Shannon formula that enforces a limit to the maximum transmission rate of the channel, according to (1):

$$C = B.\log_2\left(1 + SINR\right) \quad (1)$$

Where C is the LTE channel capacity (throughput) in Mbps and B is the LTE bandwidth in MHz. The Signal to Noise plus Interference Ratio ($SINR$) is calculated by (2):

$$SINR = \frac{P}{\left(CL + I + N_t\right)} \quad (2)$$

With P representing the Power transmitted by the LTE mobile; CL is the coupling loss and I is the total Power of the interference affecting the LTE system, which is given by (3):

$$I = I_{int} + I_{ext} \quad (3)$$

Where I_{int} corresponds to the power of internal interference among users of the LTE system and I_{ext} is the external interference power caused, in this case, by the interfering external system, DTV, given by equation 4.

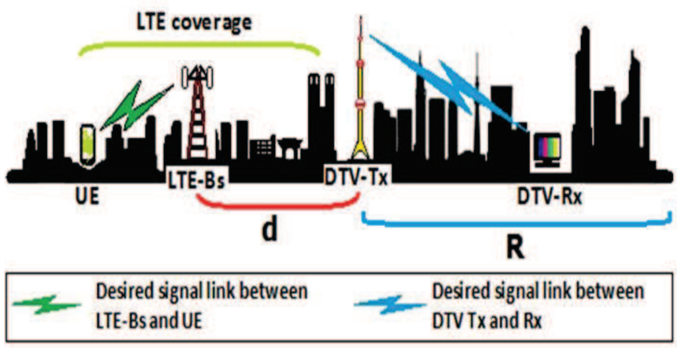

Fig. 1. Communication between end-users with LTE and DTV towers.

$$I_{ext} = \sum_{m=1}^{N_{ext}} I_{blocking}.I_{unwanted} \quad (4)$$

Where $I_{unwanted}$ and $I_{blocking}$ represent the interference power received by the interfered system, i.e., LTE, due to spurious emission and the signal blocking respectively. N_{ext} is the number of external systems that interfere with LTE. C_{max} is calculated according to (1), however, we must consider that LTE system is free of external interference, so that I_{ext} is equal to zero. Still in (2), N_t is the thermal noise of the LTE channel and is defined as follows (5) [13]:

$$N_t = 10^{\left[\frac{-174 + 10\log_{10}(N\ RBs) + NF}{10}\right]} \quad (5)$$

With N representing the number of the transmission resource blocks and RBs corresponds to the bandwidth of each resource block. NF is the noise figure of the interfered system receiver.

Having the LTE channel capacity we compute the LTE channel capacity loss using (6):

$$C_l(\%) = [(1 - \frac{C}{C_{\max}}).100] \quad (6)$$

Finally, the Bit Error Rate (BER) is computed through (7).

$$BER = \frac{1}{2}.erfc(\sqrt{(e_b / n_0)}) \quad (7)$$

Where $erfc$ represents the complementary error function [14] and e_b/n_0 is the energy-per-bit noise ratio witch is obtained by (8):

$$e_b / n_0 = \frac{2^{(C/B)} - 1}{2^{(SINR-1)}} \quad (8)$$

IV. CASE STUDY

In this section we introduce a case study to assess the interference from DTV on LTE system in urban scenarios, as illustrated in Figure 2. The LTE base stations (LTE-BS), also called eNodeBs, are installed inside the coverage area of DTV antenna and work transmitting and receiving signal from the end-users, represented by smartphone, through the link (L2), whereas the DTV transmitter is responsible to broadcast the desired signal for the respective receptor through the link (L1). Bidirectional arrows represent the transmission in both

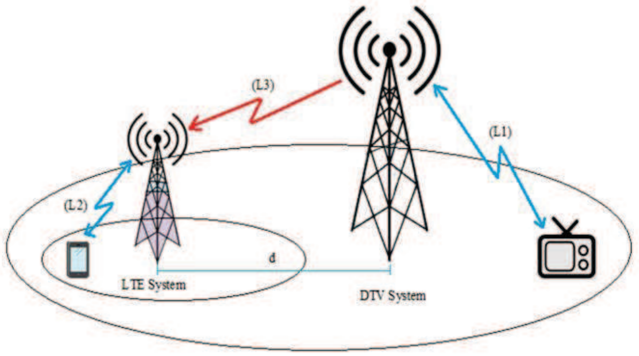

Fig. 2. Interference Scenario illustration.

directions, since DTV receivers (audience) interact with the services providers.

The eNodeBs are deployed within the DTV coverage radius (R) and share UHF spectrum separated by adjacent channel, i.e., 51 (692MHz-698MHz) and 52 onwards (698MHz 806MHz). The DD sharing may results in mutual interference between DTV and eNodeBs. In Figure 2, red link (L3) represents the interfering signal from DTV. This signal affects LTE system decreasing its performance.

In order to make sure that both systems will always be in the same geographic area the distance *d*, i.e., separating DTV transmitter and the nearest LTE base stations, varies from 1km up to 10km. In the LTE setup we assume the usage of LTE-BS having maximum connection capacity of 200 users per BS and operating in three bandwidths: 5 MHz, 10 MHz and 20 MHz.

TABLE I. SIMULATION PARAMETERS FOR LTE SYSTEM

Parameters	
Operation frequency	700 MHz (CH 52)
Number of sectors	3
BS Antenna height (m)	15, 20, 25, 30, 35, 40
BS Reseption gain	15 dBi
Number of UE per BS	200
UE height	1.5 m
Transmit power	23 dBm
Bandwidth	5, 10, 20 MHz
Coupling loss (CL)	70 dB
Noise figure (*NF*)	4 dB
Propation model	Extended Hata
Modulation	SC – FDMA (Uplink)

In the interfering system setup we considered four TV transmission classes: Special, A, B and C. Special class transmits the signal with a maximum power of 80 kW, on channels from 14 up to 46 and 100 kW on channels from 47 up to 68 in UHF band. The Special class respect the maximum contour service distance of 57 Km. The classes A, B and C transmit a maximum power of respectively 8 kW, 0.8 kW and 0.08 kW. Moreover, the classes A, B and C use channels from 14 up to 68, with the respectively contour distances: 42 km, 29 km and 18 km. All the simulation parameters for DTV and LTE systems can be found in Tables I and II.

In order to analyze the impact caused by the interference on different base stations antennas we varied the base station antenna height in a range from 15 up to 40 meters. Moreover, we assume that LTE system is fully orthogonal with no interference caused by frequency reuse, i.e., interference is equal to zero.

For analysis purposes, we defined a threshold of 43.2% for LTE capacity loss. Moreover, we assume that if capacity losses are over the threshold the signal transmission is not satisfactory, e.g., for LTE operating with 20MHz, the threshold is determined assuming a minimum data rate (C_{min}) of 50 Mbps [10]. In this case study, C_{min} corresponds to 56.8% of the maximum aggregate transmission rate (C_{max}) achieved during our simulations, which is about 88.0428 Mbps. Thus, the remaining 43.2% will correspond to the amount of losses. Therefore, 43.2% is assumed to be the loss threshold. Table III presents the maximum transmission rates and thresholds with respect to the LTE bandwidth.

TABLE II. SIMULATION PARAMETRES FOR DTV SYSTEM

Parameters		
Transmission gain	15 dBi	
Transmit power	Special class	80 dBm
	Class A	69.03 dBm
	Class B	59.03 dBm
	Class C	49.03 dBm
Antenna height	150 m	
Central frequency (MHZ)	695 (CH 51)	
Covarege radius	Special class	57 km
	Class A	42 km
	Class B	29 km
	Class C	18 km
Bandwidth	6 MHz	
Propagation Model	ITU-RP. 1546 LAND	

TABLE III. LTE TRANSMISSION RATES AND LOSSES

LTE bandwidth	C_{max} (Mbps)	Threshold (%)	Threshold (Mbps)
5 MHz	22.0107	43.2	12.5
10 MHz	44.0214		25.5
20 MHz	88.0428		50.0

V. RESULTS

The variation in the LTE antenna height did not cause any remarkable influence on the results. Therefore, in this section we present the curves obtained in the scenario having LTE-BS with 30 meters of height. The results of LTE system capacity loss, in percentage, as well as, bit error rate (BER) are presented.

Figure 3 shows the LTE capacity loss when the system suffers interference from a Special class DTV. The capacity loss is near to 100% for the three analyzed bandwidths (5MHz, 10MHz and 20MHz) when separation distance between the systems reaches 1km.

The loss threshold, which represents the requirement to the system to operate providing minimum capacity, is achieved at distances of 5.5 km, 5.1 km and 4.8 km for 5 MHz, 10 MHz and 20 MHz bandwidths, respectively. Furthermore, Figure 3 also shows that the LTE capacity loss only reaches zero when the separation distance between the systems is higher than 10km.

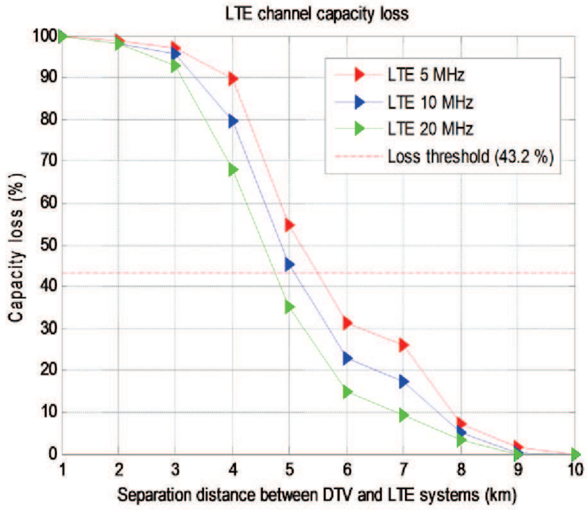

Fig. 3. LTE channel capacity loss due to interference from Special class DTV.

Figure 4 shows the LTE capacity loss caused by interference from DTV of class A. Comparing with the previous case we note a reduction of the LTE capacity loss, such reduction is mainly caused because Class A DTV operates in lower transmit power than Special Class. In Class A, the threshold for losses is reached when the separation distance between the systems is around 1 and 2 km. For the separation distances over 6 km the capacity loss remains zero percent, which means that for distance over 6 km the interference impact from a DTV of Class A is negligible.

Figure 5 shows the LTE capacity loss caused by interference from a DTV of class B. The LTE capacity loss caused by this class remains all the way below the threshold, regardless the separation distance between the systems. When the separation distance is over 3 km the capacity loss remains zero for the three analyzed bandwidths.

The last case, for class C, the LTE capacity loss caused by this class DTV is always zero regardless the separation distance between the systems. It occurs because of the very lower power transmitted by the DTV of class C.

The BER was analyzed for three different bandwidths 5 MHz, 10 MHz and 20 MHz. However, the curves showed a similar behavior, differing only in the value of BER which is relatively high for 5 MHz and 10 MHz. Figure 6 shows the

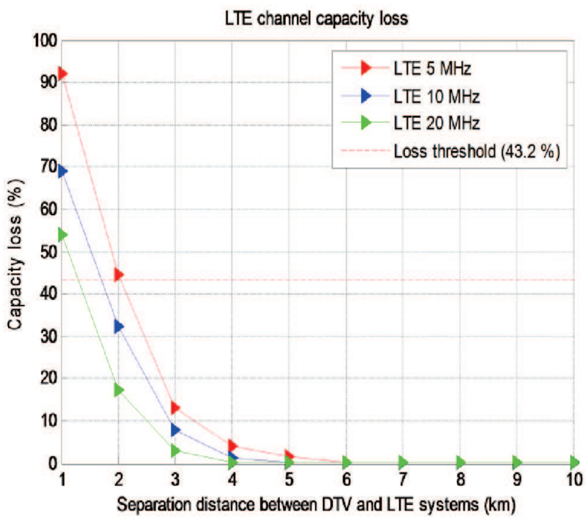

Fig. 4. LTE channel capacity loss due to interference from class A DTV.

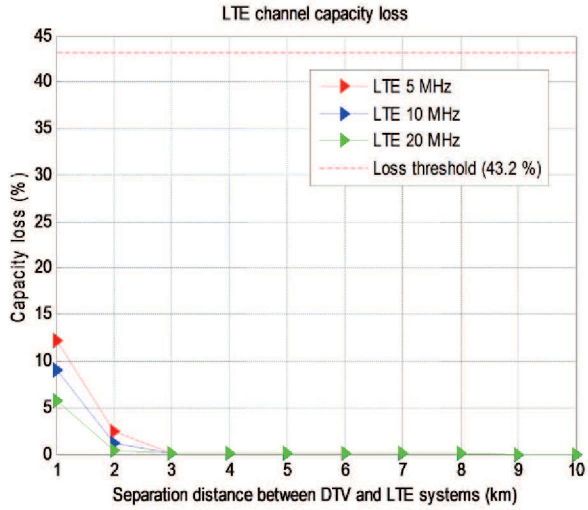

Fig. 5. LTE channel capacity loss due to interference from class B DTV.

BER in the LTE system operating with 20 MHz under interference of DTV of classes special, A, B and C. Moreover, this figure illustrates the BER as a function of SINR and separation distance. The Special class causes the higher interference on LTE, resulting in higher transmission error, while Class B and C do not cause any severe impact on LTE transmission allowing DTV and LTE to coexist in the same site. Finally, Class A causes considerable impact on LTE, which may not be neglected, but still allow the coexistence if the minimum separation distance is respected, i.e., 2km.

For all Classes the increase of separation distance between DTV and LTE towers results in increase of SINR and therefore reducing the interference impact, e.g., for Special class, which represents the worst case, the BER tends to a very small value when the separation distance of 10 km is achieved.

VI. CONCLUSIONS

This work presented a set of models to simulate the interference scenario between Digital Television (DTV) and LTE in 700MHz band, using Monte Carlo technique. We analyzed the interference from different classes of DTV on the LTE operating with different bandwidths, simultaneously. The results show that the LTE performance can be affected by interference from DTV in the 700 MHz band. The impact of this interference may result in transmission error and channel capacity losses of LTE system. However, this LTE capacity loss can be reduced in more than 90%, showing that the LTE system can operate with acceptable levels of performance since the adequate separation distances and bandwidths are respected.

Special class DTV has proved infeasible to be deployed in adjacent channel to the LTE system due to greater channel capacity losses and transmission errors that the interference from Special class causes on LTE. On the other hand, the DTV of classes B and C can be installed in the adjacent channel to LTE system, once the interference from DTV classes B and C is limited and the LTE capacity loss remains below the threshold or null. The LTE and DTV systems can coexist if Classes B and C are adopted, regardless the separation distance.

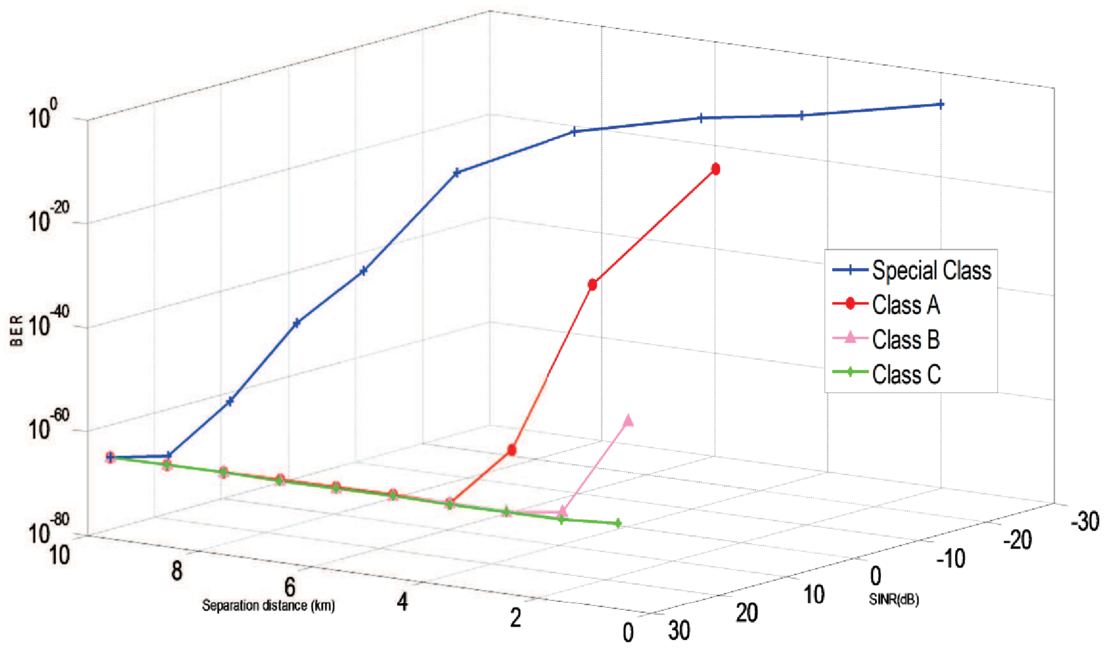

Fig. 6. BER for LTE system operating with 20 MHZ.

From our results, we conclude that the antenna height of the victim system (LTE) does not cause any major influence on the interference impact from DTV and the decrease of the DTV transmission power is one main key to reduce the interference between broadcast and broadband. Finally, we suggest for the operators to respect the minimum distance between DTV and LTE base stations aiming to reduce noisy and transmission errors.

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