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Performance evaluation of digital TV and LTE systems operating in the 700 MHz band under the effect of mutual interference

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***Abstract*— This paper presents results of the assessment of the interference between digital TV systems and LTE systems operating in adjacent bands in the 700 MHz frequency range. Measurement results are presented and used to validate a simulation tool that allows different scenarios of interference between the SBTVD systems and LTE to be created. The simulation tool was then used to analyze the probability of interference dependence on the distance between systems, transmission power, number of interferers and other parameters to allow the definition of conditions for the harmonious coexistence of the systems.**

***Index Terms*—** LTE, digital TV, Interference at 700 MHz.

I. INTRODUCTION

Most countries in the world are migrating terrestrial analogue television system to digital technology. With this change, parts of spectrum occupied by TV channels will be available for the use by wireless broadband communication systems [1]. The need for allocation of frequencies in the 700 MHz band for mobile broadband systems with LTE technology has motivated studies of potential interference between these systems and digital TV receivers using channels in adjacent bands.

In Brazil, laboratory tests with digital TV receivers were performed by ANATEL [2, 3] and field trials were conducted by Universidade Presbiteriana Mackenzie on behalf of the Brazilian TV Engineering Society (SET) [4, 5]. Federal University of Pará published results of simulations of interference between digital TV and LTE systems operating in adjacent channel on 700 MHz band [6]. Internationally, the GSMA group proposed different scenarios to assess the coexistence of TV systems (analog and digital) and LTE and presented some results [7].

The mutual interference between TV and LTE causes degradation of the performance of both systems. The LTE system interference on the digital TV receiver leads to degradation of the sensitivity, causing loss of signal decoding and, eventually, reducing the coverage of digital TV system. In the case of digital TV interference on the LTE system, the signal to noise plus interference ratio (SINR) will decrease, causing a reduction in the of data transmission rate, especially for LTE users near the digital TV transmitter [8].

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This paper presents the results of the field measurements of interference between digital TV and LTE systems performed in a controlled environment, as well as simulated results that will allow the identification of the conditions for the coexistence, in different scenarios, of these systems operating in adjacent frequency bands. In the field tests, the interference produced by the LTE system on digital TV receivers was evaluated by the subjective analysis of the image quality and the occurrence of artifacts (pixelation and freezing) following the criteria established in Rec. ITU-R 2035 [9]. The effects of the interference of digital TV on the LTE system were evaluated using a data traffic generator and measuring the uplink data rate (Mbps), the jitter (ms) and the packet loss (%).

The measured results were used to test and validate a simulation tool, the software SEAMCAT, to evaluate the interference between the LTE and digital TV systems operating in the 700 MHz frequency band. SEAMCAT [10] is a software simulation tool developed at the European Communications Office (ECO) within the frame of European Conference of Postal and Telecommunication administrations (CEPT). It permits statistical modelling of different radio interference scenarios for performing sharing and compatibility studies between radio communications systems in the same or in adjacent frequency bands. SEAMCAT produces random spatial and temporal distributions of desired and interference signals allowing the estimation, for different scenarios, the average values of signal levels, system throughput, jitter, package loss and the probability that the SINR is below an established threshold.

The validity of the use of the simulator was established by comparing its output for scenarios replicating the experimental setups with the measured results. It was found that the simulator meets the objectives of this type of analysis, allowing to extend the results of particular experiments to situations with a large number of users and interferes with random spatial distribution, that would be impossible to characterize experimentally. Hence, different scenarios of interference between the SBTVD systems and LTE were analyzed to assess the effects of the variations of distances and relative positions between systems, transmission powers of victim and interfering systems and frequency separation.

II. MEASUREMENTS CAMPAIGN

A. *Measurements setup*

In Brazil, digital TV systems are compliant to the ISDB-T_B standard, a variation of the Japanese ISDB-T standard that employs 6 MHz segmented channels and allows both the transmission to stationary and mobile receivers. The frequency separation between systems was defined based on the current allocation of TV channels and the proposed allocation for LTE systems in an adjacent band that will be employed when the full transition from analog to digital TV takes place. In the case of LTE radio base station (LTE RBS), there is a minimum gap of 60 MHz for the uppermost channel of the ISDB-Tb system, as shown in Figure 1. In this situation, the downlink of the LTE system (LTE-DL) should not cause harmful interference on digital TV receivers, due to the frequency offset. It is

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expected that the main cause of interference will be caused by the LTE uplink (LTE-UL), operating in the 703 to 748 MHz, on the channels 51 of the digital TV system, as the guard band in this case is only 5 MHz.

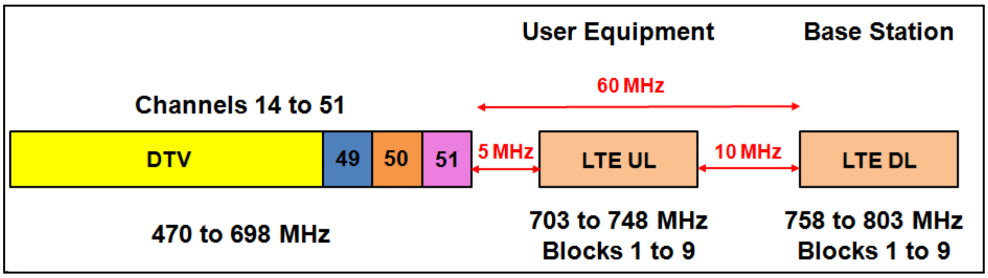

Fig. 1. Spectrum plan for the 700 MHz band

The measurement campaign was carried out in a controlled environment at the laboratory campus of the National Institute of Metrology (Inmetro) in Xerém, Rio de Janeiro. The technical characteristics and parameters associated with each technology standards, such as masks, protection criteria and thresholds were used in the trials. The resulting set of measured results enabled the evaluation of the interference between systems in simple scenarios and the validation of computer simulations of more complex scenarios that occur in real situations. The main equipment components used in the tests are listed in Table I.

TABLE I. EQUIPMENT FOR THE TESTS OF INTERFERENCE BETWEEN LTE AND DIGITAL TV

Equipment	**Model**	**Manufacturer**
Digital TV signal generator	SFU Broadcast Test System	Rohde&Schwarz
RF Amplifier	5 W TV Exciter UHF/VHF Band	DB Elettronica Telecomunicazioni S.p.A.
Panel antenna	APO8	DB Digital Broadcast
Digital TV receiver	TS2400	Telesystem
Digital LCD TV	Bravia	Sony
Vehicular antenna	CE1549L	Celta Telecomunicações
Portable spectrum analyser	FSH18	Rohde&Schwarz
LTE station	eNodeB	Nokia Solutions and Networks (NSN)
Panel antenna	APX75-864014-CT0	RFS
Android User terminal	Prototype	Qualcomm

B. Measurements of LTE interference on digital TV

The setup for the measurements of LTE interference on digital TV is schematically shown in Figure 2. Figure 3 shows the positions of the digital TV and LTE transmitters and receivers in the parking space of the Inmetro laboratory buildings. The transmitting antenna of the digital TV system was

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installed on the roof of the building at a high of 15 meters, with the generator and RF amplifier located inside the building. The digital TV signal was received by a log-periodic antenna, connected directly to a TV receiver, at 80 m distance, and the LTE radio base station antenna on the extended mast of a mobile unity at 8 m height. Figure 4 shows a ground view of the measurements setup.

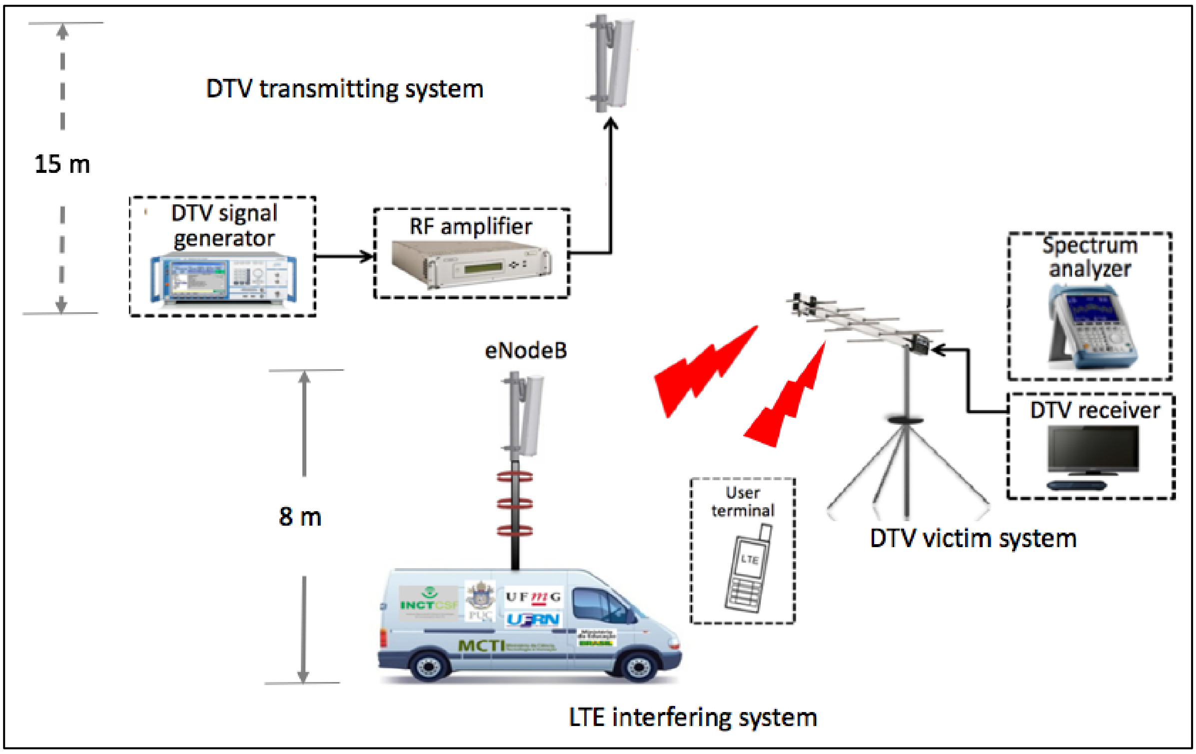

Fig. 2. Setup for the measurements of LTE interference on digital TV

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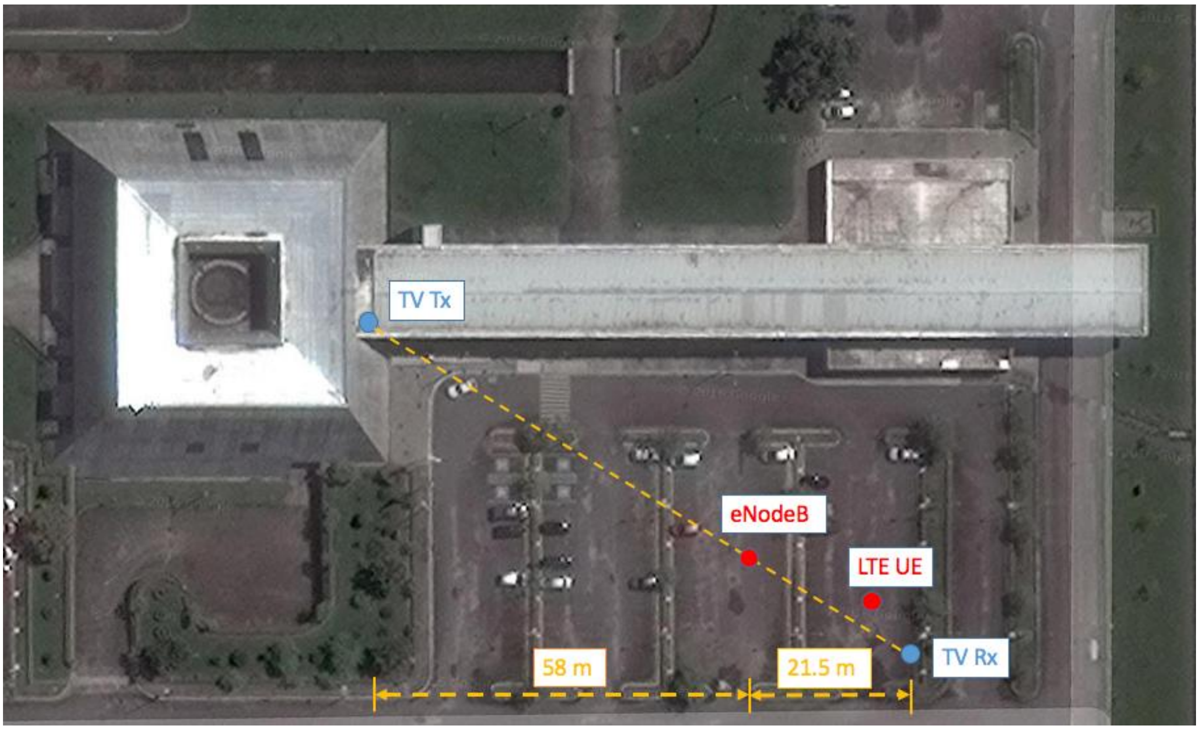

Fig. 3. Aerial view of the measurement setup of LTE interference on digital TV

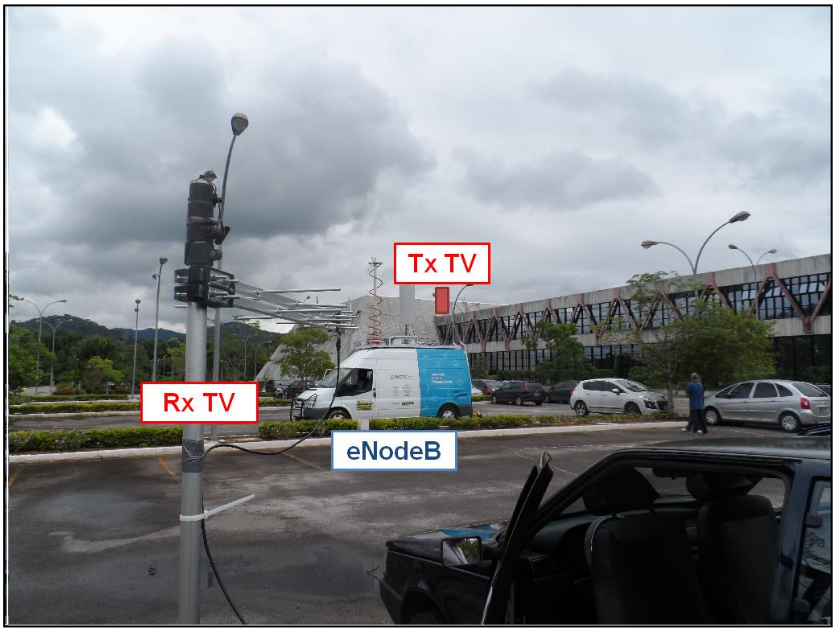

Fig. 4. Ground view of the measurement setup of LTE interference on digital TV

The tests performed are summarized in Table I. Test A is the reference test, in which only the digital transmitter TV is active. In test B, the LTE eNodeB is turned on to evaluate the effect of its interference on the TV receiver threshold. In tests C, D and E, the LTE UE (user terminal) is also activated at different positions near the TV receiver, with two different transmitting power levels.

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TABLE II. TESTS OF LTE INTERFERENCE ON DIGITAL TV

Test	**Measurement**	**Description**	**TV reception threshold (dBm)**
Test A	Measurement of the TV receiver threshold	Only the TV transmitter operating	-91.4
Test B	Measurement of LTE DL interference on the TV receiver	eNodeB transmitting 8 W, user equipment (UE) turned off	-78.9
Test C	Measurement of LTE DL and UL interference on the TV receiver	eNodeB transmitting 8 W and UE operating inside the van	-76.5
Test D	Measurement of LTE DL and UL on the TV receiver	eNodeB transmitting 8 W and UE operating 1m from the receiver	-74.4
Test E	Measurement of LTE DL and UL interference on the TV receiver	eNodeB transmitting 40 W and UE operating 1m from the receiver	-72.2

In each test the power of the TV transmitter was reduced to until the TV receiver reached the threshold of good reception, defined as the signal level for which there is pixelation or image freezing occurs at least once during a one-minute observation period.

Figure 5 shows the variation of the TV signal reception level of as a function of transmitter EIRP for test A. In this case it was possible to decode the signal without artifacts down to a threshold of -91.4 dBm. It was noted, however, that below about -80 dBm the receiver loses linearity.

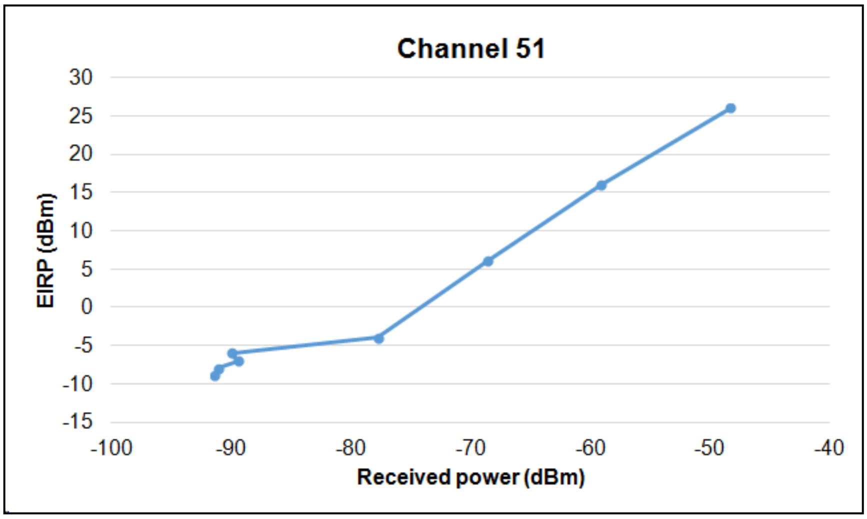

Fig. 5. Received power level vs. transmitter EIRP at channel 51 (Test A, no LTE interference)

Table II also shows the reception threshold values measured in channel 51. Each test corresponds to a single fixed relative position of the interfering and interfered systems, as the main objective of these measurements is to provide reference values that will be later used to validate the simulation tool. The results correspond to the average values of readings taken during three minutes to eliminate fluctuations.

The presence of the interference signal from the eNodeB, transmitting 39 dBm (8W) at a distance of 80 meters from TV receiver, caused an increase of the reception threshold from -91.4 dB, measured in test A, to -78.9 dBm, measured in test B. In tests C, D and E, additional interference was caused by the LTE UE and the reception threshold varied depending on the UE transmission power and position of the UE relative to the TV receiver. In the worst case, with the eNodeB transmitting its full power of 46 dBm (40W) at one meter from the TV receiver, the combined interference of the eNodeB and the UE raised the channel 51 TV reception threshold to -72.2 dBm. No significant degradation of the reception threshold was observed in channels 49 and 50 in any of the trials.

C. Measurements of digital TV interference on the LTE system

The setup for the measurements of interference of the digital TV transmitter on the LTE system is schematically shown in Figure 6. The UE was placed on different positions relatively to the eNodeB and the TV transmitter, as indicated in Figure 7. The performance indicators used to evaluate the performance of the LTE system were the data flow rate and the jitter in the uplink (UE to eNodeB). The transmission power of the LTE UE was also measured.

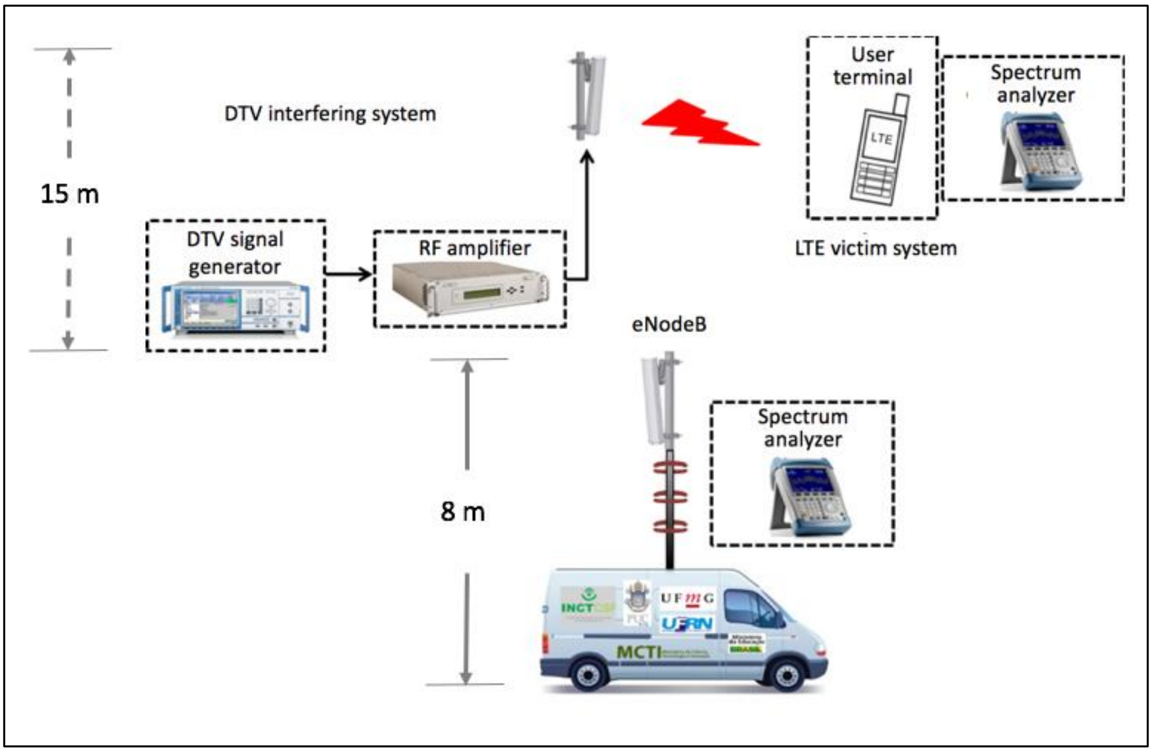

Fig. 6. Setup for the measurements of LTE interference on digital TV

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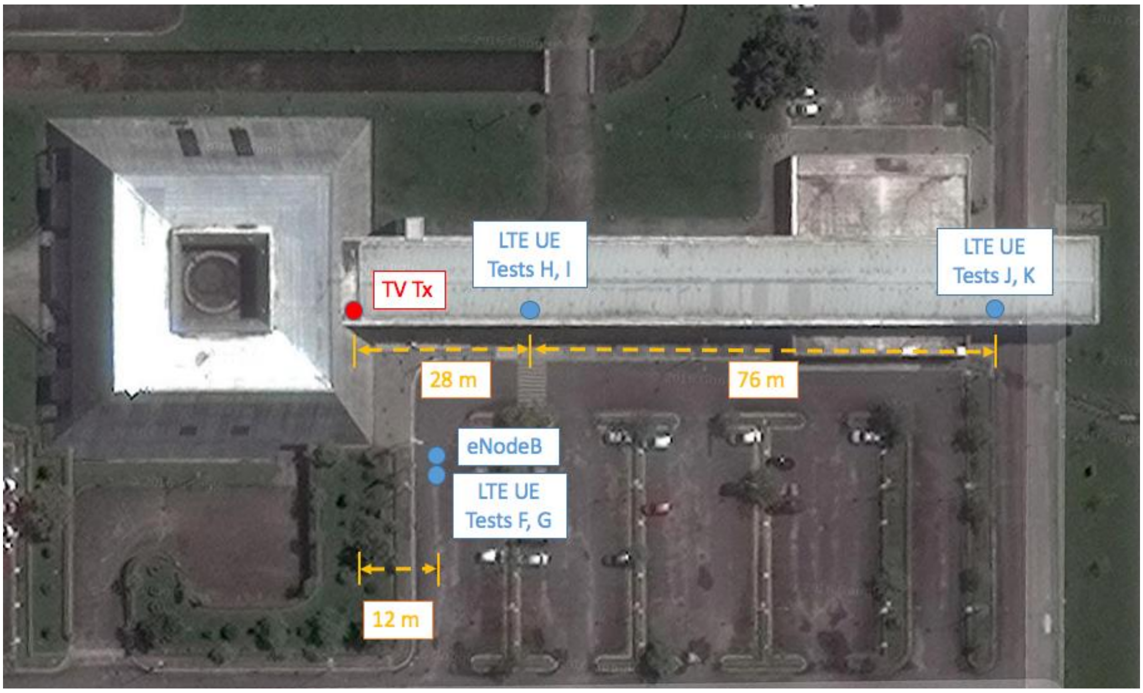

Fig. 7. Aerial view of the measurement setup of TV interference on digital LTE

The results of the measurements are summarized in Table III. With the UE positioned inside the van, its adaptive control automatically increased the transmission power by 3dB when the digital TV transmitter was turned on. The UE data flow rate of 29.5 Mbps could be maintained in this condition. With the UE positioned inside the building, the data flow rate was 32 Mbps without interference and dropped to 20 Mbps when the TV transmitter was turned on.

TABLE III. EFFECTS OF DIGITAL TV INTERFERENCE ON THE LTE SYSTEM

Test	**TV EIRP (dBm)**	**UE's position**	**UE transmission power (dBm)**	**Flow rate (Mbps)**	**Jitter (ms)**
Test F	0	Inside the van	8	29.5	0.44
Test G	31	Inside the van	11	29.5	0.4
Test H	0	Inside the building	13	32	0.3
Test I	31	Inside the building	19	20	0.4
Test J	0	At building entrance	23	17	0.8
Test K	31	At building entrance	23	2	18

The worst case occurred with the UE positioned at the entrance of the building, the farthest point in relation to the eNodeB. Due to the larger distance from the transmitter, the data flow rate was reduced from 32 Mbps to 17 Mbps without TV interference. With the digital TV transmitter turned on the degradation caused by interference was severe, with the data flow rate of the UE being further reduced from 17 Mbps to 2 Mbps and the jitter reaching 18 ms.

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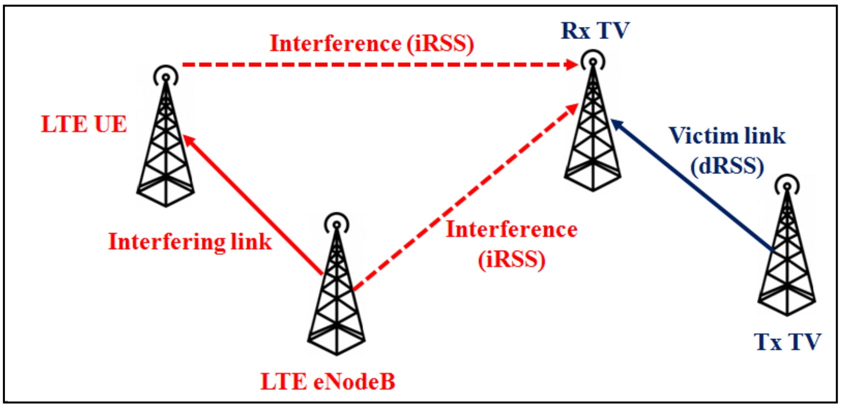
III. VALIDATION OF THE SIMULATION TOOL

To validate the use of the SEAMCAT software to statistically evaluate the effects of interference between digital TV and LTE systems, simulation scenarios reproducing the measurements described in section II were built and the simulated and measured results compared.

A. The SEAMCAT simulation software

The SEAMCAT uses four basic elements: the victim transmitter (Tx), the victim receiver (Rx), interference transmitter and receiver interference system. The victim system receiver (Rx) receives the desired signal intensity (dRSS), while the interference transmitter generates a interfering signal intensity (iRSS), as shown in Figure 8. Harmful interference occurs when the signal-to-interference ratio (dRSS/iRSS or C/I) at the victim system receptor is less than the minimum value allowed.

The user can set in the software interface the parameters of the interfering and victim links, as well as the statistical distributions of the channel model parameters and of the spatial position of transmitters and receivers. The program uses these distributions to generate random samples, called snapshots, performing a Monte Carlo simulation. For each sample, the tool calculates the interfering and desired signal levels. Thus, it is possible to calculate the probability of interference between the systems for a specified signal to interference threshold. To obtain reliable results it is recommended to use a large number of events, in the order of 20.000 [10].



Victim link (digital TV) and interfering links (LTE eNodeB and LTE UE)The software considers the effects of co-channel and adjacent channel interference, including unwanted emissions, intermodulation products and receiver blocking. The level of unwanted emissions and out-of-band spurious emissions of the interfering transmitter that fall within the band of receiver-victim is determined by the use of the transmission filter masks, victim receiver selectivity, frequency separation between interferer and victim, antenna gains and propagation loss. Receiver blocking power is the power that arrives at the victim receiver due to imperfections of its selectivity. It is determined considering the transmission power of the interferer, the victim receiver protection mask, the frequency separation between interferer and victim, the gain of the antennas and the propagation loss. The two effects are indicated in Figure 9.

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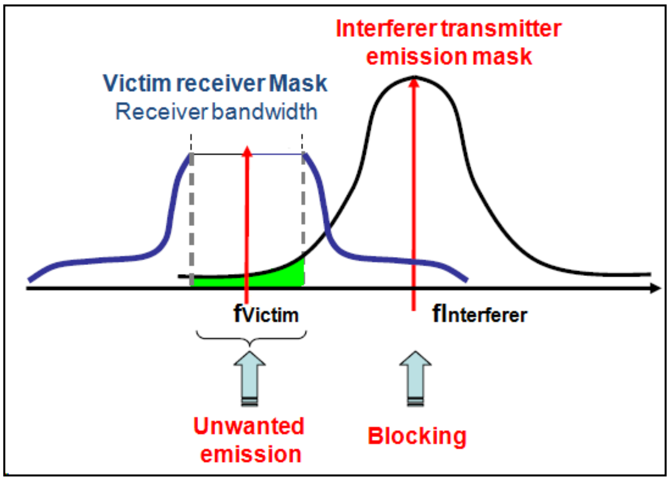
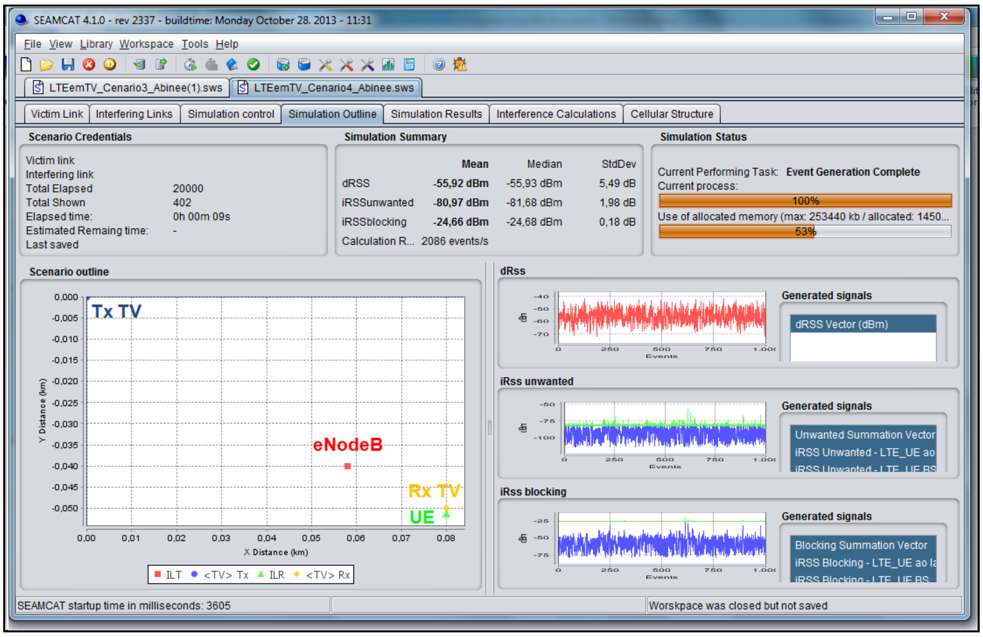


Fig. 8. Unwanted emissions and receiver blocking

B. Comparison between measured and simulated results

To validate the use of SEAMCAT as a simulation tool for application on LTE and TV interference problems, scenarios were built corresponding to the measurements carried out in test measurements A to E. In these simulations, as in the field tests, the positions of the transmitters and receivers were kept fixed the channel parameters varied randomly. The simulation run corresponding to test E is shown in Figure 10, as an example.


SEAMCAT 4.1.0 - rev 2337 - buildtime: Monday October 28. 2013 - 11:31

LTEemTV_Cenario3_Abinee(1).sws
LTEemTV_Cenario4_Abinee.sws

Scenario Credentials

Victim link
Interfering link
Total Elapsed 20000
Total Shown 402
Elapsed time: 0h 00m 09s
Estimated Remaing time: -
Last saved

Simulation Summary

	Mean	Median	StdDev
dRSS	**-55,92 dBm**	-55,93 dBm	5,49 dB
iRSSunwanted	**-80,97 dBm**	-81,68 dBm	1,98 dB
iRSSblocking	**-24,66 dBm**	-24,68 dBm	0,18 dB
Calculation R...	2086 events/s		

Simulation Status

Current Performing Task: **Event Generation Complete**
Current process: 100%
Use of allocated memory (max: 253440 kb / allocated: 1450... 53%

SEAMCAT startup time in milliseconds: 3605
Worskpace was closed but not saved

Fig. 9. SEAMCAT simulation of Test E: LTE interference on digital TV (channel 51)

On the left panel, the relative positions of transmitters and receivers are indicated. On the right, the sequence of simulated values of the wanted signal, unwanted emissions and blocking signal are shown. The simulation outputs are the mean values, median values and the standard deviations of the wanted and unwanted signals and the probability of interference, corresponding to the probability

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that the signal-to-interference ratio threshold is exceeded, calculated at the end of the simulation run.

Figure 11 shows the comparison between the simulated and measured results in tests A, B and C. The measured values are shown as solid lines and the simulated results as dotted lines, each color corresponding to a different test. The agreement between measured and simulated the results is quite good, especially considering that the filters masks used in the simulation were obtained from the technical standards of LTE and digital TV, and may differ slightly from the actual filter responses.

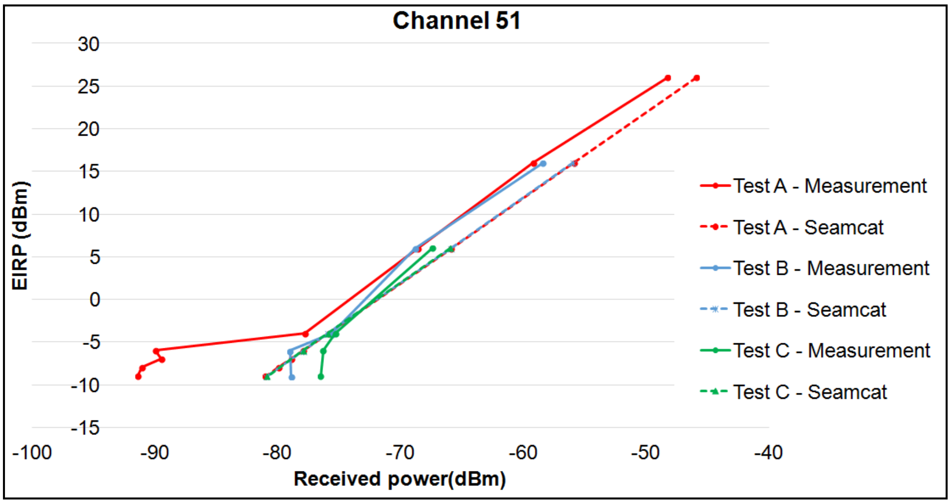

Fig. 10. Comparison of simulations with measured results of tests A, B and C

Similarly, Figure 12 shows the comparison of the results of the simulations with the measured results for tests D and E. Also, in these cases, there is a good agreement between the simulation and measurements.

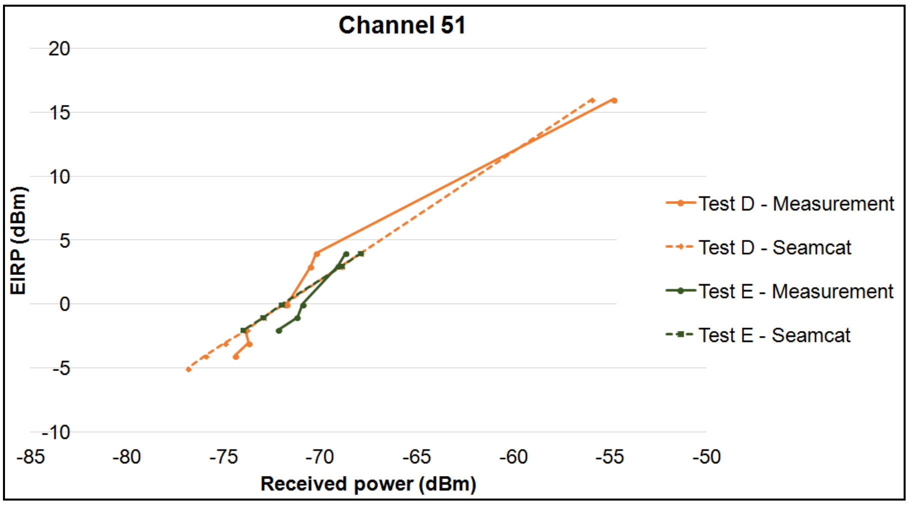

Fig. 11. Comparison of simulations with measured results of tests D and E

IV. RESULTS OF INTERFERENCE SIMULATIONS BETWEEN LTE AND DIGITAL TV SYSTEMS

For the assessment of coexistence between LTE and digital TV systems operating in adjacent bands, various interference scenarios, including multiple interfering signals and multiple TV receivers

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were considered. These scenarios with multiple transmitters and receivers would be very difficult to replicate experimentally, thus the use of the simulation tool.

A. LTE interference on digital TV

The analysis presented below, the LTE system consisted of hexagonal macrocells with 0.5 to 2.0 km radius, typically used in urban areas [14]. Each of the 19 macrocells was divided in three sectors, as shown in Figure 13.

In each sector a maximum of 21 users (UE's) are randomly positioned in each step of the simulation. The UE's are located indoor environment 1 m away from TV receivers and 1 m above the floor. The interference of the LTE system operating with a 10 MHz band, with mid-band frequencies were 713 MHz for the UE's and 765 MHz for the eNodeB's, on the digital TV channel 51 was evaluated. The simulations considered TV coverage areas of 10 and 20 km. The distance between the transmitter (Tx) and the nearest eNodeB was set at 10 m. The power of the TV transmitter was varied between 60 and 80 dBm, corresponding to class A and Special class transmitters.

The propagation loss of the TV signals was calculated using the model in Recommendation ITU-R P.1546 [15]. For the LTE eNodeB and UE's the Extended Hata [16] [17] and Extended Hata SRD [10] propagation loss models were used, respectively.

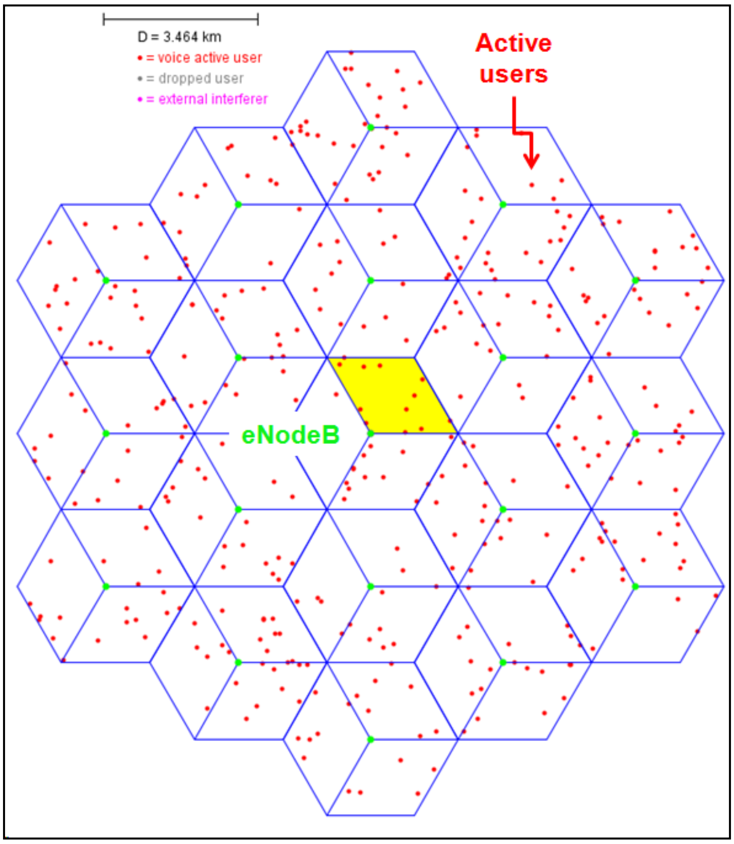

Fig. 12. Three-sector macrocells scenario

Figure 14 shows the simulated behavior of the probability of interference (IP blocking) and

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unwanted emissions (unwanted IP) as a function of the TV transmitter EIRP. As the TV transmitter EIRP increases, the C/I ratio is improved and the probability of interference reduced. A TV transmitter EIRP of 80 dBm is required to produce an interference probability below the desired threshold of 5%. Note that the blocking interference is the dominant effect, reflecting the limitations of TV reception filters.

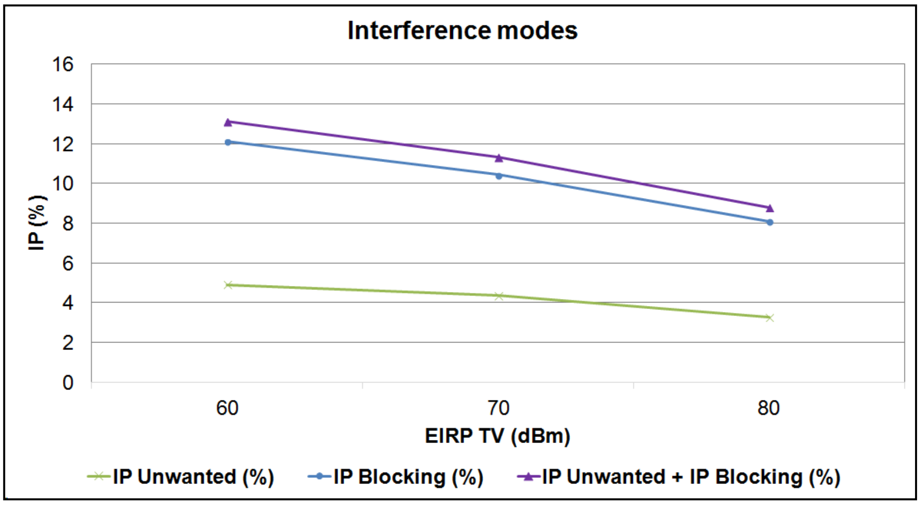

Fig. 13. Interference Probability vs. power of TV transmitter

Table IV shows the average values of interference probability, C/I (dB) ratio and percentage of TV users with received signal above the reception threshold, obtained in different simulations with varying the TV EIRP and TV coverage area. The probability of interference decreases with the increase of TV transmission power and increases with the coverage area, since users at the edge of this area will have smaller C/I relations. The probability of interference is below 5% only for the case in which the EIRP is equal to 80 dBm and the TV coverage area is equal to 10 km. Note that, with TV EIRP of 60 dBm, the percentage of users that get good reception is too small, making this scenario unrealistic in practice.

TABLE IV. LTE INTERFERENCE ON TV: SIMULATIONS WITH VARIABLE EIRP AND TV COVERAGE

EIRP TV (dBm)	TV coverage (km)	eNodeB Power (dBm)	UE Power (dBm)	IP (%)	C/I (dB)	Active TV users (%)
60	10	46	23	12.9	27.7	34.6
60	20	46	23	13.1	18.3	9.2
70	10	46	23	9.2	37.8	84.4
70	20	46	23	11.3	28.2	35.3
80	10	46	23	3.9	47.8	99.6
80	20	46	23	8.8	38.2	80.4

One possible way to reduce the interference probability is to limit the eNodeB's and UE's emissions. Table V shows the variation in the probability of interference and C/I (dB) with the average transmission powers of the eNodeB's and the UE, for a 70 TV dBm TV EIRP with 10 km coverage radius. In this scenario, the number of users of TV with received signal level above the threshold is greater than 80% and the scenario is considered viable. It can be observed that the reduction of the eNodeB's power does not cause significant improvement in the interference probability. To obtain a value for the IP below the threshold of 5% it is necessary to limit the power of the UE's to 14 dBm.

TABLE V. LTE INTERFERENCE SIMULATIONS WITH LIMITATION OF ENODEB AND UE TRANSMISSION POWER

EIRP TV (dBm)	TV coverage (km)	eNodeB Power (dBm)	UE Power (dBm)	IP (%)	C/I (dB)	Active TV users (%)
70	10	46	23	9.2	37.8	84.4
70	10	43	23	9.0	37.9	84.3
70	10	40	23	8.9	38.0	84.3
70	10	46	20	7.1	40.4	84.3
70	10	46	17	5.5	43.3	84.4
70	10	46	14	4.7	45.8	84.4

B. Digital TV interference on LTE

The effect of the digital TV on LTE system was evaluated by the loss of capacity (bit rate/user) in the presence of interference. Table VI shows the results bit rate per user in the uplink (UE to eNodeB) obtained from the simulations, for a TV coverage radius of 10 km, with the TV EIRP ranging between 60 and 80 dBm and LTE cell radius of 500 m and 2 km. The UE's transmission power is 23 dBm and the eNodeB transmission power 46 dBm. A maximum bit rate loss considered acceptable is 30%.

As expected, even without interference the bit rate per user is significantly reduced when the cell radius increases, due to the distance with respect to the eNodeB's of the UE's located on the cell border. In the presence of interference, the bit rate loss increases with the power of the TV transmitter and with the cell radius. However, only in the case with 80 dBm TV EIRP and LTE cell radius of 2 km the loss exceeded the specified limit of 30%.

TABLE VI. TV INTERFERENCE ON LTE SIMULATIONS WITH VARIABLE TV EIRP AND CELL RADIUS

TV EIRP (dBm)	Cell radius (km)	C/I (dB)	Bit rate without interference (Mbps)	Bit rate with interference (Mbps)	Bit rate loss (%)
60	0.5	8.2	13.0	12.1	6.8
60	2.0	-3.5	3.0	2.5	16.0
70	0.5	6.8	13.0	11.0	15.3
70	2.0	-5.8	3.0	2.2	28.6
80	0.5	4.0	13.0	9.4	27.9
80	2.0	-9.5	3.0	1.7	45.1

Simulations of interference of digital TV on the downlink of the LTE system (eNodeB to UE) did

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not show any significant loss in the bit rate. This is due to the larger operation frequency separation between the digital TV transmitter and the eNodeB.

V. CONCLUSIONS

Results of measurements of interference between digital TV and LTE systems operating in adjacent bands were used to validate the use of a computational Monte Carlo simulation tool, the SEAMCAT program. This software allows the simulation of a large number of events with the random positions of the interfering and victim systems and the responses of the propagation channels described by probability distributions with known parameters.

Different scenarios representing situations close to reality, with a transmitter and multiple TV receivers operating on channel 51, the last TV channel adjacent to the band of LTE, and hexagonal clusters of base stations composed of cells of three sectors and a large number of users streaming the short distances of TV receivers in adjacent band of 10 MHz were simulated. The scenarios were designed to investigate the probability of interference dependence the digital TV transmitter power, digital TV coverage area and distance between the LTE user equipment and the TV receiver. In the analysis of LTE interference on digital TV, it was found that the dominant effect is the blocking interference, due.

The probability of interference of 5% was considered as the maximum acceptable limit. For the digital TV system with 10 km, LTE cells with 2 km radius with 21 LTE users by sector, an EIRP of 80 dBm for the digital TV system was required to reach a probability of interference below this limit. When the TV coverage radius is increased to 20 km, the probability of interference is above 5% even with this maximum EIRP. The tests were repeated with cells of 1 km radius, but it was found that the variation in the probability of interference was marginal.

As the improvement of the filters of the TV receivers is a difficult solution in practice, two forms of interference mitigation were considered: limiting the transmission power of eNodeB and LTE user equipment (UE). The eNodeB power reduction did not affect significantly the probability of interference, indicating that the interference caused by the user equipment is the dominant effect. To keep the probability of interference below the threshold of 5% it is necessary to reduce the transmission power of the UE from 23 dBm to 14 dBm.

The effects of interference from the digital TV transmitter on the LTE system were also investigated. The LTE system performance degradation was measured by the reduction of the average bit rate transmission by user, with a loss threshold is 30% considered acceptable. Cell radius of 500 m to 2 km were simulated, with the other parameters maintained. In the LTE downlink there was no significant loss in the transmission rate. In the uplink the loss in average rate of transmission of users was above 40% for cells with 2 km radius. For cells with 500 m radius the transmission rate reduction is below the established threshold of 30%.

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