Coexistence of Broadcast and Mobile Technologies in UHF bands

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***Abstract* — With the spectrum liberation obtained by the deployment of Digital Terrestrial Television (DTT) and the analog TV switch-off, new bands are being assigned to IMT Long Term Evolution (LTE). In the first cellular deployments in the digital dividend of Region 1, at the 800 MHz band, problems emerged when it was observed that the LTE Downlink could interfere to DTT signals. Possible solutions imply either an inefficient use of the spectrum (increasing the guard band and reducing the number of DTT channels) or a high cost (using anti-LTE filters for DTT receivers). In this paper, the coexistence problems between LTE and DTT services in the 800 MHz band is evaluated. To accomplish this, measured protection ratios for different configurations as well as planning studies in a real environment have been performed. In addition, potential approaches for coexistence have been proposed in order to guarantee the performance of DTT services.**

***Index Terms* — Digital TV, Broadcasting, Interference, 4G mobile communication, Digital Dividend, Coexistence.**

I. Introduction

ONE of the key challenges of next-generation cellular networks is to identify spectrum to cope with the increasing traffic demand. An impending problem is to identify a frequency band, from the already scarce spectrum resources, to fulfill this requirement. Traditionally, analog TV has used the UHF frequency band IV. With the arrival of Digital Terrestrial Television (DTT) and video compression systems, the spectrum used by a single analog TV channel allows transmitting several multiplexed TV programs. This technical revolution allowed releasing some spectrum after the analog switch-off, known as Digital Dividend (DD) [1]. In the World Radiocommunication Conference (WRC) of 2007, the International Telecommunications Union (ITU) decided to allocate the upper part of the TV broadcasting band to International Mobile Telecommunications (IMT) technologies. Hence, Regions 1 and 3 allocated the 800 MHz band (790-862 MHz, channels 61-69) for Long Term Evolution (LTE) services, with a guard band of only 1 MHz, and Region 2 allocated the 700 MHz band (698-806 MHz, channels 52-69), with a guard band of 5 MHz. Problems emerged when it was observed that LTE downlink (DL) operating in the digital dividend could interfere DTT signals in the two adjacent channels [2]. The potential solutions consist in increasing the guard band by reducing the number of DTT channels or using special filters for DTT receivers.

In addition, the ITU WRC-12 concluded with a decision to allocate additional UHF spectrum to mobile services and invited to perform further coexistence studies and report the results to the next WRC-15. The new mobile allocation, also known as Second Digital Dividend (DD2), is expected to be made in Region 1 in the 700 MHz band (the actual range is to be decided in WRC-15).

Previous works of regulatory entities in the literature outline the coexistence problem between both LTE and DTT systems in the upper part of the UHF band IV. In [3], it was concluded that an external filter is required between the TV antenna and the DTT receiver. In [4], ITU provides interference protection ratios (PR) between DVB-T2 and LTE in the 800 MHz band (for both LTE UL and DL) for a LTE bandwidth of 10 MHz and different traffic loads.

In this paper, we first present the results about measured protection ratios (PR) for 700 MHz and 800 MHz bands in order to evaluate the influence of different physical layer parameters for DD and DD2 configurations. Next, those results are used to perform coexistence studies between LTE signals and DTT in the 800 MHz band, by performing a complete link budget and planning studies in a real scenario.

The rest of the paper is structured as follows. Section II summarizes the scenarios where the potential interference problem could exist. In Section III, the methodology used for measurements and planning studies is detailed. Section IV presents the results of the study, showing the particular coexistence problem based on the 700 and 800 MHz bands. Finally, the main findings of the work are summarized in Section VI.

II. DTT & 4G Coexistence Bands and Scenarios

Region 1 allocated the 800 MHz DD band for LTE services, with a guard band of only 1 MHz and DL in the immediately adjacent band. Also, the DD2 is to be made in Region 1 in the 700 MHz. The main difference compared to the 800 MHz band lies in the fact that the UL is located in the lower part, instead of the DL. Figure 1 shows a complete channelization in both 700 and 800 MHz bands.

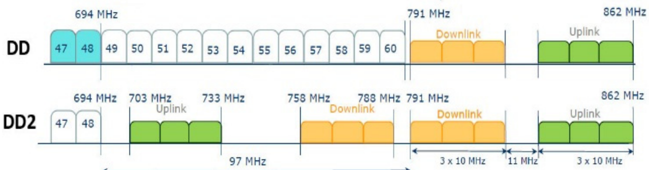

Fig. 1. Region 1 channelization. First and Second Digital Dividends.

In this study, scenarios have been classified according to: the type of LTE interfering link adjacent to DTT: UL (for DD2) or DL (for DD1); the DTT reception type: portable indoor or fixed outdoor; and the position of the LTE UE: inside or outside the building. One worst-case has been identified in the 800 MHz band (DD): LTE DL interfering with DTT fixed rooftop reception as shown in Figure 2.

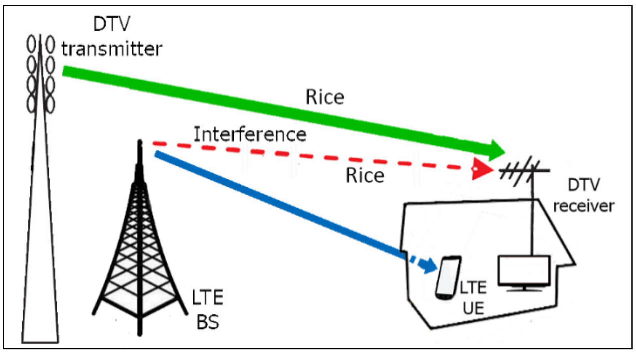

Fig. 2. Interference scenario for LTE DL interference with DTT fixed reception.

As it can be observed in Fig. 22, the most critical scenario is the one with fixed rooftop DTT reception. The LTE base station is near to the DTT antenna, which is oriented in the same direction that the base station. Moreover, it is considered that the DTT antenna is at cell edge, with a receiving power near to the threshold. The position of the cell phone, inside or outside the building, is irrelevant in this case.

III. Methodology

A. Protection Ratio Measurements

Followed methodology is mainly divided in two steps. The first step consists on measuring interference PRs for DTT interfered by LTE. A PR is the minimum value of difference between the useful (DTT) and interfering (LTE) signals, expressed in dB, at the receiver input to accomplish with a particular quality requirement. Thus, the lower the PR (even negative), the more interfering signal level allowed, and hence, the lower the interferences in a real scenario. From the calculated PR, the second step consists on performing a complete link budget analysis and planning studies.

The procedure to measure PRs between LTE and DVB is based on the Recommendation ITU-R BT.2215 [5]. Signals and channel models used in this recommendation are defined in the Recommendation ITU-R BT.2033 [6]. Several tap-delay channel models have been used in order to emulate the multipath propagation. The emulation is performed using the channel emulation facility of a vector signal generator. For DTT signals, a Rayleigh or Rice model is considered, depending on the type of DTT reception. For LTE-UL, a Gaussian channel model is used, because the UL signal is an addition of several UL signals generated by each user due to his position relative to the DTT receiver. Used channel models are shown in Figure 2.

Table I and Table II show the DVB-T2 and LTE modes used in this work. The first DVB-T2 mode is the one used currently in the United Kingdom for fixed reception. For indoor reception, a more robust DVB-T2 mode is needed to ensure the same coverage, due to the additional propagation loss. On the other hand, using a more robust mode implies a lower capacity.

TABLE I
DTT Reference Signal Parameters

Parameter	Fixed Rx	Indoor Rx
Standard	DVB-T2	DVB-T2
Modulation	256-QAM	64-QAM
Code Rate	2/3	3/5
FFT	32K Extended	16K Extended
Guard Interval	1/128 (28 μs)	1/8 (224 μs)
Pilot Pattern	PP7	PP3
Bandwidth	8 MHz	8 MHz

TABLE II
LTE Reference Signal Parameters

Parameter	UL value	DL value
Multiplex	SC-FDMA	OFDM
FFT	1024	1024
Guard Interval	Normal (4.7 μs first symbol, 5.2 μs next)	Normal (4.7 μs first symbol, 5.2 μs next)
Bandwidth	5 / 10 /15 / 20 MHz	5/ 10 / 15 / 20 MHz
Traffic loading	1 / 10 / 20 Mbit/s	IDLE / 50% / 100%

The impact of the three following LTE parameters is studied:

- Traffic loading: 1 Mbit/s (light loading where only a small number of resource blocks are used for some of the time), 10 Mbit/s (medium loading), or 20 Mbit/s (high loading).
- LTE bandwidth: 5, 10, 15 or 20 MHz.
- LTE interfering link: UL or DL.

The variation of these parameters is studied for a certain range of guard bands, i.e. from 0 to 17 MHz, taking into account all possible PRs from last to third from last channel.

B. Link Budget and Planning Analysis

In the 800 MHz band, a complete link budget for DTT fixed reception is performed. Any result for DTT portable indoor reception would be less restrictive, due to the penetration loss of both DTT and LTE signals [2]. The main objective is to obtain protection distances between the LTE transmitters and the DTT receivers, and the LTE area percentages where DTT receivers can be interfered, for different DTT field strengths. In addition, a planning study in Valencia is performed to confirm the results obtained in the link budget. Both DTT and LTE signals use the Hata propagation model [2] in the link budget, and the deterministic model ITU-R 525 [7] in the planning results, which is based in free-space model and takes into account several corrections based on the land.

IV. Protection Ratio Results

A. Influence of LTE Signal Variation

1) LTE Interfering Link Effect

Regarding the impact in the PRs of having in adjacency the DL instead of the UL, it was observed that the UL interferes more than the DL, especially for the worst traffic loading cases. For a LTE bandwidth of 10 MHz, PRs for UL are 10 dB more restrictive than for DL for all evaluated guard bands. As mentioned before, this is due to the time variation produced with the UL lower traffic loaded waveforms.

2) LTE Traffic Loading Effect

In these measurements, the LTE BW is fixed on 10 MHz. When DL is the interfering link, the most interfering loading is the 100% or fully loaded one. This is because of the OFDM modulation, in which the higher the load, the higher the power level. In the case of UL, the lower the traffic load, the higher the interference, i.e. PRs are worse (higher). LTE-UL signals vary most over time with low traffic loads, and hence they interfere more than high traffic load signals, whose spectrum is similar to white noise.

3) LTE Bandwidth Effect

In this study, the DTT fixed reception mode was used. If LTE signals are less than 4 MHz apart from DTT signals, LTE signals with lower BWs are more interfering. However, if the guard band increases, this behavior changes. This effect is due to the different out-of-band fall for each LTE channelization, and also to the difference in occupied BW, which is the 90% of the LTE BW. **¡Error! No se encuentra el origen de la referencia.**3 shows the LTE-DL signal BW effect as a function of the guard band for the worst traffic load (i.e. 100% loaded).

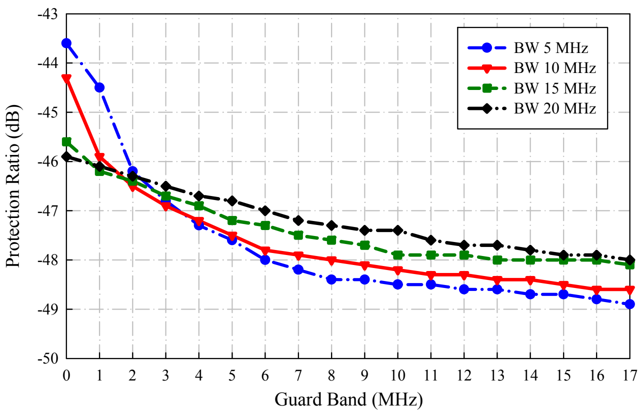

Fig. 3. Protection ratios for DTT interfered by LTE-DL as a function of different LTE bandwidths.

Something similar happens in UL, where the most interfering signal is the 1Mbit/s one, and the LTE bandwidth effect over protection ratios behave the same as for the DL, varying the inflection point from 2 to 4 MHz.

B. Effect of Multipath Channel Models

To extend the use of the PRs shown above for DTT network planning, it is necessary to take the particular PR for the fixed/portable DTT mode (6 dB of difference) and add 3 dB for fixed reception (Rice channel) and 6 dB for portable reception (Rayleigh channel). Therefore, in the DD, where 1 MHz of guard band is given, the measured PR for a LTE bandwidth of 10 MHz is -46 dB. For fixed reception, adding 3 dB, the final PR is -43 dB.

V. Coexistence Analysis in 800 MHz Band

A. Link Budget Analysis

In this section, a complete link budget for DTT fixed reception is performed, in the 800 MHz band. Any result for DTT portable indoor reception would be less restrictive, due to the penetration loss of both DTT and LTE signals [2]. PRs can be different, depending on the traffic load, LTE BW and guard band. For a guard band of 1 MHz and LTE-DL signal BW of 10 MHz, with a 100% load, the required PR is –43 dB.

Tables II and III show the DTT link budget parameters for fixed DTT outdoor reception in the transmission and reception antennas, respectively. LoS between both DTT antennas has been assumed, where the DTT Fixed reception antenna parameters are based on [8] and [9].

TABLE III
800 MHZ DTT Fixed Transmission Antenna Parameters

Parameter	Value
EIRP (urban)	72.15 dBm
EIRP (rural)	79.15 dBm
Equivalent noise bandwidth	7.6 MHz
Pointing antenna gain	15 dBi
Antenna height	100 m (urban) / 200 m (rural)
Antenna pattern	Directive [2]

TABLE IV
800 MHz DTT Fixed Reception Antenna Parameters

Parameter	Value
Noise figure	7 dB
Equivalent noise bandwidth	7.6 MHz
Antenna gain	9.15 dBi
Antenna height	10 m
Antenna pattern	Directive [9]

From Tables III and IV, the maximum DTT propagation loss and therefore, the coverage radius of the DTT base station, can be obtained. In a rural environment, the maximum allowed loss is 149.4 dB. In an urban environment, it grows until 156.4 dB. Considering the Hata propagation model [2], a coverage radius of 49.1 km and 28.4 km is obtained, for rural and urban environments, respectively.

Regarding the LTE link, Table V summarizes the transmitter antenna parameters at the base station. From this table, it is possible to calculate the maximum allowed loss, which is 133.6 dB. Considering the Hata propagation model [2], a coverage radius of 3.6 km and 2.7 km is obtained, for rural and urban environments, respectively.

TABLE V
800 MHz LTE Transmission Antenna Parameters

Parameter	Value
EIRP (limited by noise)	61 dBm
EIRP (limited by UL/DL balancing)	59 dBm
Bandwidht	10 MHz
Antenna height	30 m (urban) / 60 m (rural)
Antenna pattern	Directive [10]

In a particular environment, given both DTT and LTE coverage radius, it is possible to obtain the total percentage of the LTE cell where DTT receivers can be interfered, being these receivers inside the LTE coverage area. Taking the most critical protection ratio in this scenario, which is -43 dB; the minimum required DTT field strength for the fixed reception mode, i.e. 62 dBµV/m; and using link radiant information, different protection distances can be calculated. Table VI shows these protection distances among DTT and LTE transmission antennas, and the LTE interfering percentage area, for both rural and urban environments and typical DTT filed strengths.

TABLE VI
Protection Distances and Interfering LTE Area Percentage in the 800 MHz Band.

Field strength (dBµV/m)		Rural (3,6 km)	Urban (2,7 km)
62	Protection distance	580 m	330 m
	Interfering percentage area	2.6 %	1.5 %
72	Protection distance	340 m	145 m
	Interfering percentage area	0.9 %	0.3 %
82	Protection distance	200 m	80 m
	Interfering percentage area	0.4 %	0.1 %
90	Protection distance	90 m	10 m
	Interfering percentage area	0.2 %	0.02 %

As logical, the higher the DTT received field strength, the lower the interference percentage in a LTE coverage area. Minimum separations among DTT receivers and LTE base stations of 580 m and 330 meters in rural and urban environments, respectively, are needed. Moreover, to avoid any minimum distance between them, a minimum DTT field strength of 90 dBµV/m is recommended. In such case, there is no interference over DTT receivers in all the LTE cell (as long as the LTE EIRP does not exceed 61 dBm).

B. *Planning Study in a Real Scenario*

In order to corroborate the minimum distances between DTT receivers and LTE base stations, calculated in the link budget analysis, a particular planning study in Valencia has been performed. Figure 5 shows the coverage footprint of the DTT station, which transmits contents using the fixed reception DVB-T2 mode, shown in Table I, and the ITU-R 525-2 free-space model [10]. The approximate location of two LTE implemented networks is also shown. The LTE bandwidth is 10 MHz and cells were divided in three oriented sectors: 0º, 120º and 240º.

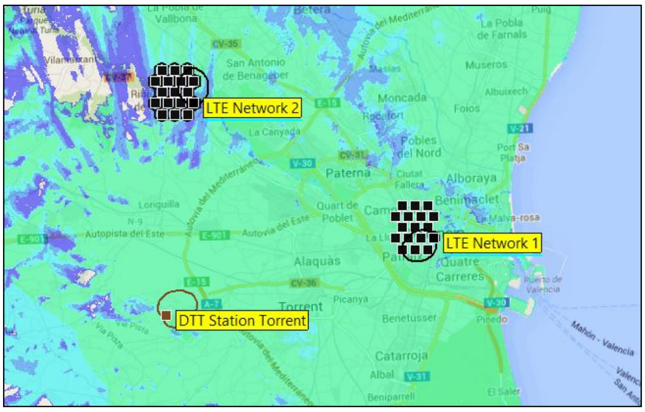

Fig. 4. Coverage footprint of the fixed reception DVB-T2 mode.

As shown in Figure 4, one of the two LTE networks was located in the city centre, where the DTT coverage is optimum. As the DTT level is higher than the LTE one, and the difference is far from the PR, no interference is obtained. However, the second LTE network has been placed in a particular zone, near the DTT coverage area limit. Due to the lower DTT received signal, LTE signals could interfere more, exceeding the PR and preventing a correct DTT reception. Figure 5 shows a zoom in the particular conflictive area, where different DTT field strengths are obtained.

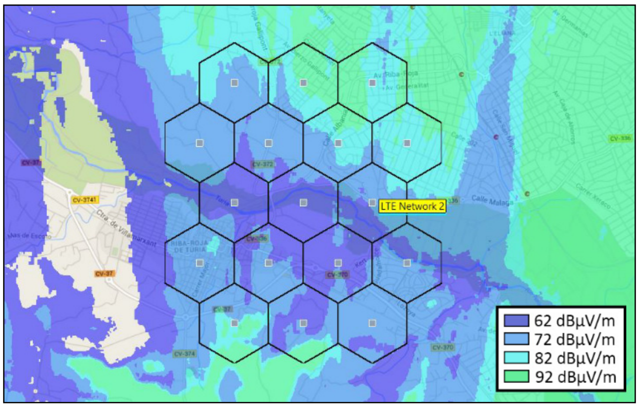

Fig. 5. Coverage footprint and signal field strength of the DVB-T2 station over the LTE network.

The critical protection distance between a DTT receiver, located in a minimum field strength area and a LTE base station calculated in the link budget was 330 meters (urban environment). The same procedure is applied in the particular scenario of Valencia. It was checked with three LTE base stations, which are separated by an average distance of 1500 meters, and located in zones whose DTT received field strengths are different. Figure 6 shows the calculated protection distance for each considered LTE base station.

It is observed that, in places where the received DTT field is near to the threshold, the protection distances are similar to the 330 meters calculated in the link budget. Specifically, the minimum required distances are between 280 and 370 meters. In addition, in the third cell, which is located in a zone where the DTT field strength is higher (82 or 92 dBµV/m), no interference is obtained

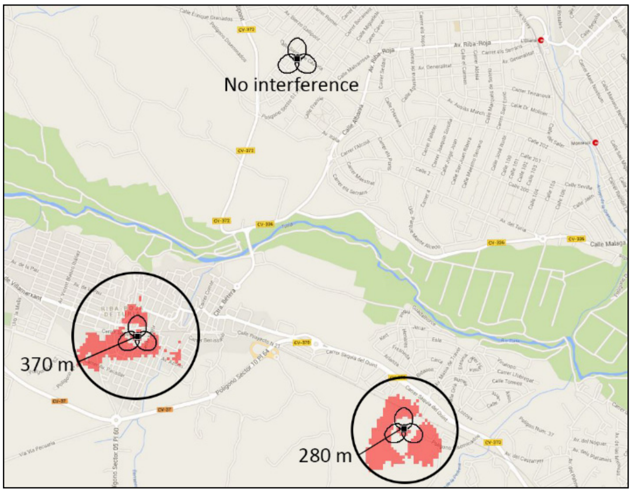

Fig. 6. Protection distance between LTE base stations and DTT receivers.

VI. Conclusion

The analysis of interferences between DTT and LTE cellular networks is crucial to establish the future coexistence between both technologies at the digital dividend bands. In this paper, the coexistence of DTT and LTE in the 700 MHz band has been analyzed for fixed outdoor and portable indoor DTT reception.

Regarding the measured interference PRs, it is observed that:

- LTE-UL generates more interference than LTE-DL, PRs are approximately 10 dB worse.
- When LTE-UL is the adjacent link to DTT, the lower the traffic load, the higher the interference level due to the higher time and frequency variability of the LTE signals.
- Different bandwidths affect in a different way to UL. On one hand, when the guard band between technologies is lower than 4 MHz, a lower LTE bandwidth affects more. On the other hand, with higher guard bands, this behavior changes and a higher LTE bandwidth is more prejudicial. This is due to difference in occupied bandwidth for each LTE channelization which is the 90% of the LTE bandwidth, and also the different out-of-band fall for each LTE channelization.
- DTT portable indoor reception is more vulnerable to interference than fixed outdoor reception. For LTE-UL as the interfering link, PRs are 1 dB worse.

Concerning the 800 MHz band coexistence analysis, performed for a 1 MHz guard band between DTT and LTE-DL, which is the case of the DD in Region 1, it is concluded that:

- For DTT fixed outdoor reception, with the receivers in the DTT coverage threshold (minimum DTT field strength), an average protection distance among them and the LTE base stations must be leaved, which is 330 and 580 meters, in urban and rural environments, respectively. Particular planning studies in Valencia confirm this critical (urban) protection distance, obtaining results of 280 and 370 meters, depending on the position of the LTE cell along the DTT coverage threshold.

- A potential solution is to use the first LTE channel in those cells where more than 90 dBμV/m of DTT services are received. Meanwhile, cells where the received DTT level is lower, should use other LTE channels, to increase the needed PR and avoid interferences.
- LTE cells with DTT field strengths higher than 90 dBμV/m do not need protection distances in relation to DTT receivers.

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