Coexistence of Digital Terrestrial Television and Next Generation Cellular Networks in the 700 MHz Band

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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 at the 800 MHz band, problems emerged due to the interference that cellular networks can cause 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). The new spectrum allocated to mobile communications is the 700 MHz band, also known as second digital dividend. In this new IMT band, the LTE Uplink is placed in the lower part of the band. Hence, the ITU-R invited to perform several studies and reported the results to WRC-15. In this paper, we analyze the coexistence problem in the 700 MHz band and evaluate the interference of LTE signals into DTT services. Several coexistence scenarios have been considered and laboratory tests have been performed to measure interference protection ratios.

KEYWORDS/INDEX TERMS

Coexistence, Digital TV, Broadcasting, 4G mobile communication, Digital Dividend.

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 4G LTE cellular networks operating in the digital dividend could interfere DTT signals in the two adjacent channels [2]. There are several solutions to mitigate interferences. The techniques analyzed in this paper are based on increasing the guard band by reducing the number of DTT channels or using LTE filters for DTT receivers. These techniques are relatively easy to implement and they do not involve any cooperation among the DTT and LTE networks as other advanced techniques such as cognitive radio or low duty cycle. The first advanced technique consists on an adaptive and intelligent radio and network technology that can automatically detect available channels in a wireless spectrum. The second one can reduce the average interference to the existing radio systems by lowering pulse repetition interval or pulse occupation time.

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 to be made in Region 1 in the 700 MHz band (the actual range is to be decided in WRC-15). The main difference compared to the 800 MHz band lies in the fact that the uplink (UL) is located in the lower part, instead of the downlink (DL). Since cellular terminals are closer to the DTT receivers than base stations, interference issues may be more relevant than for in the 800 MHz band. Implementing the DD2 within ITU Region 1 may affect up to eleven more DTT channels (49-60), creating a number of challenges. A DD2 may be particularly problematic in countries where terrestrial television is the main distribution platform, such as the United Kingdom, France, Spain, Portugal and Italy. For most countries, releasing the 700 MHz band will require a new re-tune of existing DTT networks. On the other hand, the DD2 may be an opportunity for introducing new DTT standards (e.g. Digital Video Broadcasting – Terrestrial second generation, DVB-T2) and codecs (e.g. High Efficiency Video Coding, HEVC) to increase the spectral efficiency of the networks to provide new services (e.g. Ultra High Definition TV, UHDTV).

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. For the particular case of the 700 MHz band, in [5] the coexistence issues between the IMT and the LTE systems are analyzed, with a system-level simulation based on the Monte Carlo methodology, obtaining how mutual interference influences the Quality of Signal (QoS) of both systems. In [6], CEPT analyzes the link budget to determine the minimum requirements for a correct coexistence between DVB-T2 and LTE, in case of DTT fixed outdoor and portable indoor reception in the European scenario. In [7], several PRs for DVB-T interfered by LTE DL in the 800 MHz band, and minimum distances between LTE base stations and DTT receivers are recommended. In [8], an analysis of interference from the DTMB (Digital Terrestrial Multimedia Broadcast) system below 698 MHz to the LTE system is performed. However, there are no general results about the influence of physical layer parameters on coexistence between DVB-T2 and LTE for any configuration at Regions 1 and 2, in the 700 MHz band. Moreover, this study can be easily extrapolated to any other situation in similar conditions. It should be mentioned that if other broadcasting standard such as DVB-T, ISDB-T or DTMB was used, the results obtained would be similar with a margin (as a disadvantage, equivalent coverage modes would transmit with lower capacity).

In this paper, the coexistence problem between LTE-UL signals and DVB-T2 in the 700 MHz band is analyzed in a generic way. The main objective is to obtain measured PRs between LTE and DTT signals for representative cases and evaluate the interference in most critical scenarios by using these PRs. Thus, in a complete link budget with DTT fixed reception, it is possible to know if a professional/domestic low pass filter is required, and in such a case, the out-of-band attenuation that it needs. When DTT portable indoor reception is used, minimum distances between LTE UE and DTT receiver, for different UE powers, are recommended.

The rest of the paper is structured as follows. Section II describes the scenarios where the potential interference problem could exist. In Section III, the methodology used for measurements is detailed. Section IV presents the results of the study, and analyzes the influence of some aspects like LTE traffic loading, bandwidth (BW) or DTT standard. Section V shows a particular coexistence study based on the 700 MHz band problem. Finally, the main findings of the work are summarized in Section VI.

II. Coexistence Scenarios

In this study, scenarios have been classified according to: the type of LTE interfering link adjacent to DTT: UL or DL; the DTT reception type: portable indoor or fixed outdoor; and the position of the LTE cellular phone (User Equipment, UE): inside or outside the building. Two worst-case scenarios have been identified, as shown in Fig. 1:

- Scenario 1: LTE-UL interfering fixed rooftop DTT reception with the UE outside the building.
- Scenario 2: LTE-UL interfering portable DTT indoor reception with the UE inside the building in the same room than the DTT receiver.

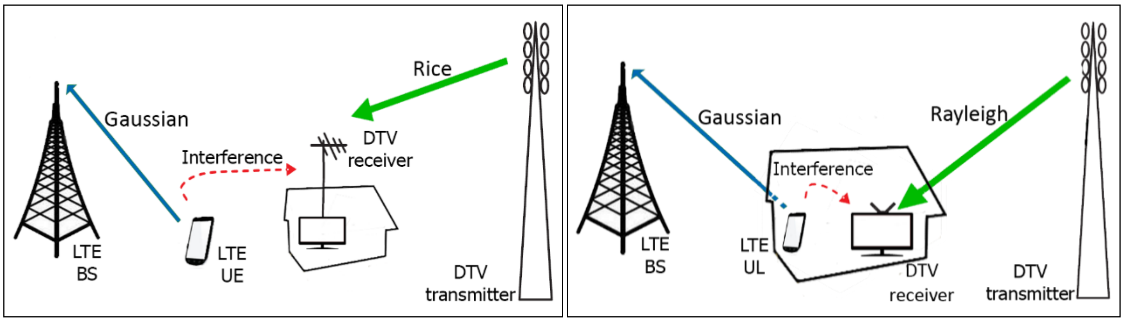

Fig. 1. Critical scenarios for LTE-UL interference: fixed (left) and indoor (right) DTT reception.

For fixed rooftop DTT reception, the worst case is when the UE is in Line-of-Sight (LoS) with the DTT antenna at the distance that maximizes the interference. Obviously, if the UE is inside the building the interfering signals will experience an additional penetration loss. The same idea applies for portable indoor DTT reception scenarios, where the UE is in a different room than the DTT receiver or outside the building. For both scenarios, the worst case is when the DTT receiver is just at the coverage edge, receiving the minimum required DTT signal power, and the UE transmits the maximum possible power level (23 dBm).

III. Methodology

Followed methodology is mainly divided in two steps. The first step consists on measuring interference protection ratios (PR) 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. In adjacent channel interference, lower PRs imply that higher interfering signal levels are allowed (even higher than the useful signal level) and hence, there are lower interferences in a real scenario. From the calculated PR, the second step consists on performing a complete link budget analysis.

The procedure to measure PRs between LTE and DVB is defined in the Recommendation ITU-R BT.2215 [9]. This QoS procedure is called Subjective Failure Point (SFP) method. The SFP method corresponds to the picture quality where no more than one error is visible in the picture for an average observation time of 20 s. The adjustment of the wanted and unwanted signal levels for the SFP method is to be carried out in small steps, usually in steps of 0.1 dB. Signals and channel models used in this recommendation are defined in the Recommendation ITU-R BT.2033 [4]. To emulate the DVB-T2 and LTE signals, two independent signal generators and a channel emulator have been used. Three TV sets and two set-top boxes were used as DTT receivers. All measurements have been done considering a Gaussian channel. Other channels can be taken into account by adding a margin.

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 Fig. 1.

Table I shows 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 AND LTE INTERFERING SIGNALS PARAMETERS

DTT			LTE		
Parameter	Fixed Rx	Fixed Rx	Parameter	UL value	DL value
Standard	DVB-T2	DVB-T2	Multiplex	SC-FDMA	OFDM
Modulation	256-QAM	64-QAM	FFT	1024	1024
Code Rate	2/3	3/5	Guard Interval	Normal (4.7 µs first symbol, 5.2 µs next)	Normal (4.7 µs first symbol, 5.2 µs next)
FFT	32K Extended	16K Extended	Bandwidth	5 / 10 /15 / 20 MHz	5/ 10 / 15 / 20 MHz
Guard Interval	1/128 (28 µs)	1/8 (224 µs)	Traffic Loading	1 / 10 / 20 Mbit/s	IDLE / 50% / 100%
Pilot Pattern	PP7	PP3			
Bandwidth	8 MHz	8 MHz			

The impact of the three following LTE parameters is studied [4]:

- LTE interfering link: UL or DL.
- 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.

Only LTE parameters that affect the useful DTT signal are considered. Using different types of LTE modulation or coding rates will not affect the DTT communication, as they do not change the shape of the LTE signal. In this manuscript, all traffic loads and configurations have been considered for a QPSK modulation [10]. The variation of the 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.

To perform a complete link budget, it is necessary to obtain the required PR for adjacent channel and also compare with the measured adjacent channel and co-channel PRs, in order to estimate the required Adjacent Channel Interference Ratio (ACIR) at the UE. Thus, a low pass band filter will be necessary if the Adjacent Channel Selectivity (ACS) value is not higher than the ACIR [6]. In a scenario with portable indoor DTT reception, the measured PRs are used in order to calculate the minimum distance between the LTE UE and DTT receiver to avoid interferences.

Results are given for Region 1 DD2 conditions, where the guard band between last DTT channel and 4G LTE-UL may be 1 or 9 MHz (to be decided in WRC-15). Results for Region 2, in which the guard band is 5 MHz, can be calculated following the same procedure.

IV. PROTECTION RATIO MEASUREMENTS

A. Influence of LTE Signal Variation

1. LTE Traffic Loading Effect

Fig. 2 shows the measured PRs for DTT fixed reception, for all considered traffic loads as a function of the guard band from 0 to 11 MHz. In these measurements, the LTE BW is fixed on 10 MHz. As it can be observed, 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. For the indoor reception mode, all PRs can be extrapolated by subtracting a margin of 6 dB.

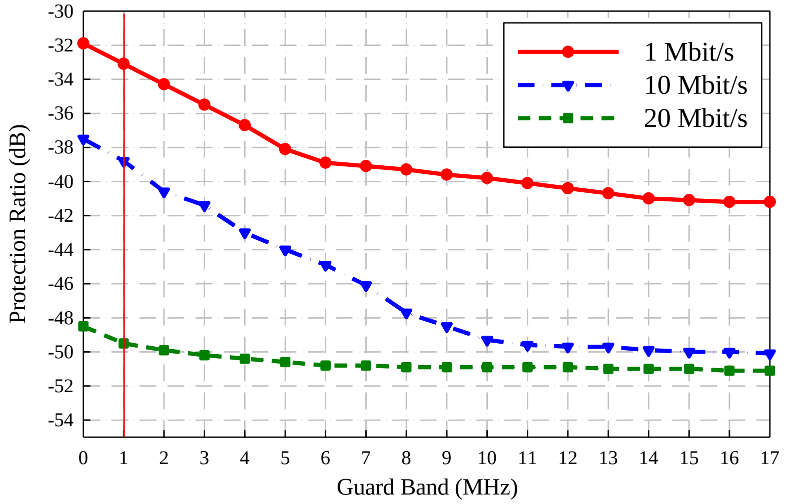

Fig. 2. Protection ratios for DTT interfered by LTE-UL with a bandwidth of 10 MHz, for different traffic loadings.

2. LTE Bandwidth Effect

Fig. 33 shows the LTE-UL signal BW effect as a function of the guard band for the worst traffic load (i.e. 1 Mbit/s). 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. For 5 MHz LTE channel, the occupied BW is 4.5 MHz while for 20 MHz the occupied BW is 18 MHz. Therefore, the real guard band is 0.25 MHz higher for 5 MHz channelization and 1 MHz higher for 20 MHz one. For the DTT indoor reception mode, all PRs can be extrapolated also by subtracting a margin of 6 dB.

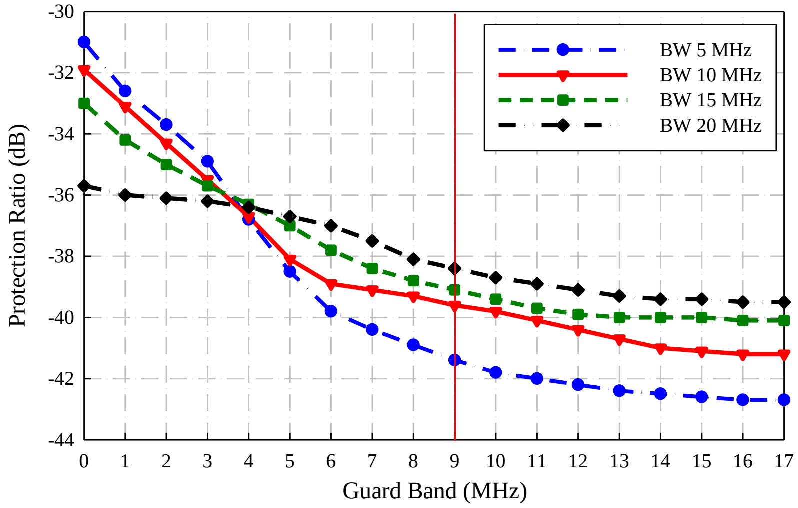

Fig. 3. Protection ratios for DTT interfered by LTE-UL for different LTE BW.

3. 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.

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 1 dB for fixed reception (Rice channel) and 2 dB for portable reception (Rayleigh channel).

V. Coexistence Analysis in the 700 MHz Band

In this section, a complete link budget for fixed and portable indoor reception is performed. From Fig. 3, the difference in PRs is from 3 to 10 dB worse, depending on the LTE BW. For a guard band of 9 MHz and LTE-UL signal BW of 10 MHz, the required PRs for fixed outdoor and portable indoor DTT reception are -39 dB and -44 dB, respectively.

A. Fixed Outdoor DTT Reception

Table II shows the link budget parameters for fixed DTT outdoor reception. LoS between the UE and the fixed DTT antenna has been assumed.

TABLE II
700 MHz Link Budget parameters

DTT antenna		LTE UE	
Parameter	Value	Parameter	Value
Noise figure	7 dB	Maximum transmitted power	23 dBm
Equivalent noise Bandwidth	7.6 MHz	Typical rural/urban power	2 / -9 dBm
Antenna gain	9.15 dBi	Antenna gain	- 3 dBi
Height	10 m	Height	1.5 m
Pattern	Directive [2]	Pattern	Omni
BW	8 MHz	BW	10 MHz

The required PR to avoid interferences can be computed from the minimum required DTT power, P_{min}, by subtracting the LTE interference, I, and adding the receiver desensitisation value δ. The receiver desensitisation is caused by the odd order intermodulation products within a receiver amplifier or mixer chain, which reduce the wanted signal strength. A typical value for commercial receivers is 1 dB.

The minimum required power for demodulating DTT signals depends on the transmission mode. Assuming a minimum CNR_{min} of 19.9 dB, a receiver noise figure and an equivalent noise BW as defined in Table II, the minimum power required is -78.2 dBm ($P_{min} = 10log(kTB) + NF + CNR_{min}$).

The received LTE interference at the DTT receiver is given by (1), where P_{TX} is the LTE UE transmit power, G_{TX} the LTE UE antenna gain, FSL is the free-space attenuation, G_{DIR} is the net gain of the DTT antenna including feeder loss, G_{RX} is the antenna discrimination associated with the vertical radiation pattern of the DTT antenna, and L_{body} is a term to account for body loss.

$$I = P_{TX} + G_{TX} - G_{DIR} + G_{RX} - L_{body} - FSL \tag{1}$$

For both UE and DTT antenna heights shown in Table II and both antenna patterns, the worst-case occurs at a horizontal separation distance of 23.6 meters, where the overall path gain between the UE and the fixed DTT antenna is higher, obtaining a free-space attenuation of 58.3 dB. Using a typical value for body loss (4 dB), the proposed DTT net antenna gain (Table II), vertical discrimination (-0.45 dB) and free space loss at 700 MHz (58.3 dB), 53.6 dB of total path gain are obtained. If a LTE UE transmits using the maximum power P_{TX} and the antenna gain G_{TX} shown in Table II, the received interference at the DTT receiver is given by (1).

Using this equation, the received IMT power at the reference geometry is -33.6 dBm. In this case, the required PR is -50.5 dB. The measured PR calculated for the critical case was -39 dB, which is 11.5 dB higher (worse) to the required PR.

To measure the co-channel PR, both technologies DTT and LTE were centered at 786 MHz (channel 60 of DTT). The result was 15 dB for the worst case, i.e. when the interfering LTE signal has a 20 Mbit/s traffic loading (not 1 Mbit/s, as occurs with adjacent channel interference).

As mentioned before, the measured PRs for adjacent channel and co-channel are necessary to estimate the required ACIR at the UE. A low pass band filter will be necessary if the ACS measured is not higher than the ACIR required. ACIR can be calculated as the co-channel PR minus the required PR. In (2), equation used for calculating the ACS is shown.

$$ACS(dB) = -10\log\left(10^{-\frac{PR_{CO} - PR_{meas}}{10}} - 10^{-\frac{ACLR}{10}}\right) \tag{2}$$

Where *ACLR* (~80dB) is the ratio of the transmitted power (LTE-UE) to the power in the adjacent radio channel (DTT) required to restrict the interference to a level equivalent to a loss of sensitivity of 1 dB. An ACIR of 65.5 dB is obtained. From (2), an ACS of 54 dB is calculated. As the ACS value must be higher than the ACIR one, an extra low pass filter is needed with at least 11.5 dB out-of-band attenuation. This out-of-band attenuation is feasible with a domestic low past filter, taking into account that the guard band between technologies is 9 MHz. However, a filter may not be required if the UE transmits with a lower power or if the DTT received input power is higher than the minimum threshold. The actual conditions for no requiring a filter are:

- If LTE transmitted power is lower than 11 dBm. For typical powers for rural and urban environments (2 and -9 dBm, respectively), this filter is not need.
- If DTT received power is higher than -66 dBm.

B. Portable Indoor DTT Reception

In a scenario with portable indoor DTT reception, the minimum distance between the LTE UE and DTT receiver to avoid interferences, d_{min}, can be computed as:

$$d_{min} = 10^{\frac{147{,}56 - 20\log(f) - G_{CG} + G_{WL} + L_{body} + G_{RX}}{20}} \tag{3}$$

Where f is the frequency, G_{CG} is the coupling gain calculated as the received interfering power level minus the maximum allowed one, G_{WL} is the additional wall loss and L_{body} is an additional loss due to human body.

The parameters of the DTT antenna are defined in Table II, by changing the antenna gain to 2.15 dBi. Assumed parameters for LTE UE in this study are also shown in Table II. It is assumed that UE and DTT receiver are in the same room. Assuming the same noise power that in the previous section, the maximum allowed interfering power is -104 dBm. In addition, assuming an ACS of 80 dB, typical of DTT receivers, the interfering received LTE power is -56 dBm. Therefore, the coupling gain, G_{CG}, is -47.7 dB. Taking a wall loss of 0 dB (DTT antenna and UE are in the same room) and a coupling gain of 2.15 dB, the total link loss is -45.8 dB. Finally, it is possible to obtain the minimum distance between UE and DTT from the free-space model formula (3).

This distance, in the most critical case is 6 m. In practice, UE will rarely operate at maximum power. The actual transmit power of a UE is influenced by a number of factors including its location in relation to its serving cell, whether it is indoors or outdoors, the specifics of the scheduler and power control algorithms employed, the data-rate demanded, etc. For this reason, minimum distances for typical powers of rural and urban environments have been calculated. These results are presented in Table III. Results show that using a typical band pass filter with 8 dB of out-of-band attenuation at the receiver input and leaving higher guard bands offer better behaviors.

TABLE III
MINIMUM DISTANCES BETWEEN UE AND DTT RECEIVER,
FOR DIFFERENT DTT CHANNELS. WITH OR WITHOUT BAND PASS FILTER

LTE Power	GB 9 MHz, without filter	GB 9 MHz, with filter	GB 17 MHz, without filter	GB 17 MHz, with filter
Max: 23 dBm	6 m	3.1 m	4.5 m	2.1 m
Rural: 2 dBm	0.6 m	0.45 m	0.55 m	0.3 m
Urban: -9 dBm	0.2 m	0.14 m	0.17 m	0.1 m

From Table III, results are critical with a maximum UE transmitted power of 23 dBm. For typical powers of rural and urban environments, minimum distances can be totally assumed. Maximum UE transmission power to allow any distance between both devices is -13 dBm.

VI. CONCLUSIONS

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 protection ratios (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.

Regarding the link budget analysis performed for a 9 MHz guard band between DTT and LTE-UL, which is likely to be the case for Region 1, it is concluded that:

- For fixed outdoor DTT reception, an extra low-pass filter with an out-of-band attenuation of 12 dB is needed for the critical case. There are two conditions for no requiring a filter: when the LTE transmitted power is lower than 11 dBm, and when the DTT received power is higher than -66 dBm, 12 dB over the threshold.

- For portable indoor DTT reception, the minimum distance between the LTE-UE and the DTT receiver to avoid any interference is 6 m. With a low-pass filter, this distance is reduced to 3.1 m. For typical values of LTE-UE transmit power, the minimum distances without filter are 0.6 m in rural environments and 0.2 m in urban environments (2 dBm and -9 dBm transmit power, respectively). Maximum UE transmission power to allow any distance to the DTT antenna is -13 dBm.

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BIOGRAPHIES

Manuel Fuentes received the Telecommunications Engineering degree in 2012 from the Universitat Politècnica de València, Spain. In 2013 he also obtained a second M.Sc. degree in Communications Technologies, Systems and Networks. He participated in several R&D projects focused on coexistence between DTT and 4G (LTE) technologies. He is a current member of the DVB and ATSC forums. Now, he is studying his PhD degree, and his research interests are focused on BICM and MIMO systems.

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