DTT Performance Degradation in Presence of Coexisting LTE Network Interference

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***Abstract*—This paper investigates the Digital Terrestrial Television (DTT) performance degradation in presence of interference from the Long Term Evolution (LTE) mobile services operating in adjacent frequency band. The simulated DTT performances reveal the importance of the coexistence analysis between the LTE and the DTT networks. The proposed methodology investigates the degradation of the DTT service reception taking into account the aggregate LTE interference effects on the DTT systems that operate in the upper part of the DTT band. The relevant evaluation metrics are: the percentage of affected pixels (locations) and the probability of service degradation taking the territory of the Republic of Macedonia as evaluation area. The obtained simulation results identify the most critical locations that might require interference management, in order to ensure an acceptable TV service quality.**

Keywords—DTT, LTE, BS, overloading threshold, interference assessment, protection ratio, service degradation

I. Introduction

The Digital Switchover process is already completed in the majority of countries, providing the new communication technologies to gain access to the part of the UHF TV band [1]. In particular, the World Radiocommunication Conference 2007 (WRC-07) has re-allocated the band 790-862 MHz (TV channels 61 to 69) to mobile services on a primary basis. This band (referred as Digital Dividend 1) is identified for IMT (International Mobile Telecommunications) starting from 2015 in Region 1. The European preferred frequency arrangement of this band consists of frequency-division duplex (FDD) of 2×30 MHz, with a duplex gap of 11 MHz [2]. The FDD downlink starts at 791 MHz, while the FDD uplink starts at 832 MHz, introducing 1 MHz guard band between the mobile and broadcasting services [2].

The WRC-07 decision enforce the emergence to cope with new interference issues, due to the necessity to enable coexistence of digital broadcast television and mobile services in two adjacent frequency bands. These interference issues are mainly due to the spectral proximity and the facts that the existing DTT receivers are designed to receive signals on channels that now are allocated to the LTE mobile network. In particular, the most susceptible households to DTT coverage degradation due to interference from the adjacent-frequency LTE base stations are those that receive the television signal on channels 59 and 60.

There are several extensive efforts to assess the influence of the LTE mobile services to the reception in the existing DTT bands. Previous works generally focus on the DTT system that has to be protected, by providing the operational constraints for the LTE system, considered as an interferer. The European Conference of Postal and Telecommunications Administrations – CEPT, issued a report that defines the set of common and minimal (least restrictive) technical conditions optimized for mobile communications networks, whilst enabling the protection of the broadcasting DTT services that operate according to the Geneva 2006 agreement [3]. Lately, initial extensive measurement activities address the problem of coexistence and assess different possible origin of interference. The authors of [4] describe the significant impact of the LTE network topology (Base Stations placement in relation to the DTT transmitters, antenna directivity, antenna polarization) on the interference generated to the DTT service. In [5], the authors report the performance measurements of DTT receivers operating in the 470–790 MHz band, in presence of interference from LTE service in the 790–862 MHz band. These results are in line with the results presented in [6] that describe the impact of UMTS (Universal Mobile Telecommunications System) on DTT receivers. In the past few years, Ofcom (the UK regulatory body) has initiated several measurement trials in the UK related to this topic [7], [8]. Furthermore, Ofcom proposed an algorithm (software tool) that predicts the interference to DTT receivers from mobile services in the 800 MHz band [9]. The authors of [10] and [11] propose several techniques for interference mitigation, using in-line filters installed before the receiver amplifier. Installing an RF filter at the input of the DTT receiver preamplifier mitigates interference in several field trials performed in European countries [12].

The measurement results based on practical trials for LTE and DTT coexistence provide the carrier-to-interference protection ratio (PR) and overloading threshold (O_{th}) assuming single LTE interferer [10]. The obtained PR and O_{th} from the measurement trials at the ERA Technology site in Leatherhead will serve as a base for the simulation analysis presented in this paper. This paper extends the coexistence analysis in the trials in terms of the aggregate interference generated from random distributions of LTE base stations into the DTT service. In this manner, we evaluate the DTT service quality degradation on channels 60 down to 52, in order to account for the N+9 effect, where certain DTT receivers become particularly susceptible to adjacent channel interference [7]. This susceptibility is due to the adjacent channel selectivity (ACS) characteristic of the DTT receivers [7]. The ACS characterizes the overall behavior of the receiver in response to adjacent channel interference.

The paper is organized as follows: after the introduction, Section II describes the DTT system modeling and presents the relevant metrics. The proposed criteria for interference assessment are presented in Section III, while Section IV evaluates the performances of these criteria, presents and discusses the obtained results. The last section concludes the paper and pinpoints the possible directions for further activities in this research area.

II. DTT Coverage Assessment and Relevant Metrics

This section presents the general aspects of the DTT system modeling and the relevant metrics used in the interference assessment methodology.

The DTT network is a multi-frequency network, introducing the use of multiplexes. Each of the DTT multiplexes is carried on different frequencies in different geographical areas. A multiplex aggregates several digital signals together into a single digital signal, which is then transmitted over 8 MHz channel [13]. In the Republic of Macedonia, there are seven multiplexes supporting the existing TV services available over the DTT network [14].

A. DTT system model

The Agency for Electronic Communications (the Macedonian regulatory body responsible for broadcasting network planning, configuration and derivation of operational constraints [14]) provides the DTT planning and operational parameters. TABLE I. presents the DTT parameters used in the evaluation process of this paper.

TABLE I. DTT planning parameters

Reception	*E_{med} [dB(µV/m)]*	*Operating channels*	*Time variability [%]*	*Location variability [%]*
fixed	56	21 – 60 (470 – 790 MHz)	95	99

We use the open source software (SPLAT! [15]) for RF signal propagation and path loss computation (including the terrain effects), simulating a real terrestrial television broadcasting network and deriving minimal median coverage area range for DTT reception without degradation. This type of DTT coverage estimation does not incorporate constraints regarding cross-border frequency arrangements in the band of interest. The SPLAT! software implements a Longley Rice Irregular terrain model to predict the signal propagation losses taking into account parameters such as: earth conductivity, relative permittivity, atmospheric bending constant, antenna polarization and height above ground level. It also incorporates digital elevation data provided by NASA. This data is publicly available in SRTM format with 90 meters of resolution. For the purposes of this analysis, the SPLAT! software generates sufficiently accurate DTT coverage maps based on F(95,99) criteria. These criteria denote the maximum path loss that occurs in 95% of the cases (Location variability) and 99% of time (Time variability). Due to the absence of TV service transmission on channels 60 and 58, and the considerably small DTT coverage area on channel 59, Fig. 1 illustrates the DTT coverage area for channel 57 (the marked zone), employing the described methodology for coverage map generation. The pixels located outside this coverage area have significantly degraded location probability and therefore, non-acceptable TV reception quality. These DTT coverage areas serve as a base for the evaluation process of the DTT-LTE coexistence scenarios as one of the major concerns regarding efficient spectrum management when mobile operators will start to exploit the Digital Dividend 1.

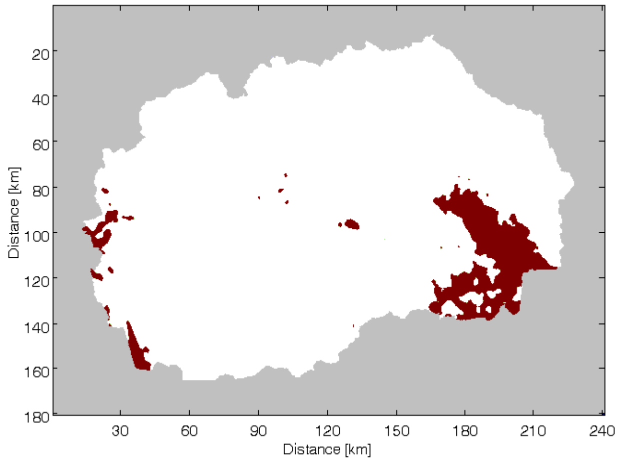

Fig. 1 DTT channel 57 coverage area

B. Relevant metrics

The CEPT Report 30 [3] introduces some basic definitions of the metrics relevant to the coexistence of the LTE and the DTT services that operate on different frequency separations in the UHF band. Three of them are the most important:

1) RF signal to interference plus noise ratio ***(C/(I+N))****:* Ratio expressed in dB, between the power of the wanted signal and the power of the interfering signals and noise, evaluated at the receiver input.

2) RF protection ratio ***(PR)****:* The minimum value of the signal-to-interference ratio required to obtain specified reception quality under specified conditions at the receiver input, defined as a function of the frequency offset between the wanted and the interfering signals. It reflects the receiver ability to operate under interfering signals on frequencies differing from that of the wanted signal.

3) Receiver overloading threshold ***(O_{th})****:* The interfering signal level expressed in dBm, above which the receiver starts to lose the ability to discriminate against interfering signals at frequencies differing from that of the wanted signal. Exeeding this threshold will result in the receiver acting in non-linear manner.

The following section presents the implementation of these metrics in the evaluation of the LTE and DTT coexistence.

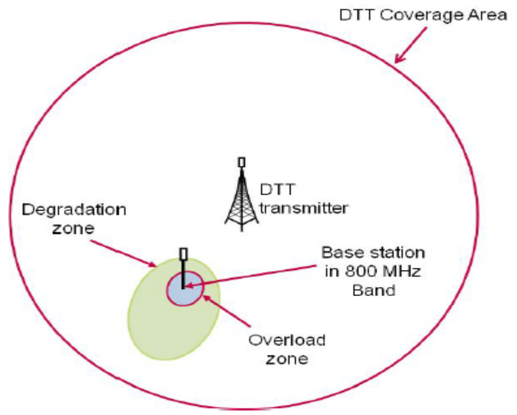

Fig. 2 SINR degradation and overload [7]

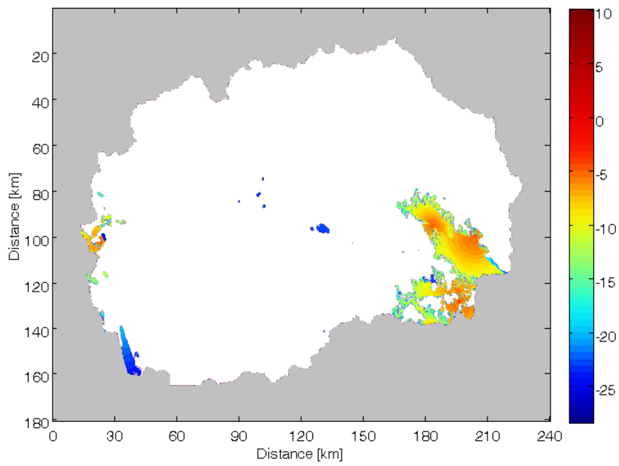

Fig. 3 DTT channel 57 maximum tolerable interference level [dBm]

III. Interference Assessment Methodology

There are two possible interference manifestations, (produced by the LTE base stations that operate in the digital dividend band 1), which can affect the reception of the DTT services [7]:

1) SINR degradation: If the ratio between the wanted signal and the interfering signals including the noise (SINR at the receiver input) drops below a certain threshold specified for a particular channel, the DTT receiver fails to operate correctly and the reception of the transmitted multiplex will be lost or degraded.

2) Overload: If the power of all unwanted signals at the DTT receiver input exceeds the overload threshold, the DTT receiver becomes overloaded and the reception of the DTT services is lost.

Fig. 2 illustrates the Overload and SINR degradation zones within the DTT coverage area where the reception of the Digital TV service is lost due to the LTE Base Station operation in 800 MHz band.

This paper presents the performance assessment of the interference from the LTE mobile network to the DTT services. The simulation analysis accounts for the total (aggregate) interference from multiple deployed LTE base stations into a standard DTT receiver (Set Top Box). The analysis uses the obtained *Protection Ratios* and *Overloading Thresholds* from the measurements conducted in the UK ([10]). These measurements assume interference from a single LTE interferer into a single DTT receiver (considering different classes of DTT receivers).

The paper focuses on the receiver with the worst characteristics (in terms of interference tolerance), in order to account for the worst-case scenario. We use linear interpolation (according to the PR curves obtained from measurements and depicted in Figures 10-15 in [10]) to derive protection ratios for intermediate values of wanted DTT signal level C, and for appropriate interferer-victim frequency separations. The simulation analysis uses the obtained Protection Ratios to evaluate the aggregate interference generated from the total number of the LTE BSs that operate on channel 61 (796 MHz or block A) onto DTT channels from 60 down to 52, for different values C, of the received DTT signal power. The analysis considers 9 DTT channels for evaluation, since the interference into the DTT channels below 51 is negligible [7].

The interference assessment strategy in this paper is the DTT channel based. Applying the appropriate protection ratio, Fig. 3 illustrates the maximum tolerable interference level expressed in dBm (overloading threshold) for DTT broadcasting network transmitting multiplexes on channel 57. This heat map representation is pixel wise, where each pixel represents a 120m × 120m of actual territory in the reality. For each pixel, if the aggregate interference level exceeds the maximum tolerable interference threshold, there is TV service degradation and the DTT receiver becomes overloaded.

IV. Performance Evaluation

The scenario setup considers the LTE network deployment within the targeted area (territory of the Republic of Macedonia). A spatial Poisson Point Process defines the distribution of the LTE base stations, applying various densities over square kilometer. Each base station uses fixed in-block transmission power of 59 dBm (assuming typical LTE transmit power of 43 dBm and LTE typical antenna gain of 16 dB [16]) and operates on 10 MHz block (channel 61 or block A), with central frequency at 796 MHz. The analysis assumes Hata Suburban path loss model for propagation loss modeling of the LTE system. This path loss model also incorporates lognormal shadow fading with zero mean and standard deviation of 5.5 dB. The terrain is assumed to be flat, and the antenna radiation pattern is omnidirectional, in order to assess the maximum number of pixels affected by disturbing interference.

The performance evaluation focuses on each DTT channel from 60 down to 52, since the interference from coexisting LTE networks that operate on channel 61 (796 MHz downlink using FDD duplexing scheme) into the remaining DTT channels is negligible. In reality, since there is no DTT service transmitted on channels 60, 58 and 53 over the target area,

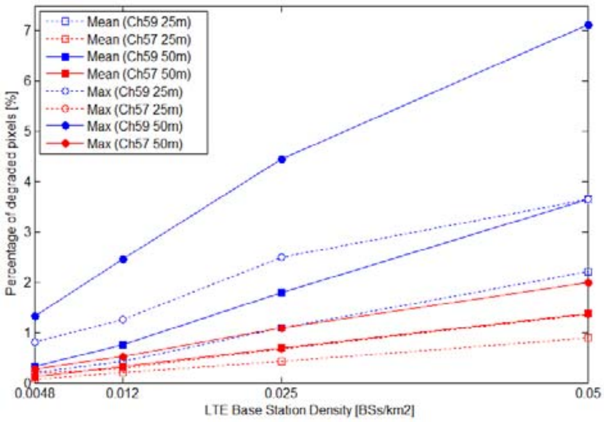

Fig. 4 Percentage of interference degraded pixels on channel 59 and channel 57

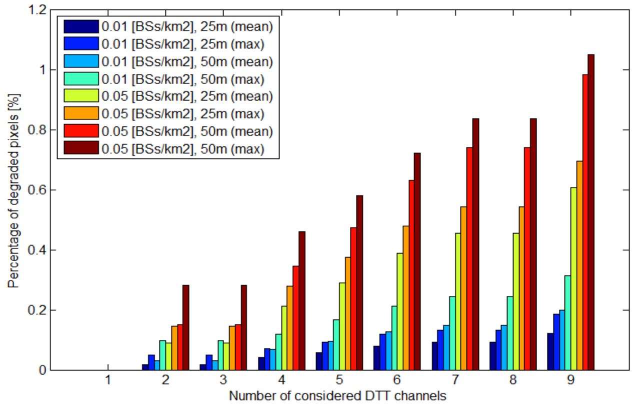

Fig. 6 Percentage of interference degraded pixels considering multiple channels degradation (1, 2, … , 9)

these channels are excluded from the evaluation process. The results are calculated averaging over 100 Monte Carlo trials in order to obtain indicative results. The analysis also considers the worst-case estimate (the maximum degradation) of all the 100 Monte Carlo realizations of random Poisson Point Process distribution of the LTE base stations.

Fig. 4 depicts the dependence of the percentage of locations affected by the interference from the coexisting LTE network, normalized by the number of pixels in the appropriate DTT coverage area, i.e. the percentage of pixels where the DTT receivers fail to operate efficiently and the reception of multiplexes on channels 57 and 59 is degraded. The *protection ratio* and *overloading threshold* are used as performance metrics for the calculation of the percentage of degraded pixels within the DTT coverage area. The figure shows that the number of deployed base stations and the LTE base station antenna height have significant effect on the number of pixels with DTT service degradation. It is also evident that the criteria for protection of DTT channel 59 needs to be more rigorous compared to channel 57. The DTT receivers tuned to channel 59 are more sensitive to interference from the LTE BSs, than those tuned to channel 57, due to the higher outband leakage from the LTE signals and the difference in the frequency offset.

Fig. 5 visualizes the probability of pixel DTT service degradation on channel 57. This heat map presents the spatial dependence of pixel DTT service degradation, illustrating the most critical pixels and the degradation probability per pixel, calculated using Monte Carlo simulation with 100 trials. In particular, this figure shows which pixels (locations) will be most probably affected by interference from the LTE base stations (assuming LTE base stations realization with random Poisson Point Process).

It is essential to jointly evaluate the impact of the LTE interference onto the multiple DTT channels (N-1, N-2, N-3 …, and N-9) where N represents the LTE operating channel (796 MHz). Fig. 6 depicts the dependence of the percentage of pixels affected by interference on any of the DTT channels 60 down to 52 within the observed territory by considering the interference on channels N-1, N-2..., N-9. The percentage of pixels with DTT service degradation rises with the increase of the number of considered channels. The figure can provide guidelines for management of the interference by choosing to protect the DTT service reception on channels that most probably will be affected and degraded.

Fig. 7 visualizes the probability of the pixel DTT service degradation on any of the affected DTT channels (from 60 down to 52) in the joint DTT coverage area of the inspected channels (i.e. a union of the coverage areas of the DTT channels 52-60, as illustrated in Fig. 8). This type of representation is pixel based and it considers multiple channels degradation per pixel. According to the Fig.7 heat map, a pixel is considered as degraded if any of the observed DTT channels

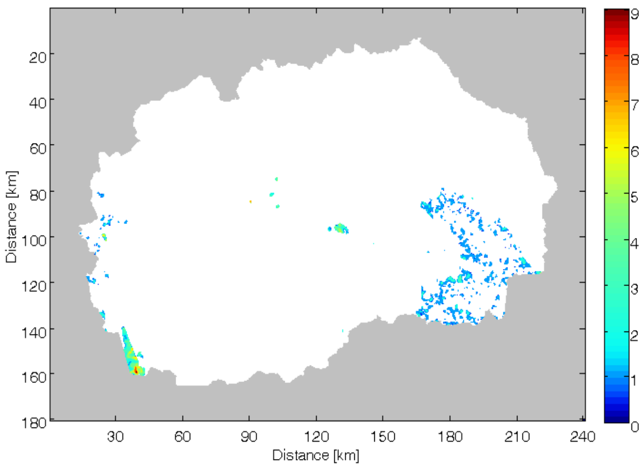

Fig. 5 Probability [%] for pixel DTT service degradation on channel 57 (LTE BSs density 0.05 [BSs/km^2] and 50m LTE antenna

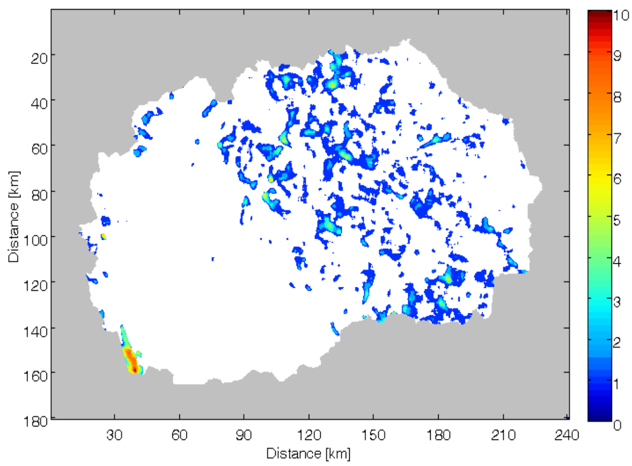

Fig. 7 Probability [%] for pixel DTT service degradation on channels 60 down to 52, (LTE BSs density 0.05 [BSs/km^2], 50m LTE antenna heights)

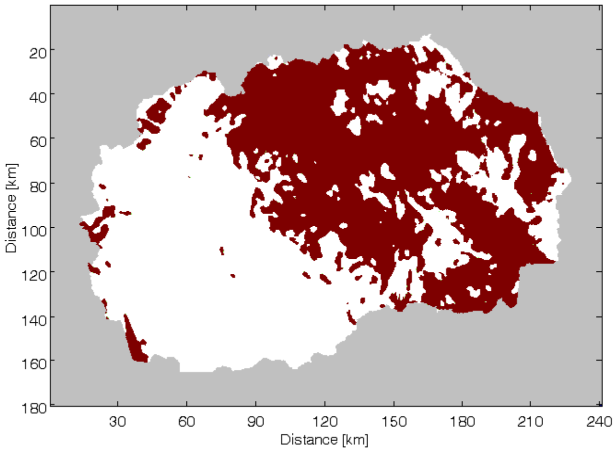

Fig. 8 DTT channels 60 down to 52 joint coverage area

(52-60) is degraded. It is also evident that only a subset of the pixels can be subject to degradation caused by interference, which depends on the density and the particular realization of the Poisson Point Process distribution of the base stations.

V. CONCLUSION

The 790 – 862 MHz (Digital Dividend 1) band re-allocation to the mobile services (LTE) implies the necessity to ensure spatial coexistence of the LTE and DTT networks that operate in adjacent frequency bands. Measurement trials presented in [10], derive the required Protection Ratio and Overloading threshold for efficient DTT service reception, based on single LTE interferer. Using the obtained PR and O_{th} for performance evaluation, this paper provides a simulation based aggregate interference assessment. The results reveal the existence of the DTT service degradation and the probability of degradation, considering one or multiple affected DTT channels, calculated for a particular LTE BSs distribution and density. The percentage of pixels degraded by the interference increases significantly with the number of deployed LTE BSs within the evaluation area. The effect of the LTE Base Station antenna height is also evident.

In order to account for more realistic LTE network deployment, the focus of the future work may broaden the proposed assessment strategy to include population densities, environmental characteristics (urban, suburban and rural), some terrain details and cross-border constraints. Introducing more advanced spatial point processes for generation of the scattered collection of LTE base station locations will also improve the relevance of the interference assessment methodology and thus, facilitate the definition of techniques for interference suppression.

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