http://dx.doi.org/10.5755/j01.eee.21.4.12788 ELEKTRONIKA IR ELEKTROTECHNIKA, ISSN 1392-1215, VOL. 21, NO. 4, 2015

Assessment of DVB-T Compatibility with LTE in Adjacent Channels in 700 MHz Band

Guntis Ancans[1], Evaldas Stankevicius[2], Vjaceslavs Bobrovs[1]
[1]*Institute of Telecommunications, Riga Technical University, Azenes St. 12-201, LV-1048, Riga, Latvia*
[2]*Vilnius Gediminas Technical University, Sauletekio al. 11, LT–10223, Vilnius, Lithuania*
guntis.ancans@rtu.lv

***Abstract*—The 2012 World Radiocommunication Conference allocated the 694 MHz-790 MHz (700 MHz) band to the International Telecommunication Union Region 1, which includes also Europe, for the mobile service on a co-primary basis with other services to which this band is allocated on a primary basis, and was identified to the International Mobile Telecommunications. However, countries of Region 1 will also be able to continue the use of these frequencies for their digital terrestrial television services, if necessary. This allocation will be effective immediately after the 2015 World Radiocommunication Conference. The objective of this paper is to assess the electromagnetic compatibility of Digital Video Broadcasting - Terrestrial operating below 694 MHz and mobile broadband (LTE) operating in 700 MHz band. The Minimum Coupling Loss method and Monte Carlo simulation within SEAMCAT software was used for interference analysis. An adjacent channel scenario between Digital Video Broadcasting - Terrestrial and LTE was performed to evaluate the impact of Digital Video Broadcasting - Terrestrial on LTE systems. The results obtained provide the minimum coupling distance required between Digital Video Broadcasting - Terrestrial and LTE in the 700 MHz band to maintain the necessary performance level of the LTE system.**

***Index Terms*—4G mobile communication, TV broadcasting, electromagnetic compatibility, frequency, interference, Monte Carlo method.**

I. INTRODUCTION

In response to proposals expressed at the World Radiocommunication Conference (WRC-12) by International Telecommunication Union (ITU) administrations, the conference drafted and adopted Resolution 232 (WRC-12) relating to the allocation of the frequency band 694 MHz-790 MHz (commonly referred to also as the *second digital dividend*) in Region 1 to the mobile service, except aeronautical mobile service (ITU Radio Regulations (RR) footnote 5.312 A), on a co-primary basis with other services to which this band is allocated on a primary basis and identified it to International Mobile Telecommunications (IMT). The allocation will become effective immediately after the 2015 World Radiocommunication Conference (WRC-15).

This frequency band has already been allocated to the mobile service in Regions 2 and 3 [1]. If the 694 MHz–790 MHz band is used for mobile service, then it corresponds to decrease of 12 digital terrestrial television (DTT) channels.

Resolution 232 (WRC-12) invites ITU-R to study the compatibility between the mobile service and other services currently allocated in the frequency band 694-790 MHz, including in adjacent bands [2]. This frequency range can be put into use only after all the necessary electromagnetic compatibility studies have been completed. These studies must be completed by the WRC-15.

The issue of electromagnetic compatibility becomes more substantial following the extreme development of mobile communications networks [3], [4]. The density of mobile networks is increasing at staggering rates. Such a process causes not only intra-cell interference between base or mobile stations, but also has influence on the adjacent frequency bands and existing services. Hence independent and equitable analysis is essential. Moreover, any system can not start to operate in the newly formed frequency band without evaluation of possible harmful influence to existing systems [5], [6]. This analysis allows to understand more detailed view on the possible deployment of LTE networks in the 700 MHz band.

The following generic case study elaborates on assessment of Digital Video Broadcasting - Terrestrial (DVB-T) when operating below 694 MHz compatibility with Long Term Evolution (LTE) operating in the 700 MHz band. Although these systems are placed in different frequency bands, there exists a probability of interference occurring from DVB-T transmitter to the LTE base station receiver. This interference can cause performance degradation in the LTE system. Therefore, it is essential to define frequency planning measures to protect receivers of LTE base stations from possible interference. The case study assesses the necessary minimum coupling distance between these systems in the 700 MHz band to maintain the necessary performance level of the LTE system.

Authors found that sharing and compatibility studies under WRC-15 agenda item 1.2 on assessment of DVB-T transmitters operating in DTT channel 48 and its impact on the LTE base station receiver operating above 703 MHz have not been performed within the ITU-R study group JTG-4-5-6-7 [7]. Therefore this paper contains an important part of assessment of DVB-T compatibility with LTE in

Manuscript received November 13, 2014; accepted April 19, 2015.

adjacent channels in 700 MHz band.

However authors found that in a study [8] presented results of the performance degradation of the mutual interference between the IMT and DTT operating in adjacent channels. The average cell throughput loss due to the interference from the DTT transmitter for various separation distances between the DTT transmitter and the LTE base stations was evaluated. It was observed that the throughput loss considerably decreases as the Adjacent Channel Interference Ratio (ACIR) increases. As a result, in order to keep the throughput loss below 5 %, separation distances of more than 13 km, 27 km, and 37 km are required for 76 dB, 66 dB and 56 dB of AICR, respectively. The Monte Carlo methodology was used in the study.

Unlike the abovementioned study this paper presents results of using both the Minimum Coupling Loss (MCL) and Monte Carlo method. This paper does not include an evaluation of AICR. Also different technical parameters of LTE and DTT systems, propagation models and compatibility evaluation methodologies were used in these two studies. Common technical parameters of DVB-T and LTE, agreed within the ITU-R study group JTG-4-5-6-7, were used in our study.

The paper is organized as follows. The second chapter is devoted to the technical characteristics. The third chapter represents the protection criteria. The fourth chapter is devoted to the compatibility evaluation methodology. The fifth chapter describes the compatibility scenario. The sixth chapter is devoted to the compatibility analysis and results, and in the last one conclusions are derived.

II. Technical Characteristics

The study contains an assumption of a preferred frequency division duplex (FDD) channelling arrangement which contains confined 2 × 30 MHz block aligned with 3GPP band 28 lower frequency: 703 MHz–733 MHz (uplink) and 758 MHz–788 MHz (downlink). The 700 MHz band channel arrangement is presented in Table I.

TABLE I. 700 MHz BAND CHANNEL ARRANGEMENT.

694-703	703-733	733-758	758-788	788-791
Guard band	LTE Uplink	Duplex gap	LTE Downlink	Guard band
9 MHz	30 MHz	25 MHz	30 MHz	3 MHz

This channel arrangement establishes possible interference problems between TV broadcasting and LTE networks. The most critical situation is between the DTT channel 48 (686 MHz–694 MHz) and the first LTE uplink channel (703 MHz–713 MHz). LTE (4G mobile communication) [9] channels with 10 MHz bandwidth were used in this study in order to evaluate a more realistic scenario where one mobile operator uses one 2 × 10 MHz frequency block.

A. DVB-T Parameters

The DVB-T parameters used in this study are summarised in the following table. The parameter values used are taken from inputs to JTG 4-5-6-7 from WP6A for DVB-T [10]. The basic characteristics of DVB-T are presented in Table II.

The out-of-band (OOB) emission level, which interferes with the receiver of the LTE base station, is the most sensitive factor of DVB-T. The spectrum emission mask of DVB-T station is presented in Fig. 1. This spectrum emission mask conforms to the GE06 Agreement [11].

TABLE II. BASIC CHARACTERISTICS OF DVB-T.

Parameter	Value
Frequency	690 MHz
Channel bandwidth	8 MHz
e.r.p.	200 kW (high power)
e.i.r.p.	85.15 dBm
Tx antenna height	300 m
Rx antenna height	10 m
Rx antenna pattern	Horizontal: omnidirectional BT.419
Rx antenna gain (including feeder loss)	9.15 dBi
SNR	21 dB (for fixed reception)
Feeder loss	3 dB
DVB-T coverage range	70.53 km (using P.1546-4 with 10 m clutter)

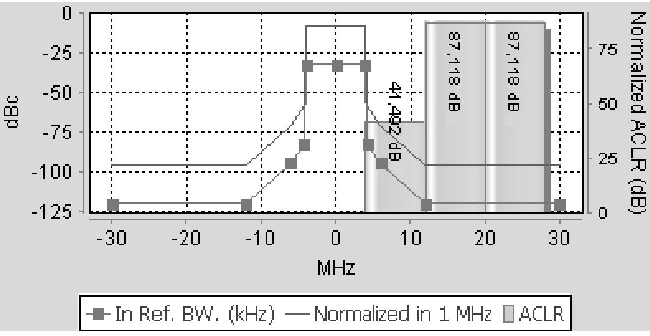

Fig. 1. DVB-T station spectrum emission mask.

This spectrum emission mask describes the harmful interference level in the newly formed LTE frequency band. The adjacent channel leakage ratio (ACLR) of DVB-T station is shown for better understanding of the OOB level.

B. LTE Parameters

The LTE parameters used in this study are summarised in the following tables. The parameter values used are taken from inputs to JTG 4-5-6-7 from WP5D for IMT (LTE) [12] and Report ITU-R M.2292-0 [13].

The basic characteristics of LTE bases station are presented in Table III.

TABLE III. BASIC CHARACTERISTICS OF LTE BASE STATION.

Parameter	Value
Tx frequency	763 MHz
Rx frequency	708 MHz
Channel bandwidth	10 MHz
Signal bandwidth	9 MHz
Maximum output power	46 dBm
e.i.r.p.	58 dBm
Antenna height	30 m
Antenna gain	15 dBi
Feeder loss	3 dB
Base station (BS) antenna pattern	ITU-R F.1336 with k = 0.7
Antenna downtilt	3 degrees
Noise figure	NF = 5 dB
Cell size/radius	8 km (macro rural scenario)
Sectorization	3 sectors
Antenna polarization	± 45 degrees
Reference sensitivity	-101.5 dBm
I/N	-6 dB
Receiver blocking mask	Table 6.6.3.2.1-3 of 3GPP TS 36.104 (V11.2.0)

The receiver blocking (filter) mask is the most critical parameter of the LTE base station in this study. The receiver blocking mask of LTE base station is presented in Fig. 2.

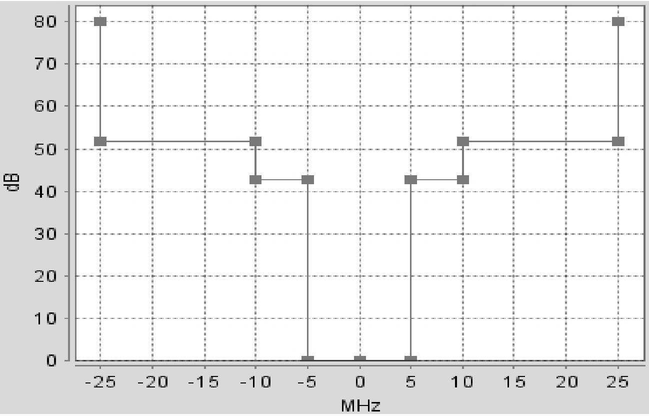

Fig. 2. LTE base station receiver blocking mask.

The receiver mask shows the selectivity level of the particular device. This characteristic conforms to 3GPP TS 36.104 recommendation. It can be considered as the least restrictive technical condition for LTE BS. The basic characteristics of LTE user equipment (UE) are presented in Table IV.

TABLE IV. BASIC CHARACTERISTICS OF LTE USER EQUIPMENT.

Parameter	Value
Tx frequency	708 MHz
Rx frequency	763 MHz
Channel bandwidth	10 MHz
Maximum output power, e.i.r.p	23 dBm
Antenna height	1.5 m
Antenna gain	-3 dB
Body loss	4 dB
Receiver thermal noise	NF = 9 dB
Reference sensitivity	-95.5 dBm
Number of active LTE UE per BS cell	3

All LTE user equipment parameters conform to 3GPP TS 36.101 recommendation.

III. PROTECTION CRITERIA

Two methods were used in this study to assess the interference from DVB-T to LTE service, namely Minimum Coupling Loss (MCL) and Monte Carlo simulation. Two different protection criteria were used to analyse the interference from DVB-T to LTE:

a) the protection criterion used in MCL calculations – $I/N = -6$;

b) the protection criterion used in Monte Carlo simulations – the minimum throughput should be not less than 95 % of the maximum throughput of the channel. This criterion was derived from 3GPP TS 36.104 recommendation.

IV. COMPATIBILITY EVALUATION METHODOLOGY

A. MCL Method

The Minimum Coupling Loss (MCL) method calculates the isolation required between the interferer and the victim to ensure that there is no interference. This method is the worst case analysis and produces a spectrally inefficient result for scenarios of statistical nature. The victim receiver is assumed to be continually operating 3 dB above reference sensitivity. Interference must be limited to the noise floor to maintain the victim's protection ratio.

The MCL method is useful for the initial assessment of compatibility. MCL between the interfering transmitter (I_t) and the victim receiver (V_r) is calculated further.

The thermal noise power, P_n, for the receiver of 1 MHz bandwidth is obtained from

$$P_n = -114dBm + 10\log_{10}\left(10^{\frac{NF}{10}} - 1\right). \quad (1)$$

Then the noise power, P_{nBS}, at the mobile service base station receiver is

$$P_{nBS} = -114dBm + 3.4dB = -110.6\,[dBm]. \quad (2)$$

For a given target interference to noise ratio I/N, the target interference level, P_I, is given by

$$P_I = P_n + I/N. \quad (3)$$

Protection ratio I/N for the IMT base station is -6 dB [13].

The interference level, P_{IBS}, at the mobile service base station receiver of 1 MHz bandwidth is

$$P_{IBS} = -110.6dBm + (-6dB) = -116.6\,[dBm]. \quad (4)$$

The total maximum equivalent isotropically radiated power, $P_{e.i.r.p.}$, of the transmitter is obtained from

$$P_{e.i.r.p.} = P_{T_x} + G_{T_x}, \quad (5)$$

where: P_{T_x} – transmit power; G_{T_x} – transmitter antenna gain including cable losses.

The total maximum equivalent isotropically radiated power, $P_{e.i.rp.\_DVB-T}$, of the DVB-T transmitter is

$$P_{e.i.r.p.\_DVB-T} = 85.15dBm + 0dBi = 85.15\,[dBm]. \quad (6)$$

The isolation required (MCL) between the interferer and the victim to ensure that there is no interference is obtained from

$$\begin{aligned} Isolation = {} & P_{e.i.r.p.\_DVB-T} + \\ & + f\left(dBc_{DVB-T}, P_{e.i.r.p.\_DVB-T}\right) + \\ & + G_{R_x} - P_{I\_BS}, \end{aligned} \quad (7)$$

where G_{R_x} – receiver antenna gain including cable losses; $f\left(dBc_{DVB-T}, P_{e.i.r.p.\_DVB-T}\right)$ – function defining the power of the wideband noise at the frequency offset being considered relative to the interferer's carrier power.

The isolation required, $Isolation_{DTT_{BS}}$, for the receiving mobile service base station from the DTT transmitter out-of-band transmission is

$$Isolation_{DTT_{BS}} = 85.15dBm - 86dBc + \\ + (15dBi - 3dB) - (-106.6dBm) = 117.75\,[dB]. \quad (8)$$

The result of an MCL calculation is an isolation figure which can subsequently be converted into a physical separation, choosing an appropriate path loss model [14].

The isolation is then converted into a separation distance using the *Free-Space* attenuation, $L(loss)$, between isotropic antennas by formula

$$L(loss) = 32.4 + 20\log_{10}(f) + 20\log_{10}(d), \quad (9)$$

where f – frequency (MHz); d – distance (km).

The required protection distance, $d_{sep\_req\_DVB-T-BS}$, between the mobile service base station and the DTT station is:

$$d_{sep\_req\_DVB-T-BS} = 10^{\frac{L(loss)-32.4-20\log_{10}(f)}{20}}, \quad (10)$$

$$d_{sep\_req\_DVB-T-BS} = 10^{\frac{117.75-32.4-20\log_{10}(708)}{20}} = \\ = 26.15\,[km]. \quad (11)$$

The analytical MCL calculations revealed that minimum separation distance between DVB-T transmitter and LTE BS receiver is more than 26 km. This result will be verified performing Monte-Carlo simulation with SEAMCAT software. Then conclusions could be drawn.

B. *Monte Carlo Method*

The Monte Carlo modelling is used for simulation methodology in this study in order to simulate the interference from DVB-T to LTE BS receivers. SEAMCAT software tool based on Monte Carlo method was used [15].

V. COMPATIBILITY SCENARIO

A. *Interference Scenario*

The interference scenario where DVB-T station interferes with E-UTRA (LTE) uplink was evaluated in this study.

This scenario reflects the situation where DVB-T and LTE networks are deployed in two neighbouring countries. One country uses DVB-T stations near the border below 694 MHz, the other country – LTE networks in the 700 MHz band. This scenario also covers the situation where these two services are implemented within the same country in corresponding frequencies. LTE BS and LTE UE are working in the coverage area of DVB-T network. General scenario of the SEAMCAT simulation is presented in Fig. 3.

The minimum required separation distance between the DVB-T station and the LTE base station, in which LTE base station receiver would work without disruption, will be found in this situation.

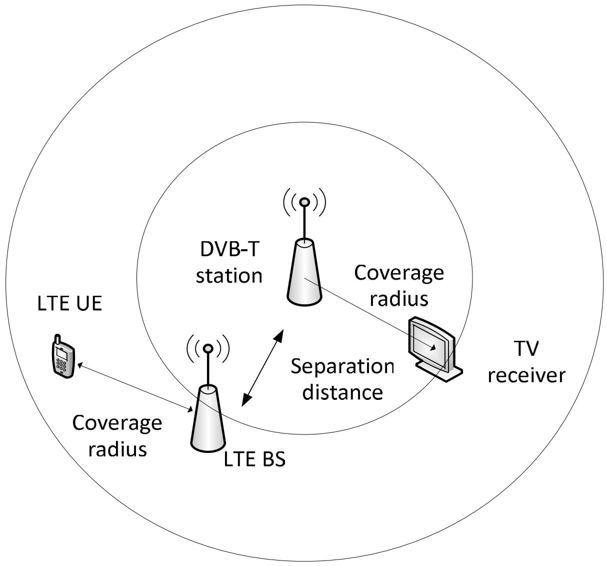

Fig. 3. SEAMCAT simulation general scenario.

B. *Modelling of Systems*

The model consists of two elements, a DVB-T system and a LTE network. DVB-T transmitter is located at the centre of the DVB-T coverage area. The configuration of DVB-T model: TV receivers are located throughout the TV coverage area.

LTE network of 7 base stations (each base station has three cells, each cell has three users) were created on Monte Carlo simulations. Only the most disturbing interferer was analysed in MCL calculations. Spectrum emission mask of DVB-T station, which shows what level of disruptive power will be emitted, is the most important issue in this analysis.

VI. COMPATIBILITY ANALYSIS AND RESULTS

A. *MCL Calculation Results*

The Minimum Coupling Loss (MCL) approach uses deterministic calculations to analyse the maximum level of interference from interfering transmitter into victim receiver, under a particular set of conditions. The MCL results show that the required separation distance between the DVB-T transmitter and the LTE base station receiver is 26.15 km.

B. *Monte Carlo Simulation Results*

SEAMCAT Monte Carlo simulation results show the required separation distance between the DVB-T transmitter and the LTE base station receiver, keeping the acceptable level of interference – the loss of throughput in the LTE network must not exceed 5 %. The results of SEAMCAT simulations are presented in Table V.

TABLE V. RESULTS OF SEAMCAT SIMULATIONS.

Separation distance between DVB-T Tx and LTE BS Rx, km	**Throughput loss in LTE network, %**
5	16.06
10	7.68
11	6.45
13	4.89

The simulation results show that the required separation distance must be more than approximately 13 km.

Additionally it is possible to analyse the signal-to-interference plus noise ratio (SINR) distribution during this simulation, which gives more detailed view on the conditions of LTE base station. The SINR distribution is presented in Fig. 4.

In this simulation the SINR level ranges from -5 dB to 19 dB. SINR is directly coherent with the Channel Quality Indicator (CQI). This parameter describes information about the channel condition (how good or bad the operational channel quality is) [16]. The LTE system has 15 different levels of CQI – from 1 as the worst channel and 15 as the best quality channel. The SINR level allows to select the appropriate quality level – SINR = ~-5 dB characterises the worst channel or CQI = 1. In cases where SINR exceeds 19 dB, it characterises the best quality channel or CQI = 15.

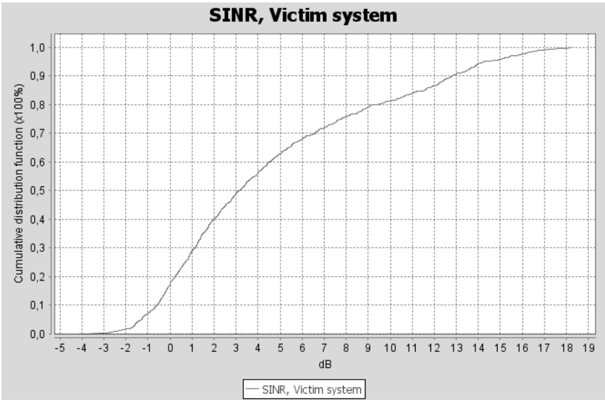

Fig. 4. SINR distribution.

VII. CONCLUSIONS

This particular study covers assessment of DVB-T when operating below 694 MHz compatibility with LTE operating in the 700 MHz band. Technical parameters of DVB-T and LTE, agreed within the ITU-R study group JTG-4-5-6-7, were used in our study. This paper contains an important part of assessment of DVB-T compatibility with LTE in adjacent channels in 700 MHz band.

This paper presents results of using both the MCL and Monte Carlo method. The MCL results give more conservative results in comparison to the Monte Carlo simulation results. According to the Monte Carlo simulation results the minimum coupling distance must be more than approximately 13 km to maintain the necessary performance level of the LTE base station receiver using pre-defined parameters.

The out-of-band emission level, which interferes with the LTE base station receiver, is the most sensitive factor of DVB-T. These results give also a valueable indication on applicability of selected channelling arrangement for the 700 MHz band and on a required guard band.

According to the results when planning LTE networks in the 700 MHz band and using the selected frequency arrangement the mitigation techniques such as antenna discrimination, spatial LTE planning in relation to DTT, downtilting of antennas etc. should be used. The acquired compatibility assesment results can be used by National Regulatory Authorities (NRAs), which are responsible for spectrum planning at the national level, mobile operators and other interested parties when planning mobile services in the 700 MHz band and broadcasting service below 694 MHz.

Planned future studies will assess the interference scenario where LTE uplink interferes with the DVB-T downlink.

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