

Influence of the LTE System using Cognitive Radio Technology on the DVB-T2 System using Diversity Technique

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Original scientific paper

In recent years, the development of advanced wireless communication systems has been rapidly progressing. In Europe, the 2nd Generation Terrestrial Digital Video Broadcasting (DVB-T2) and Long-Term Evolution (LTE) are the most promising techniques to provide multimedia services efficiently (in flexible quality and with high spectrum efficiency). The purpose of this work is to explore possible influences of the LTE uplink services, using cognitive radio (CR) technology, on the area which is covered by DVB-T2 services. In the case of DVB-T2, both single-input single-output (SISO) and multiple-input single-output (MISO) transmission techniques are considered. The defined coexistence scenarios are measured with an appropriate measurement testbed. The performance of the received TV signal is evaluated on its physical layer (PHY) level. The obtained results allow better understand the influence of LTE system on DVB-T2 which is using diversity technique in the same RF channel (co-channel coexistence). One of the main results is that there are the same requirements on the Forward Error Correction (FEC) decoding process in the DVB-T2 receiver, when power imbalances between TV transmitters (an both SISO and MISO modes) are considered at the interfering LTE signal. This finding was also proved by analysis of variance (ANOVA).

Key words: DVB-T2, LTE, cognitive radio, SFN, SISO/MISO, coexistence, interference, SDR, BER, MER

Utjecaj LTE sustava zasnovanog na kognitivnoj radio tehnologiji na DVB-T2 sustav zasnovan na metodi diverzifikacije. U posljednje vrijeme se znatno ubrzao razvoj naprednih bežičnih komunikacijskih sustava. U Europi metode prijenosa signala zasnovane na DVB-T2 (eng. 2nd Generation Terrestrial Digital Video Broadcasting) i LTE (eng. Long-Term Evolution) metodama najviše obećavaju u području učinkovitog pružanja multimedijalnih usluga (s prilagodivom kvalitetom i s visokom učinkovitosti spektra). U ovom radu je razmotrena mogućnost korištenja LTE signala uzlazne veze, uz korištenje kognitivne radio tehnologije, u području pokrivenom DVB-T2 signalom. Razmotrene su metode prijenosa DVB-T2 signala s jednim ulazom i jednim izlazom (eng. Single-Input Single-Output, SISO) te više ulaza i jednim izlazom (eng. Multiple-Input Single-Output, MISO). Definirani su scenariji koegzistencije i isti su izmjereni korištenjem prikladnog mjernog ispitnog stola. Kvaliteta primljenog TV signala je evaluirana na fizičkom sloju. Prikupljeni rezultati omogućuju bolje razumijevanje utjecaja LTE sustava na DVB-T2 koji koristi metodu diverzifikacije u istom radio-frekvencijskom kanalu (koegzistencija susjednog kanala). Jedan od glavnih rezultata je postojanje istih zahtjeva na proces dekodiranja s ispravljanjem pogrešaka u prijemu (eng. Forward Error Correction) DVB-T2 prijemnika kada se neravnoteža snaga između TV predajnika (MISO i SISO režimi rada) uzima u obzir na interferirajućem LTE signalu. Navedeni rezultat potvrđen je analizom varijance.

Ključne riječi: DVB-T2, LTE, kognitivni radio, SFN, SISO/MISO, koegzistencija, interferencija, SDR, BER, MER

1 INTRODUCTION

Many people use different kinds of smart devices (phones, tablets and TVs). Depending on the type of communication standard, supported by the user's equipment, there are many ways to provide different wireless multimedia services offering different user experience. Requirements on modern multimedia services (image, audio and data content) in superb quality are common among the

users. For the providers of these services the limited usage of radio frequency (RF) spectrum is the one of the biggest challenges. Hence, there is a great effort to optimize existing wireless infrastructures and develop new architectures which increase spectral efficiency [1,2]. Otherwise, the increasing amount of wireless services provided by different wireless techniques escalate the risk of unwanted coexistence scenarios [3–5].

The last decade in the development of advanced wire-

less communication standards was very intensive. In the near future, from the viewpoint of current technical requirements (advanced source coding, flexible system configuration and efficient spectrum usage), the Digital Video Broadcasting - 2nd Generation Terrestrial (DVB-T2) [6] and Long-Term Evolution (LTE) [7] systems will be deployed to provide all types of multimedia services in required quality, mainly in Europe. Due to its highly flexible system configuration [8, 9], the DVB-T2 system can provide digital TV (DTV) services in different transmission scenarios (mobile, portable and fixed). Furthermore, these services can be broadcasted by using multiple-input single-output (MISO) transmission technique, besides the traditional single-input single-output (SISO) transmission technique. The usage of modified Alamouti coding in the DVB-T2 system and two transmitting antennas which do not radiate the same transmitted signal can increase the signal robustness through transmit diversity [8, 9].

3GPP LTE [10] supports high data rates and flexible system configuration in order to adapt transmission parameters to the actual state of a radio link. This system can use flexible channel bandwidths, advanced signal processing and duplexing for downlink and uplink scenarios.

On the last World Radio Conference (WRC-2007), the International Telecommunication Union (ITU) has decided to harmonize the "700 and 800 MHz bands" for LTE technology. However, these RF bands are allocated to and used by DTV services, e.g., the DVB-T/T2 system. In Europe, several countries (e.g. Germany, Finland and United Kingdom) have already announced their intentions to allocate the 700 MHz band to mobile services. Consequently, there is a likely possibility for second digital dividend to effectively harmonize the usage of UHF bands "700 MHz" and "800 MHz" [11], [12].

Nowadays, significant attention is being dedicated to TV white spaces (TVWS) which can resolve the interference problem through cognitive radio (CR) technology in the coexistence scenarios [13, 14]. On the other hand, possible interferences may occur when narrowband systems (e.g. DTV) are operating under severe environmental conditions [15]. In this work, a possible negative impact of the LTE uplink signals, using CR technology (marked as LTE-CR), on DVB-T2 services (broadcasted by SISO/MISO techniques), received by fixed home receiver, is explored. For these purposes a special measurement testbed is used, based on [16, 17]. Attention is devoted to exploring the overall performance of DVB-T2 system, using SISO/MISO techniques, at co-channel coexistence with LTE-CR system.

The rest of this paper is organized as follows. After the Introduction, a brief state-of-the-art in the field of coexistence between DVB-T/T2 and LTE systems is presented in Section 2. This section also outlines the main contribution

of our article. In Section 3, a description of the analyzed coexistence scenarios is presented. Section 4 contains a description of our proposed measurement workplace, including measuring method. Obtained results from measurements, their evaluation and discussion are presented in Section 5. Finally, the conclusion is given in Section 6.

2 RELEATED WORKS

Nowadays, exploring the possible coexistence scenario between the DVB-T/T2 and LTE/LTE-A standards and mitigation of interferences from these undesirable scenarios is still a hot topic [11]. This fact is also evidenced by many published studies available.

Guidotti et al., in [5], present the mutual co-channel interference problem between DVB-T and LTE mobile link. An analysis of the coexistence between the LTE downlink and DVB-T signals by simulation is outlined in [18]. Based on the achieved results, authors recommend several protection ratios (PRs) for DVB-T and minimum distances between LTE base station and DTV receivers. In [19], an impact of a small LTE cell on a large broadcast cell in the spectral overlap scenario between LTE and DVB-T technologies is explored. Results from simulations prove that the broadcast data rate is highly dependent on the separation distance between the DTV receiver and the LTE eNodeB. Influence of DVB-T system on the LTE system performance below 700 MHz at different distances between the two transmitters and different offset distances is investigated in [20, 21]. For the evaluation of the obtained results an adjacent channel interference ratio (ACIR) was used. Unwanted interference, generated by LTE services, to the DTV and its possible mitigation by using filters installed before the DTV receiver is presented in [22]. The common output of the mentioned studies is that these (spectrum) interferences can significantly decrease the capacity and the performance of the considered networks.

Authors in [12] deal with possible interferences from the coexistence between LTE uplink signal and DVB-T2 signal in the shared 700 MHz band. In this work, a fixed outdoor and portable indoor DTV reception is considered. Polak et. al. in [16] and [17] investigate possible coexistence scenarios between current and emerging mobile (from GSM to LTE) and TV broadcasting (DVB-T/T2) systems. Measurement results of mutual interactions between LTE and DVB-T2-Lite services under different coexistence scenarios were outlined in [23]. However, the influence of LTE uplink signal on DVB-T2 signal in fixed reception scenario, broadcasted by MISO technique, has not been explored yet. To be more precise, study of the impact of LTE uplink signal (based on CR technology) in the area covered by DVB-T2 using diversity technique is still an open topic. Therefore, based on the above presented works, the aim of this research article is as follows:

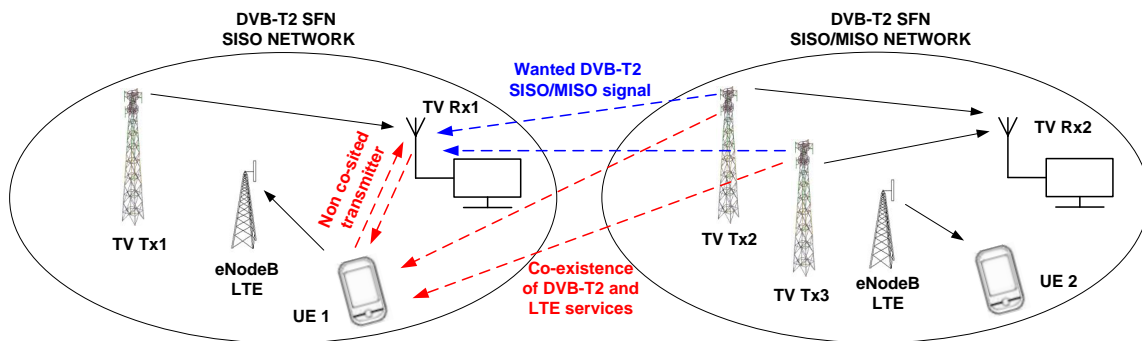


Fig. 1. Possible coexistence scenarios between mobile networks (LTE-CR) and DVB-T2 SISO/MISO SFN networks.

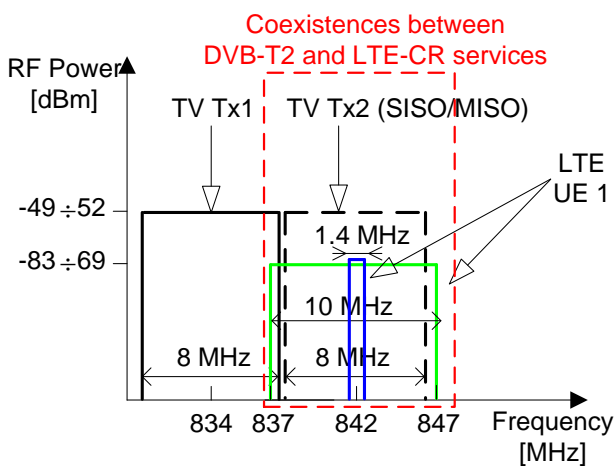


Fig. 2. The RF spectrum of analyzed coexistence scenarios (marked by red dashed rectangle) between DVB-T2 (8 MHz) and LTE-CR (1.4 MHz and 10 MHz) services.

3 COEXISTENCE SCENARIO AMONG DVB-T2 SISO/MISO AND LTE-CR SYSTEMS

It has been mentioned above, that in the TVWS band the CR technology can play a key role in the effective frequency band usage in the near future. Therefore, it can be expected that the features of CR technology in connection with TVWS will be mainly applied in LTE mobile networks. Nevertheless, when the spectrum sensing mechanism in CR is not able to accurately detect levels of other RF signals then possible coexistences scenarios can occur. The concrete coexistence scenario, investigated in this work, is plotted in Fig. 1.

The considered scenario is as follows. There are two single frequency networks (SFNs) in which DTV signals are broadcasted by TV towers. In the first SFN network, the SISO transmission mode is applied at a center frequency of 834 MHz while in the second SFN network, SISO or MISO techniques can be used at 842 MHz. Furthermore, in the first SFN network, an LTE base station (marked as eNodeB) is operated. It ensures LTE mobile network services for the user of smartphone, marked as UE1. The path of the data transmission is from the user to eNodeB (upload) and the LTE uplink system uses CR technology. Consequently, mutual interferences can not occur.

For the CR technology a transmit power control rule-based spectrum sharing technique is assumed [25–27]. Furthermore, for the LTE-CR system a special "worst case" scenario is considered when a limited number of RF channels are allocated to provide LTE services. Consequently, its move to the next "free" channel (in the case of detecting another RF signal) is difficult. Now a situation is assumed in which a user of TV set is receiving broadcasted TV signal from the second SFN network at the frequency 842 MHz. It means that the LTE mobile network, operating in the RF band (832÷862) MHz, can negatively affect this remote TV reception [28]. As a result, unwanted co-channel coexistence between DVB-T2 and LTE-CR systems can occur when the receiver of DTV services is located at the edge of cell coverage for LTE eNodeB [17]. It

- 1) Propose an appropriate measurement testbed, based on [16] and [24], to measure the coexistence between DVB-T2 (SISO/MISO) and LTE-CR (uplink) networks on their physical layer (PHY) level;
- 2) Explore the influence of the unwanted interferences from the co-channel coexistence between DVB-T2 SISO/MISO RF signal (consider different power imbalances) and LTE-CR uplink RF signal on the performance of DVB-T2 on its PHY level;
- 3) Evaluate the overall impact of the possible co-channel coexistence scenario (DVB-T2 vs LTE-CR (uplink)) networks on the DVB-T2 (SFN-SISO/MISO) performance.

is assumed that both receiving equipments (TV and UE1) are stationary. For SFN-MISO network, we consider a 2x1 Alamouti MISO reception (diversity mode) [29, 30].

A graphical representation of the described RF coexistence scenario is clearly shown in Fig. 2. The bandwidth of LTE signal is 1.4 MHz and 10 MHz, respectively.

4 EXPERIMENTAL MEASUREMENT SCENARIO

For the measurement of the interactions between DVB-T2 and LTE-CR systems an extended version of an earlier presented testbed [16] was used. Its general block diagram is shown in Fig. 3.

Two single frequency units (SFUs) from Rohde&Schwarz (R&S) are used, where the first one is marked as a master (central unit) and the second one is marked as a slave transmitter. By using the internal T2-modulator interface (T2-MI) generator, the master SFU unit can provide a 10 MHz reference clock as well as other synchronization signals (T2-MI & 1pps) required for the slave SFU unit and not only for itself. In the master SFU unit, appropriate video transport streams (TSs) are generated for SISO and MISO transmission modes, respectively. To be more precise, two different streams are used, one each for the SISO and MISO modes. After that, in MISO mode, the TV input signal in the slave transmitter must be set as an external signal ("received" from the master SFU). From the point of correct synchronization and same system configurations (in both master and slave devices) this is extremely important. Otherwise, highly destructive spectral interferences can occur [24]. After its system parameter setting, the complete DVB-T2 signal is generated and RF modulated.

The generated LTE signals, which interact with DVB-T2 services, are produced in R&S SMU200A. The bandwidths of LTE signals are 1.4 MHz and 10 MHz, respectively. Ten sub-frames were generated, where only QPSK modulation was used. LTE transmits in the uplink, using frequency-division duplexing (FDD) duplex mode.

Finally, both RF signals are combined and then Wilkinson splitter is used for dividing signals for the further analysis and evaluation. During the measurement, the level of the LTE signal is set gradually. The Gaussian (AWGN) channel environment is assumed.

System parameters of both systems are summarized in Table 1. Different Pilot Pattern (PP) schemes are used for SISO (PP2) and MISO (PP1) techniques. The difference is caused by different system requirements of SISO/MISO mode settings [8, 9].

5 EVALUATION OF THE OBTAINED RESULTS

Before the discussion of the obtained results the most important parameters for the evaluation of the DVB-T2

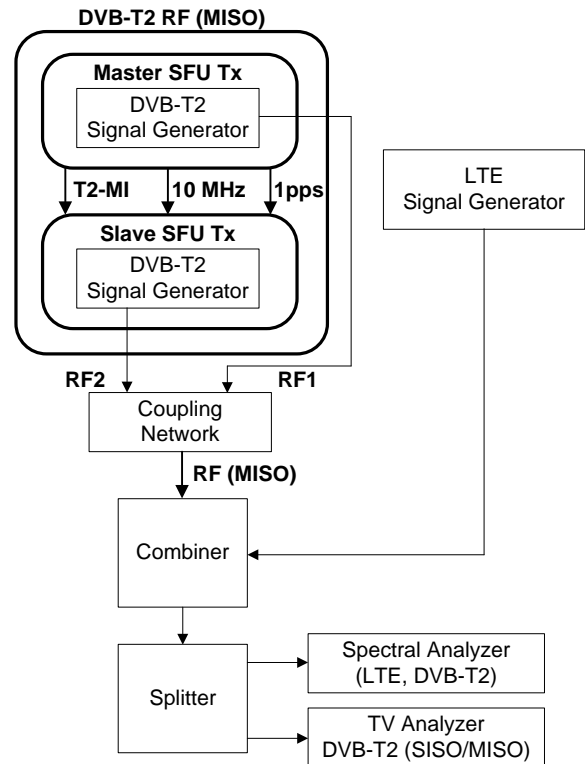


Fig. 3. General block diagram of workplace for measuring the interaction between DVB-T2 (SISO/MISO configuration) and LTE-CR networks

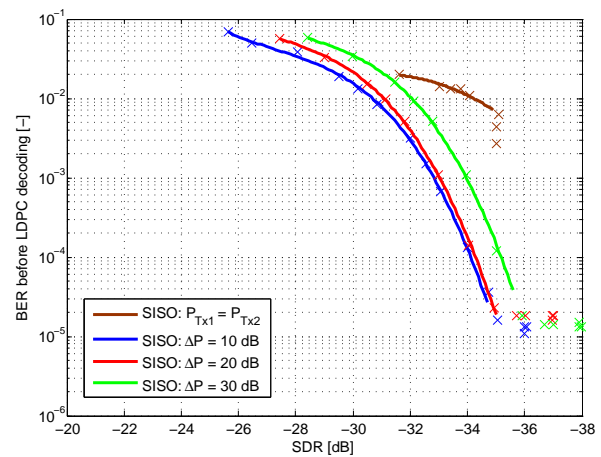


Fig. 4. Dependences of BER at the input of FEC decoder in DVB-T2 on the SDR ratio when DVB-T2 SISO and LTE-CR services coexisting. Power levels DVB-T2 RF signals from TV transmitters are either equal (brown curve) or different (other curves). LTE-CR bandwidth 10 MHz.

performance are briefly outlined at the beginning of this section. In order to evaluate the influence of inter-

Table 1. Settings of DVB-T2 and LTE-CR main system parameters, used for exploring the described coexistence scenarios

Settings	DVB-T2	LTE-CR
FEC code rate	2/3(BCH+LDPC)	1/3 (Turbo)
Type of modulation	256QAM	QPSK
Constellation rotation	No	-
Spectrum access method	OFDM	SC-FDMA (FDD)
FFT size	16384 (16K)	128 and 1024
Channel bandwidth	8 MHz	1.4 MHz and 10 MHz
Type of PP pattern	PP2 (SISO) PP1 (MISO)	- -
Cyclic prefix duration	266 μ s (19/128)	4.7 μ s (short)
Transmission mode	SISO/MISO	SISO
Scenario (reception)	Fixed	Mobile
Channel frequency	834 MHz (SFN1) 842 MHz (SFN2)	(832÷862) MHz
RF power	(-52÷-49) dBm	(-83÷-69) dBm
Channel environment	AWGN	AWGN
FEC decoding	1D LLR (soft)	Max Log-Map

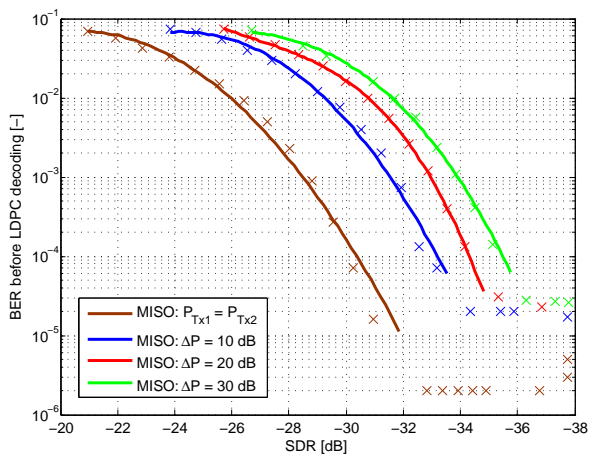


Fig. 5. Dependences of BER at the input of FEC decoder in DVB-T2 on the SDR ratio when DVB-T2 MISO and LTE-CR services coexisting. Power levels of DVB-T2 RF signals from TV transmitters are either equal (brown curve) or different (other curves). LTE-CR bandwidth 10 MHz.

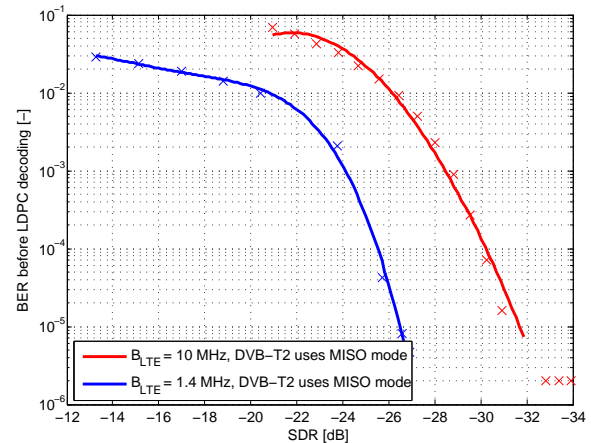


Fig. 6. Dependence of BER at the input of FEC decoder on the SDR ratio when DVB-T2 (using MISO technique and both TV transmitters have the same transmit power) and LTE-CR services coexisting. LTE-CR bandwidth 1.4 MHz and 10 MHz.

fering LTE signals on the performance of the DVB-T2 SISO/MISO system on its PHY level, bit error rate (BER) at the FEC decoder input and output, and the modulation error rate (MER) at the receiver input are measured.

The BER values before forward error correction (FEC) represent raw errors which occur during the broadcasting between transmitter and receiver. The measure of the BER values after Low-Density Parity-Check (LDPC) decoding are monitored for the assessment of a correctly received DTV signal. For the assessment of a correctly received DVB-T2 signal, the quasi-error-free (QEF) operation is

used. The QEF requires less than one uncorrected error event occurring per hour, corresponding to a BER after LDPC decoding lower than or equal to 10^{-7} [8,9].

To evaluate the overall performance of the DVB-T2 system in the considered transmission modes and channel environments, the modulation error ratio (MER) was used [8,9].

Obtained results were analyzed as a dependence on the spectral density ratio (SDR). The SDR is defined as the power ratio between T2 and LTE signal per unit of the used

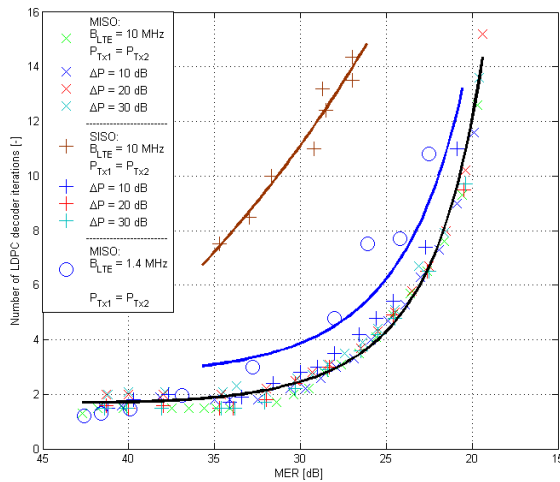


Fig. 7. Dependence of the amount of repeated (number of iterations) LDPC decoding on MER, at which the BER after FEC decoding is less or equal to 10^{-7} (limit for QEF reception). LTE-CR bandwidth 1.4 MHz and 10 MHz.

bandwidth. Such value is calculated as follows [23]:

$$SDR = P_{LTE} - 10\log(B_{LTE}) + \\ = -((P_{TV1} + P_{TV2}) - 10\log(B_{TV})), \quad (1)$$

where P_{LTE} is the power level of the LTE signal, B_{LTE} expresses the bandwidth of the used LTE channel, P_{TV1} and P_{TV2} are the power levels of DVB-T2 signals from the considered Tx1 and Tx2 transmitters respectively and B_{TV} represents the bandwidth of the used TV channel. There are considered zero (72 and 72 $\text{dB}\mu\text{V}$) and non-zero power imbalances (72 and 62 $\text{dB}\mu\text{V}$; 72 and 52 $\text{dB}\mu\text{V}$; 72 and 42 $\text{dB}\mu\text{V}$) of TV towers, marked as ΔP . From (1) it can be clearly seen that the spectral density of the TV level is higher than the level of LTE-CR with negative SDR values.

Figure 4 shows the BER versus SDR values at the DVB-T2 channel decoder input when the SISO technique is used. In the case of equal power levels of TV signals the BER values are high, independent of the SDR values. This is caused by the SISO-SFN configuration which results in an overlay of more-or-less identical signals in the receiver. Such scenario is known as 0-dB echo [9] and represents the situation when two TV towers broadcast TV signal in the same SISO-SFN network. This can lead to significant destructive spectral interference. Performances of DVB-T2 SISO configuration at considered non-zero power imbalances are comparable. Convincing results are achieved at $\Delta P = 10$ dB.

Figure 5 shows the BER dependences on the SDR at the DVB-T2 channel decoder input when MISO technique is used. DVB-T2 MISO performances at the same TV signal levels, compared to SISO, are much better. This is caused

by applying the modified Alamouti coding technique [9]. Interestingly, in the remaining cases (non-zero power imbalances) the DVB-T2 MISO performances are comparable with SISO ones. To be more precise, for large power imbalances the MISO gain, compared to SISO one, is decreasing. All in all, there is assumed a perfect channel estimation and synchronization at the receiver. Hence, as described in [31], the influence of the relative delay on the MISO gain can be neglected.

Table 2. SDR ratios where conditions for QEF in DVB-T2 are fulfilled

Scenario	DVB-T2 SISO mode	DVB-T2 MISO mode
$\Delta P = 0$ dB; $B_{LTE} = 10$ MHz	at any SDR	-20.9 dB
$\Delta P = 10$ dB $B_{LTE} = 10$ MHz	-25.6 dB	-23.9 dB
$\Delta P = 20$ dB $B_{LTE} = 10$ MHz	-27.5 dB	-25.7 dB
$\Delta P = 30$ dB $B_{LTE} = 10$ MHz	-28.2 dB	-26.7 dB
$\Delta P = 0$ dB $B_{LTE} = 1.4$ MHz	at any SDR	-13.8 dB

In previous scenarios we considered $B_{LTE} = 10$ MHz. Curves, channel BER versus SDR for DVB-T2 MISO (in the case $\Delta P_{TV} = 0$ dB) at interfering LTE-CR with $B_{LTE} = 1.4$ and 10 MHz are plotted in Fig. 6. Obtained results proved that narrowband interfering LTE-CR signal has lower impact on DVB-T2 MISO performance than same level wideband interference.

The overall performance of the DVB-T2 TV signal distributed by the SISO/MISO technique, coexisting with the LTE-CR signal, was investigated too. For this purpose, dependences of the number of LDPC decoding repetitions (needed for successful decoding of FEC frames) on MER were measured. The obtained results are shown in Fig. 7. To prove that at power imbalances higher than 10 dB the DVB-T2 SISO and MISO FEC performances at interfering LTE signal are the same, the results were subject to analysis of variance (ANOVA). From the distribution of measured values in R^2 (MER, Number of LDPC decoder iterations) it is assumed that the distributions of measured values are independent of the transmitters' power difference in the case of the SISO and MISO techniques. A null hypothesis was tested where the values of square errors are the same for all power difference (Δ) clusters:

$$H_0 : \mu_{\Delta_{iterations}^2}(\Delta_0) = \mu_{\Delta_{iterations}^2}(\Delta_1) \\ = \mu_{\Delta_{iterations}^2}(\Delta_2) = \mu_{\Delta_{iterations}^2}(\Delta_3), \quad (2)$$

where $\Delta_0, \Delta_1, \Delta_2, \Delta_3$ denote values of power imbalances (0, 10, 20 and 30) dB, respectively. One-way ANOVA confirmed the assumption, because p-level ($p = 0.6986$) is higher than the chosen significant level $\alpha = 0.05$. In case of the DVB-T2 SISO/MISO system at $\Delta P \geq 10$ dB and at the same RF channel conditions, power imbalance has no effect on the broadcasted TV signal from TV towers. This leads to the same DVB-T2 FEC decoder performance at interfering LTE-CR signals. The black curve in Fig. 6 is the minimum mean square error (MMSE) interpolation for all measured MER values in DVB-T2 SISO and MISO mode. Lastly, the dependence of iteration number = f (MER) on $B_{LTE} = 1.4$ MHz was measured (see Fig. 9 values marked by blue "o").

Table 2 summarizes the maximum SDR values at considered scenarios of interfering signal where conditions of QEF reception in DVB-T2 are still fulfilled. Its threshold is related to BER after LDPC decoding equal to 10^{-7} [9]. The results have also been proved subjectively, as in [18]. Once again, these results were obtained in the Gaussian reference channel. For more relevant transmission scenarios it is necessary to increase the SDR values. For fixed outdoor reception the SDR values should be increased by 1 dB for Rice channel (RC20) and by 5-6 dB for Rayleigh channel [11], [12]. In this study, the influence of multipath phenomenon at fixed transmission scenario (RC20 and RL20 channel models) [9], related to the influence of coexistence, can be considered as an additive noise.

Finally, we have studied compatibility of DVB-T2 with LTE. To be more precise, we present the required minimal protection distance (no interference) between the UE and DTV station. This calculation is based on a method which has been presented in [21]. We consider a scenario for DVB-T2 SFN-SISO mode (see Table 2): $\Delta P = 10$ dB, $B_{LTE} = 10$ MHz and $SDR = -25.6$ dB.

To ensure the QEF reception in the area covered by DVB-T2 signal, we consider field strength between $47 \text{ dB}\mu\text{V/m}$ (E_{TVmin}) and $60 \text{ dB}\mu\text{V/m}$ (E_{TVmax}). The RF power for UE can be considered in the interval from 0.02 to 0.2 W (13 to 23 dBm) [10]. The antenna gain (G_{UE}) can be in the interval from 0 to 3 dBi. The maximal field strength ($E_{UE|max}$) at UE antenna far region, based on [32], can be calculated as follows:

$$E_{UE|max} = \sqrt{\frac{480P_{UE}}{G}} \frac{\pi f}{c}, \quad (3)$$

where G is the gain of an antenna, f [Hz] is the working frequency (at the coexistence) and c [m/s] is the speed of light. For $P_{UE} = 0.02$ W and $G = 1$, the $E_{UE|max}$ will be 27.32 V/m which is $148.73 \text{ dB}\mu\text{V/m}$. The equivalent maximal field strength $E_{UE|TVmax}$, where QEF for DVB-T2 is fulfilled, can be calculated as:

$$E_{UE|TVmax} = SDR + 20\log(B_{LTE}) + 10\log(B_{TV}) + E_{TVmax}. \quad (4)$$

Hence, the $E_{UE|TVmax}$ will be $28.29 \text{ dB}\mu\text{V/m}$. The isolation loss is then converted into a separation distance using the free-space attenuation $L_{(loss)}$. The $L_{(loss)}$ is calculated as $(E_{UE|max} - E_{UE|TVmax})$. In our case it is equal to 120.44 dB. Finally, the required protection distance (in km) between the mobile station and the DTT receiver is [21]:

$$d = 10^{\frac{L_{(loss)} - 32.4 - 20\log(f)}{20}}. \quad (5)$$

Considering the values above, the minimal distance between the mobile station and DTT receiver should be 29.97 km.

6 CONCLUSIONS AND FUTURE WORK

In this paper, coexistence of the DVB-T2 and LTE services in the same frequency band was explored and measured. More precisely, we explored possible influences of the LTE system, using cognitive radio technology (for uplink), on the area covered by DVB-T2 SISO (the case when two TV towers operating in the same SISO SFN network) and/or MISO services. For this purpose, an appropriate measurement testbed was realized.

The results show that the overall performance of the DVB-T2 MISO technique against co-channel interferences, compared to the SISO one, is better. Connection between spectral density ratio and measured objective quality indicators of DVB-T2 services was also found. From the obtained results in the explored coexistence scenario it is observed that:

- The impact of LTE-CR system performance on the DVB-T2 system performance in their co-channel coexistence scenario in a shared frequency band highly depends on the bandwidth of the LTE signal, on the used DVB-T2 transmission technique and on the power imbalance between RF signals;
- The DVB-T2 MISO gain against interferences from LTE-CR system at power imbalances higher than $\Delta P = 10$ dB is gradually decreasing. In the considered coexistence scenarios, the overall performance of the DVB-T2 FEC decoder for SISO and MISO transmission mode at $\Delta P \geq 10$ dB is almost the same;
- Different bandwidths of LTE-CR uplink RF signal affect the DVB-T2 RF signal (broadcasted by SISO and MISO technique) in a different way.

All in all, it was proved that overall resistance of DVB-T2, broadcasted by MISO technique at considered zero and lower non-zero power imbalances of TV tower signal strengths, to unwanted interfering LTE signal is evident and promising successful implementation and real operation without any disturbances.

Our future work will continue by finishing and improving the proposed methods for measuring interactions between DVB-T2 and LTE services. Moreover, we are also considering extending our research with fading channel models with Doppler shift [33–35]. Field trial measurements are also considered [36].

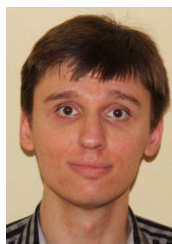
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