Coexistence analysis of DVB-S satellite services with DVB-T based terrestrial service in the 11.7–12.5 GHz frequency band

TOMAZ JAVORNIK, IGOR JELOVCAN and MIHAEL MOHORCIC
Department of Communication Systems
Jozef Stefan Institute
Jamova 39, SI-1000 Ljubljana
SLOVENIA \

Abstract: - In this paper we investigate the possibility of coexistence of DVB-S satellite services in the 11.7–12.5 GHz frequency band with the terrestrial service using a DVB-T transmission technique. We analyze the impact of the DVB-T signal on the DVB-S signal in terms of increased bit error rate for different coding and modulation schemes and calculate the increase of unavailability of satellite services. We compare different satellite spectrum sharing criteria and give some recommendations for the implementation of the terrestrial system to minimize the impact of terrestrial interferer on the satellite services.

Key-Words: - Spectrum sharing, DVB-S, DVB-T, interference, satellite service unavailability

1 Introduction

Broadband wireless access (BWA) systems are due to their flexibility, fast deployment, dynamic sharing of resources and relatively low cost becoming increasingly attractive solution for the provision of broadband services to urban as well as to remote areas. Radio resources, however, are scarce and in most frequency bands administratively allocated to different services by regulators. This requires the development of new techniques for more efficient utilization of frequency spectrum and, if possible and allowed, sharing of the same frequency spectrum by multiple services. For instance, according to the ITU Footnote S5.487 the frequency band 11.7–12.5 GHz is allocated in ITU Region 1 to the fixed and broadcasting-satellite radio services on a co-primary basis, typically using digital video broadcasting from satellite (DVB-S) [1]. The same frequency band may be shared on a secondary basis by terrestrial services, such as multipoint video distribution system (MVDS) based on ETSI standard ETS 300 748, upconverted digital video broadcasting for digital terrestrial television (DVB-T) based on ETSI standard ETS 300 744 or adjusted Microwave Multipoint Distribution System (MMDS) based on ETSI standard ETS 300 749 [2]. However, such terrestrial system shall not cause any harmful interference to the space services operating in conformity with the broadcasting satellite Plan for Region 1 contained in ITU Appendix S30 [3].

In this paper we investigate the possibility of coexistence of DVB-S satellite services with the terrestrial service using a transmission technique based on DVB-T. We first provide a brief background to the study, followed by the analysis of the impact of interfering signal in DVB-T format on the DVB-S signal in terms of an increase of bit error rate (BER) for different coding and modulation schemes. Finally, we provide calculation results for the increase of the satellite service unavailability due to additional interference of the terrestrial transmission for the reference satellites with signal available in Slovenia. The paper concludes with the discussion on simulation results and suggestions for mitigation techniques suitable to minimize the impact of terrestrial interferer on the satellite services.

2 Background assumptions

The use of DVB-T transmission scheme appears an attractive solution for the coexistence with the DVB-S satellite services both due to technical as well as economic reasons. In comparison to MVDS and MMDS the DVB-T transmission scheme supports the widest range of spectral efficiencies (from 0.622 bits/Hz/s up to 3.95 bits/Hz/s) and C/N operational range (from 3.1 dB to 20.1 dB), thus giving more freedom to adapt the system parameters, such as modulation and convolutional coding, to instantaneous properties of the radio channel. In addition to this, the use of DVB-T transmission scheme may also support the economy of scale, which should manifest in lower cost of equipment.

In order to analyze the possibility of coexistence of the terrestrial service signal transmitted in DVB-T format with the DVB-S signal in the 11.7–12.5 GHz frequency band, we carried out computer simulations based on the following simplifying assumptions:

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- Only forward link of the terrestrial service based on DVB-T transmission scheme is in the frequency band 11.7–12.5 GHz.
- The bandwidth of the DVB-T interfering signal is equal to 8 MHz.
- The DVB-T interfering signal uses 16-QAM modulation scheme.
- The OFDM modulation of the DVB-T interfering signal is based on 2048 carriers (2k mode).
- The transposition of the DVB-T interfering signal from UHF band to the frequency band 11.7–12.5 GHz is assumed linear in amplitude and phase.

In general, the DVB-T signal can be placed at any position within the DVB-S signal with the bandwidth of 27 MHz. We have restricted our simulations to three different signal position scenarios presented in Fig. 1:

(a) The DVB-T channel is positioned on the edge of the DVB-S channel; frequency offset of the DVB-T signal is 8 MHz.
(b) The DVB-T channel is positioned in the center of the DVB-S channel; frequency offset of the DVB-T signal is 0 MHz.
(c) Three DVB-T channels are positioned within the DVB-S channel, each with one third of the total DVB-T channel power.

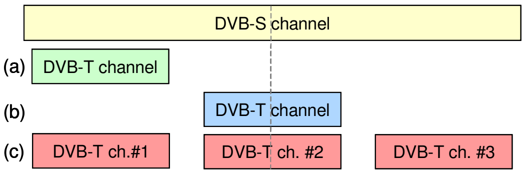

Fig. 1. DVB-T signal position scenarios.

3 BER performance of DVB-S signal in the presence of DVB-T interferer

In order to determine the degradation of the DVB-S satellite services we first analyse the impact of interfering signal in DVB-T format, which is frequency shifted to Ku frequency band, on the DVB-S signal using a baseband simulation model of the DVB-S waveforms. The block scheme of the simulation model is depicted in Fig.2.

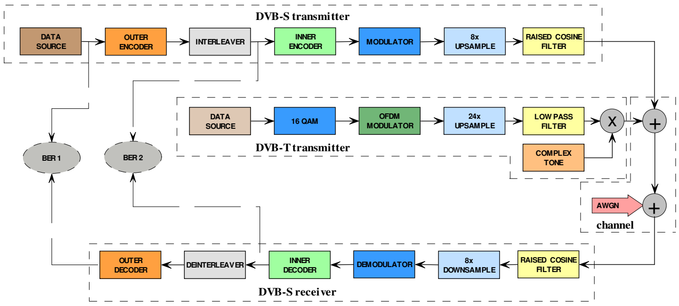

Fig. 2. Block scheme of the simulation model.

The simulation model consists of four basic parts: the transmitter and receiver of DVB-S signal, the transmitter of DVB-T interfering signal and the satellite propagation channel. The DVB-S transmitter encodes the random bit stream with the outer (shortened Reed Solomon code RS(204, 188)) and inner (punctured convolutional codes with coding rates 1/2, 3/4 and 7/8 and constraint length 7) encoders. The 1632 bits long convolutional interleaver inserted between encoders protects data against burst errors. The encoded bits are mapped to QPSK symbols and upsampled by factor of eight. Then the I and Q components of the signal are shaped by a square-root raised cosine filter with the roll-off factor $\alpha = 0.35$.

In the satellite channel, the transmitted DVB-S signal is distorted by additive white Gaussian noise (AWGN) and by DVB-T interfering signal. The power of both signals can be adjusted in order to achieve the target carrier to noise plus interference ratio (C/N+I).

The DVB-T interfering signal is generated by using OFDM modulation with 2048 carriers (2k mode). On each carrier a random bit stream is mapped onto 16-QAM modulation. For such interfering signal we assume that the non-linear conversion to Ku frequency band does not cause significant frequency spreading of the DVB-T signal in neighboring frequency bands and that the forward error correction should not have significant impact on the spectral properties of the signal. The DVB-T signal is upsampled twenty-four times to adjust the sampling frequency to that of the DVB-S signal and to enable the required frequency shift of the DVB-T signal from the DVB-S carrier frequency as shown in Fig. 1.

In the DVB-S receiver, the distorted signal is filtered with a square-root raised cosine filter and soft demodulated. After that, the signal is decoded with soft Viterbi decoding algorithm, deinterleaved and RS decoded. The obtained bit stream is compared with the transmitted one and the bit error rate (BER) is calculated. The BER is also calculated after the inner decoder. Thus the impact of the interfering DVB-T signal on the DVB-S signal can be expressed in terms of BER versus signal to noise ratio for different coding and modulation schemes of DVB-S signal and different frequency offsets of the DVB-T interferer.

In order to ensure an accurate comparison all C/N_0 values were converted to E_b/N_0, respecting appropriate overall coding rate. Therefore, the BER curves are shifted to the left or right proportionally to $10 \cdot \log(R)$. The error performance requirements [1] are defined at quasi-error free BER (10^{-10}–10^{-11}), when RS and convolutional codes are used, and at BER = $2 \cdot 10^{-4}$, when only convolutional codes are used. For each BER value the simulation was carried out so that at least 300.000 bits were transmitted or 200 errors were detected, thus actually obtaining the simulation results only down to BER = 10^{-5}, which is sufficient for the performance comparison and to draw the required conclusions.

First we obtained BER versus E_b/N_0 performance results for the DVB-S signal transmission when only AWGN distorts the transmitted signal, shown in Fig. 3. The results were generated for three different coding rates of convolutional encoder (CC) with and without RS codes. It is obvious that all three curves satisfy the required E_b/N_0 for $\mathrm{BER} = 2\cdot 10^{-4}$ [1], i.e. 4.5 dB for CC(1/2), 5.5 dB for CC(3/4)and 6.4 dB for CC(7/8).

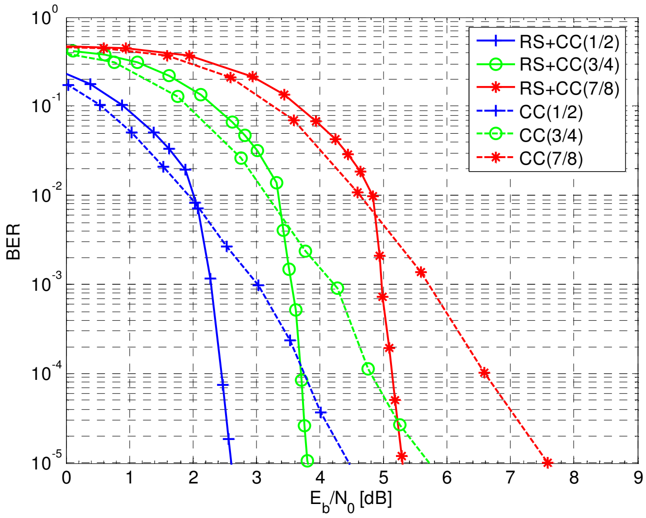

Fig. 3. BER performance of DVB-S without DVB-T interferer.

Results for the DVB-S performance in the presence of AWGN and DVB-T signal are shown in Fig. 4 for the convolutional coder with coding rate 3/4 with and without Reed Solomon codes and for three levels of noise to interference ratio (N/I), i.e. 10 dB, 5 dB and 0 dB.

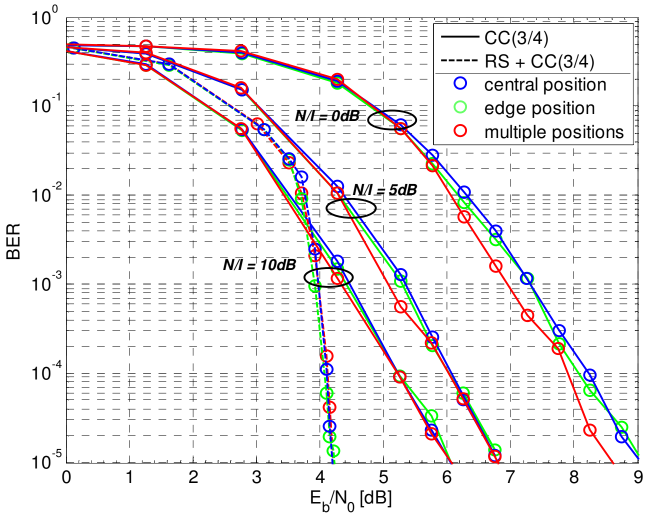

Fig. 4. Performance results for different interference levels (N/I) and DVB-T signal offsets.

The simulation results show that the position of the DVB-T interfering signal does not have a significant impact on the BER performance of the DVB-S signal. The worst results are obtained when the carrier frequency of the interferer is equal to carrier frequency of the DVB-S signal. In this case the majority of the interferer power is added to the DVB-S signal in the frequency band where the majority of the DVB-S signal power is located. It has to be noted that in the case of three DVB-T interfering signals each of them has only one third of the power compared to the power of a single DVB-T interferer, to allow fair comparison.

The results in Fig. 4 also show that the BER degradation increases with the interference power, i.e. for N/I = 10 dB the system performance degradation is less than 0.5 dB while for N/I = 0 dB the system performance is decreased by additional 3 dB.

Fig. 4 also depicts BER curves obtained after RS decoder for the three DVB-T signal position scenarios and N/I = 10 dB, but as expected they are very steep and practically indistinguishable.

Based on the above results we can conclude that the DVB-T interferer frequency offset from the DVB-S center frequency does not results in notable differences in DVB-S system degradation. Thus, the case with three DVB-T interfering signals, promising better utilisation of frequency spectrum by the terrestrial service and thus a significant advantage over MVDS and MMDS solutions, is considered as preferential case in the rest of this paper.

At the first glance it appears that with the additional DVB-T interferer the DVB-S specification requirements can hardly be met and no transmission in co-frequency band is possible. However, the ETSI requirements [1] specify the E_b/N_0 without interferer, while results in Fig. 4 include the interferer. Thus, in order to calculate the impact of the DVB-T interferer an increase of the DVB-S services unavailability has to be calculated. The standard approach to calculate the increase of the services unavailability due to interferer is based on the assumption that the interferer waveform performance is similar as but not worse than the waveform performance of AWGN. For that reason we rearranged the simulation results and plotted BER as a function of C/(I+N) instead of E_b/N_0. An example for code rate $R = 3/4$ is depicted in Fig. 5, showing that noise and interference are equally detrimental to the system performance. The BER depends only on the total (N+I) power, thus the BER versus C/(N+I) curves are identical regardless of the N/I ratio. We can find the reason for such behavior in the OFDM signal properties. The OFDM signal can be seen as a sum of frequency shifted narrow band random signals. By increasing the number of subcarriers the amplitude distribution of the OFDM signal becomes approximately Gaussian. The BER results reported in this paper for the DVB-T interferer are slightly worse than those obtained for single carrier interferer [4], where a gain of 0.65 dB to 0.79 dB was obtained in comparison to AWGN interferer. Nevertheles, these BER results still allow the calculation of the increase of system unavailability based on AWGN as interferer.

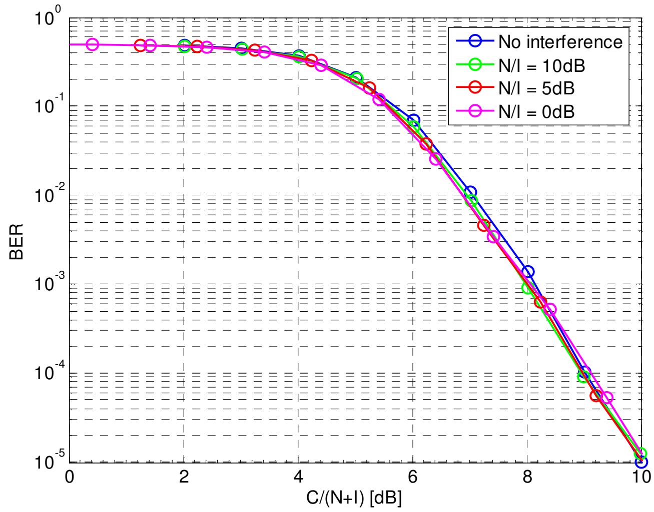

Fig. 5. Impact of N/I level on the BER performance for $R = 3/4$ considering three DVB-T interfering signals.

4 Increased DVB-S service unavailability in the presence of DVB-T interferer

In the previous section we have shown that the interference caused by the DVB-T signal introduces lower or equal system performance degradation as the AWGN with the same signal energy. Thus the use of AWGN as interferer is justified in consequent analysis of the system unavailability, representing a conservative approach.

As a reference DVB-S service in the frequency band of interest ranging from 11.7 to 12.5 GHz, which may be affected by the terrestrial interfering signal in the same frequency band, we assume the satellite service provided on the territory of Slovenia by Astra and Hot Bird satellites. The equivalent isotropic transmitted power (EIRP) for Hot Bird 2 and Hot Bird 3 in Slovenia is 50 dBW, and the recommended size of satellite dish for these two satellites is 0.6 m. For the Hot Bird 7A satellite, on the other hand, the EIRP power in Slovenia is 52 dBW to 53 dBW, and the recommended dish size is 0.5 m. The Astra satellites, which need to be analyzed, are located at 19.2°E, and have recommended size of antenna dish for Slovenia between 0.5 m and 0.6 m, corresponding to the EIRP values of 51 dBW and 50 dBW, respectively. The parameters for the relevant Astra and Hot Bird satellites are summarized in Table 1. Considering these parameters we followed the standard approach to calculate the increase of the satellite service unavailability due to the additional interferer that causes the same or lower degradation on the DVB-S signal as AWGN with equivalent power [4]. We numerically determined the rain margin for each satellite such that the C/(N+I) threshold of DVB-S is reached for quasy-error free BER. Then the percentage of time of DVB-S outage due to rain and interference is determined from the ITU-R Recommendation P.618-6. Once the outage time is obtained, the system availability and the service outage time in minutes per average year can be calculated. The total outage time can also be split between the outage time due to rain when interference is not present and the increase of that time due to the presence of the interfering signal.

Table 1. Considered combinations of parameters for the relevant satellites visible in Slovenia.

Satellite	Elevation (deg)	Azimuth (deg)	Distance (km)	EIRP (dBW)
Hot Bird 2&3 (13°E)	37.06	181.39	38012	50
Hot Bird 7A (13°E)	37.06	181.39	38012	53
Astra 1E&1F (19°E)	36.84	173.07	38030	50

The criteria that shall not be exceeded by the terrestrial services for sharing the DVB-S frequency band can be given in terms of maximum total unavailability of satellite services, maximum relative increase in unavailability of satellite services, maximum unavailability increase of satellite services, minimum carrier to interference (C/I) ratio, etc. In the following we present results for the service unavailability for Astra 1F and Hot Bird 2 satellite parameters. Different gains of the satellite antennas are assumed in calculations, namely 35 dB and 37 dB, which approximately correspond to antenna dishes of 0.5 m and 0.6 m using Equation (1), where D is antenna diameter, λ is wavelength of the signal and η is antenna efficiency typically between 0.55 and 0.80.

$$G_a = \eta \frac{\pi \cdot D}{\lambda^2} \qquad (1)$$

We have calculated the results for two coding modulation modes; one with higher power efficiency and one with lower power efficiency, which are represented in figures by two different coding rates of the DVB-S system convolutional encoder, i.e. $R = 3/4$ (cf. Fig. 6) and $R = 7/8$ (cf. Fig. 7). The EIRP power of the Astra 1F satellite is slightly lower than that of the Hot Bird 2 satellite, which is the main reason for slightly higher unavailability of satellite services.

If the total satellite services unavailability of 0.5 % is chosen for the sharing criteria, which corresponds to 44 hours of outage per year, the highest transmission data rate can be achieved ($R = 7/8$) in Slovenia even with the 35 dB gain antenna. From the curves depicted in Fig. 6(a) and Fig. 7(a) we can determine the minimum C/I ratio to fulfill the sharing criteria specified as a total system unavailability. For antenna gain of 35 dB the C/I ratio for low bandwidth efficient system ($R = 3/4$) should be higher than 11 dB and or for high bandwidth efficient system ($R = 7/8$) higher than 19 dB.

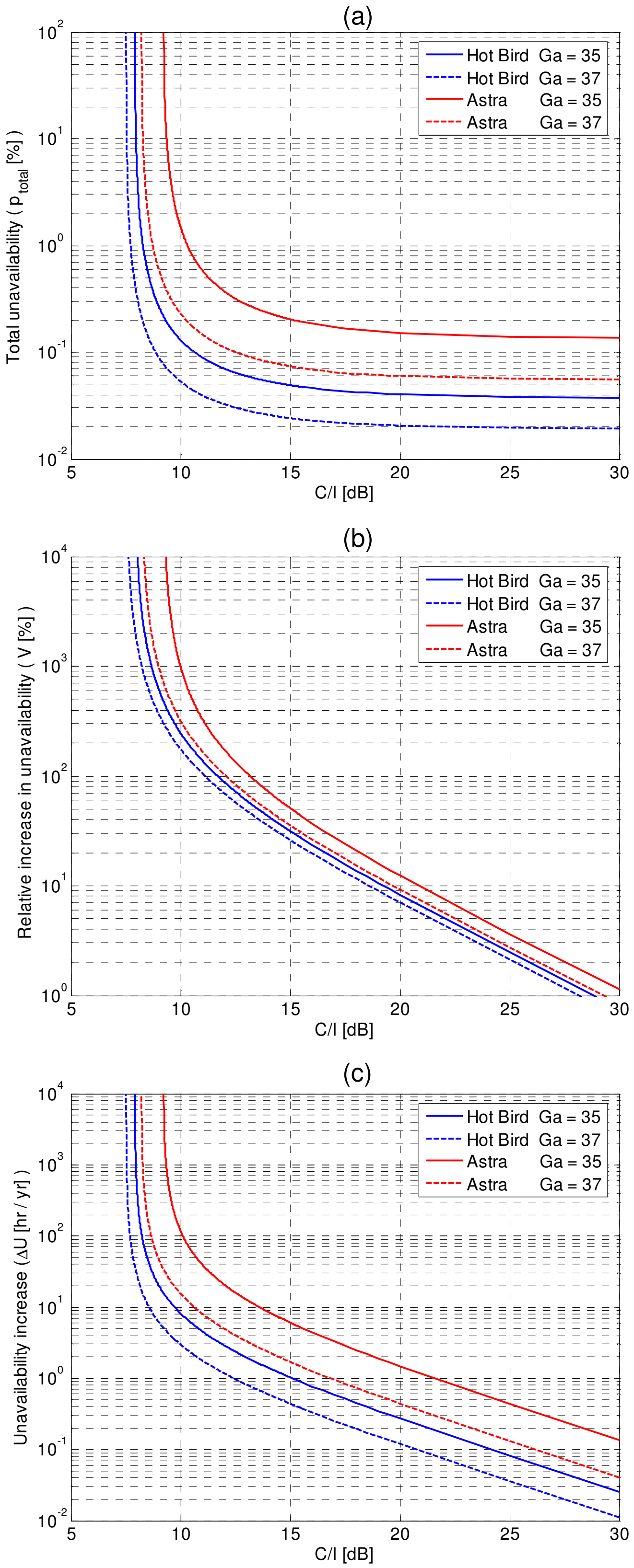

Fig. 6. Service unavailability versus C/I ratio for convolutional encoder with rate *R* = 3/4:
(a) total unavailability (in percentage);
(b) relative increase in unavailability (in percentage);
(c) unavailability increase (in hours per year).

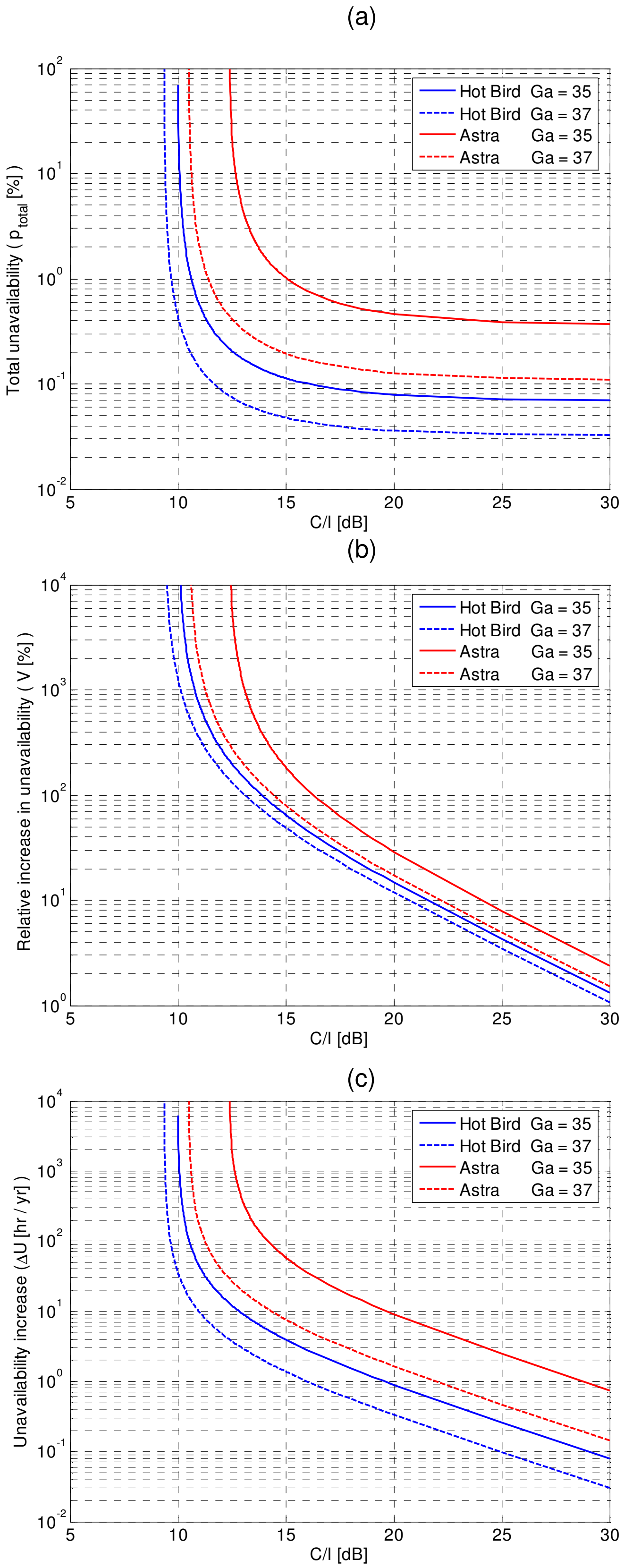

Fig. 7. Service unavailability versus C/I ratio for convolutional encoder with rate *R* = 7/8:
(a) total unavailability (in percentage);
(b) relative increase in unavailability (in percentage);
(c) unavailability increase (in hours per year).

If we increase the antenna gain by 2 dB, the C/I ratio constraint is relaxed to 9 dB and to 12.5 dB for the transmission mode with convolutional encoder rate of $R = 3/4$ and $R = 7/8$, respectively.

Results for the relative increase in satellite service unavailability due to terrestrial system interference in percentage and the system unavailability increase in additional hours per year are depicted in Figs. 6(b-c) for low bandwidth efficient system ($R = 3/4$) and in Figs. 7(b-c) for high bandwidth efficient system ($R = 7/8$). If we assume a 10 % limitation for the maximum relative increase of satellite service system unavailability, the worst case (Astra 1F and 35 dB antenna gain) minimum required C/I ratio is 21 dB for coding rate $R = 3/4$ and 24 dB for coding rate $R = 7/8$. Assuming 5 hours of additional outage per year as a spectrum sharing criterion, the worst case (Astra 1F and 35 dB antenna gain) minimum required C/I ratio is 15 dB for the transmission mode with $R = 3/4$ and 22.5 dB for the transmission mode with $R = 7/8$.

Comparison of results for different spectrum sharing criteria, i.e. 0.5 % of total unavailability, 10 % relative increase of satellite service unavailability and 5 hours of additional satellite outage time per year, shows slightly different required minimum C/I ratio at the receiver side. For the worst case satellite service in the observed frequency band, the one provided by the Astra 1F satellite with coding rate of $R = 7/8$ and antenna gain of 35 dB, the minimum required C/I ratio is 18 dB, 24 dB and 22.5 dB for the above mentioned criteria. It is obvious that the relative increase of satellite service unavailability by 10 % is the most constraining limitation, while the total satellite service unavailability equal to 0.5 % is the least constraining limitation.

5 Conclusion

In this paper we analyzed the possibility of coexistence of the terrestrial signal in DVB-T format and the DVB-S satellite services in the frequency band 11.7–12.5 GHz. First we have shown that the OFDM signal as an additive co-channel interferer does not cause higher degradation of the DVB-S system performance in terms of BER than the AWGN with the same power. Consequently we have calculated an increase of the system unavailability using AWGN as interferer with the same signal energy. As criteria that shall not be exceeded by the terrestrial services for sharing the DVB-S frequency band we considered maximum total unavailability of satellite services (0.5 %), maximum relative increase of satellite service unavailability (10 %) and maximum unavailability increase of satellite service (5 hours). For these criteria we determined the minimum required C/I ratio for the satellites visible in Slovenia that are providing services in the frequency band of interest.

We have shown that co-frequency band terrestrial signal transmission poses a significant interference threat to DVB-S services. Nevertheless, the band sharing is feasible if the terrestrial service provider guarantees countermeasures necessary to minimize the interference to the DVB-S service users affected by the terrestrial signal. The impact of the terrestrial interfering signal on the DVB-S signal is geographically dependent, and it is unlikely that spectrum sharing criteria will be met both in near and in far area from the terrestrial service base station. Thus, the implementation of different interference mitigation techniques may be necessary for preventing or reducing terrestrial service interference in DVB-S receivers. The terrestrial service transmitting power should be kept as low as possible, the azimuth and elevation directions of terrestrial transmitting antenna should be adjusted to minimize the interference with the satellite signal, and adaptive coding and modulation should be used together with power control in the DVB-T system, in order to minimize the interference and maximize the system throughput.

Although developed for multi-path transmission environment at UHF frequency band, and thus not optimal for the operation at the satellite frequencies, DVB-T technology appears an attractive candidate for sharing the DVB-S satellite spectrum. Its most appealing characteristics are wide range of supported spectral efficiencies, wide C/N operational range, possibility to position multiple channels within the band of a single DVB-S channel, and the potential use of the economy of scale due to large expected production volumes of DVB-T equipment for the digital terrestrial television service.

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