Parametrical Analysis of DVB-T Channels

Lidia Jordanova[1], Georgi Karpov[2], Dobri Dobrev[3]

Abstract – **The paper deals with the influence of channel coding, modulation and diversity reception on the error probability in DVB-T channels. Two mathematical models of the channel are presented, which are used for determining the BER at the decoder output, when receiving signals by one or more antennas. The CNR values are determined, that are required to achieve Quasi Error Free reception, depending on the code rate, modulation type and number of diversity branches.**

Keywords – **DVB-T, concatenated RS-convolutional code, M-QAM, BER, CNR, Antenna diversity technique.**

I. Introduction

According to DVB-T standard, quality receiving of terrestrial digital programs is achieved when BER at the input of MPEG-4 demultiplexer is less then 10^{-11}. This criteria corresponds to Quasi Error Free (QEF), it means less than one uncorrected error event per hour of system's work [1].

The main difficulty in terrestrial television broadcasting systems is multipath radio signal propagation that causes intersymbol interference (ISI), from where, the bit error probability in received video and audio information, increases. In DVB-T systems the criteria for QEF receiving can be achieved by using two-step Reed-Solomon - convolutional channel coding, COFDM method of transmitting the signal through radio channel and special diversity antennas with received signals combining [2].

For transmitting of payload digital stream (video, audio signals and additional programs data) plus bits for inner, outer error protection and synchronization bits, the DVB-T standard uses two modes – 2K with 1512 subcarriers and 8K with 6048 subcarriers. Subcarriers are equally distributed through the baseband of one TV channel, which is 8 MHz. The used methods for modulation of subcarriers are QPSK, 16-QAM and 64-QAM.

Significant improvements of the CNR at the receiver input without increasing the transmitted power can be achieved by using of diversity reception [3]. There are different variants of this technique, which differ in the criteria for combining the signals, received by spatial diversity antenna system. Signal combining can be selectively (Selective Combining – SC), combining according to the criteria for maximum signal to noise ratio (Maximum Ratio Combining – MRC), combining with the same amplification of signals from different antennas (Equal Gain Combining) and others [4].

The aim of this work was to investigate the influence of the channel codes parameters, the modulation types and the number of diversity branches on the BER characteristic of digital terrestrial television channels.

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II. Error probability in DVB-T channel

The amplitude of received signal in the fading channel can be present as $A_c = \alpha \cdot A_{c0}$, where A_{c0} is amplitude of signal without influence of channel fading and α is the fading amplitude. The received carrier amplitude A_{c0} is modulated by α. The parameter α is a random variable with mean-square value Ω, the probability density function of α depends on type of channel fading. Since, the power of received signal attenuates with α^2, the instantaneous value of energy per bit to spectral power density $\gamma = \alpha^2(E_b/N_0)$. The mean-square value of γ is calculated by the formula

$$\overline{\gamma} = \overline{\alpha}^2 E_b/N_0 = \Omega E_b/N_0 \,. \tag{1}$$

For Rayleigh fading channel, used for transmitting the M-QAM modulated signal, the bit error probability (BEP) is defined as [4]

$$P_b(\gamma) = \frac{2}{\log_2 M}\left(1-\frac{1}{\sqrt{M}}\right)\left(1-\frac{1}{\Phi}\right) - \left(1-\frac{1}{\sqrt{M}}\right)^2\left(1-\frac{4}{\pi}\cdot\frac{1}{\Phi\cdot \mathrm{tg}(\Phi)}\right), \tag{2}$$

where

$$\Phi = \left(\frac{M-1+1.5\overline{\gamma}\,\zeta\log_2 M}{1.5\overline{\gamma}\,\zeta\log_2 M}\right)^{1/2}. \tag{3}$$

When no channel coding is applied, ζ = 1.

In DVB-T systems the channel coding is performed in two stages, as firstly the MPEG-4 digital stream is applied to the input of RS-coder and then, RS-coded stream is applied to the input of convolutional coder.

The bit error probability after the RS decoder $P_{RS,out}$ is related to the bit error probability at the input of RS decoder $P_{RS,in}$ by the following dependence [5]:

$$P_{RS,out} = \frac{1}{N\log_2 M}\sum_{i=t+1}^{N}\beta_i\binom{N}{i}\times \left(P_{RS,in}\log_2 M\right)^i\left(1-P_{RS,in}\log_2 M\right)^{N-i}, \tag{4}$$

where N is the number of symbols in a RS-coded block (N = 204), t is the maximal number of erroneous symbols, that can be corrected with RS code ($t = 8$), β_i is the average number of symbol errors remaining uncorrected in the received block after decoding. According to DVB-T standard [6] it is accepted that $\beta_i = i$. In formula (4) $P_{RS,in}$ actually represents BEP after the convolutional decoder.

BEP after convolutional decoder $P_{C,out}$ depends on parameters of transmitted signal, and on the characteristics of the communication channel. The upper bound of BEP after convolutional decoder is defined as [6]

$$P_{C,out} \le \frac{1}{k} \sum_{d=d_{free}}^{\infty} w(d) P_d \left(E_b / N_0 \right), \quad (5)$$

where $P_d(E_b/N_0)$ is the probability of choosing an incorrect path at Viterbi decoding, which differs from the correct path in terms of d positions, k is the constructive code length, d is the free distance of convolutional code, $w(d)$ is the number of paths with distance d, d_{free} specifies the free distance of the used code. Values of parameters d and $w(d)$ are given in [5].

For the Rayleigh fading channel there is the following dependence between probability P_d and BEP in communication channel P_{in} [7]:

$$P_d = P_{in}^d \sum_{k=0}^{d-1} \binom{d-1+k}{k} (1-P_{in})^k . \quad (6)$$

To determine P_{in} the expressions (2) and (3) are used, where the following substitution is made: $\zeta = R_{RS} \cdot R_C$. The Reed-Solomon code rate $R_{RS} = 0.92$ and the convolutional code rate R_C can be 2/3, 3/4, 5/6 and 7/8.

III. Influence of DVB-T signal parameters on radio channel noise immunity

To estimate the noise immunity of DVB-T channel the dependence of BER at channel decoder output from CNR at demodulator input is used. The relation between CNR and E_b/N_0, expressed in dB, is given by [2]

$$CNR = E_b / N_0 + 10\lg m - 10\lg\left(1 - \alpha / 4\right) +$$
$$+ 10\lg\left(R_{RS} R_C\right) + 10\lg\frac{N_{pl}}{N_{nz}} + 10\lg\frac{T_s}{T_s + T_\tau}, \quad (7)$$

where $m = \log_2 M$ is the number of bits per symbol; α is the roll-off factor of $\sqrt{\cos^2}$-filter ($\alpha = 0{,}35$); N_{pl} is the number of subcarriers, used to carry payload information; N_{nz} is the number of non-zero subcarriers, used to carry TPS (Transmission Parameter Signaling), pilot carriers and data; T_s is the period of one OFDM symbol and T_τ is the guard interval length.

The noise immunity of DVB-T channel depends on the modulation type, the channel code rate and the parameters of communication channel, that take into account the influence of white Gaussian noise and multipath propagation.

The influence of modulation type and convolutional code rate on the noise immunity of DVB-T channel is shown on

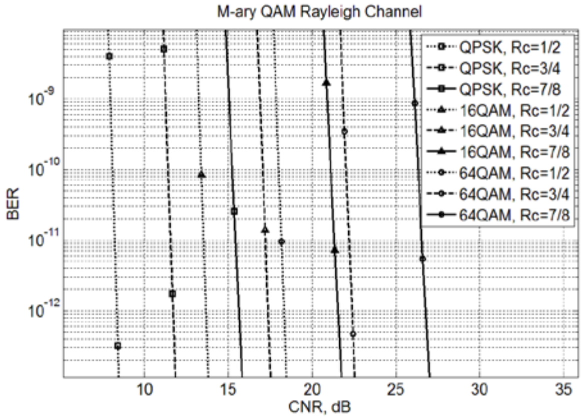

Fig. 1 BER dependences for different modulations and convolutional code rates.

Fig. 1. In this simulation research is accepted that $k = 6$, $\bar{\gamma} = E_b/N_0$, $N_{pl} = 6048$, $N_{nz} = 6817$ and $T_\tau = T_s/32$.

The obtained results show that for the three convolutional code rates when using different modulation for OFDM subcarriers, the values of CNR, that are required to achieve BER = 10^{-11}, are the following (see Tab. I):

Table I
Values of CNR

R_C	1/2	3/4	7/8
QPSK	8.2 dB	11.6 dB	15.4 dB
16QAM	13.5 dB	17.2 dB	21.3 dB
64QAM	18.1 dB	22.2 dB	26.6 dB

It is evident that increasing the modulation level in order to achieve higher transmission rates through radio channel requires working at lower convolutional code rates.

The influence of OFDM symbol guard interval on the channel noise immunity can be estimated from Fig. 2. It can be seen that in order to maintain a certain quality of reception, when T_τ decreases from $T_s/4$ to $T_s/32$, it is necessary to increase CNR by 1 dB. Moreover, the system spectral

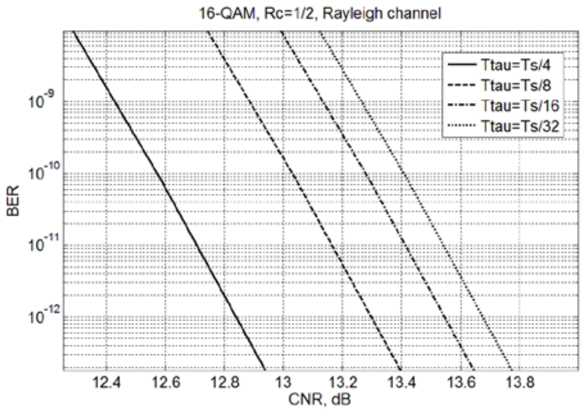

Fig. 2 Impact of OFDM guard interval length on the noise immunity of DVB-T channel for 16QAM and $R_C = 1/2$.

efficiency increases, because the data transmission rate is higher at lower values of T_τ.

IV. IMPROVEMENT OF BER PERFORMANCE OF DVB-T CHANNEL USING DIVERSITY RECEPTION

The method of diversity reception allows increasing the CNR at the receiver input by combining of some copies of received signal in a certain way. The increase of CNR at the receiver input implies the decrease of BER at MPEG-4 decoder. The researches, presented in this paper are based on Selective combining (SC) of signals in receiver. SC is technique of the switched type, it means, that in a current moment the receiver selects the antenna with the highest received signal power and ignores inputs from the other antennas. The advantage of SC method is simple and cheap technical implementation. Usually, two or four diversity branches are used, as in the first case the realization is simpler and cheaper, and in the second case higher system efficiency is achieved. The number of diversity branches is determined by the number of receive antennas [3].

To determine the bit error probability when SC receiving scheme with L branches is used, the following dependence can be applied [9]

$$P_{b,SC}(\lambda_k) = \frac{1}{\log_2 M} \sum_{k=1}^{L} \binom{L}{k} (-1)^{k-1} \left\{ q \left(\frac{1-\lambda_k}{2} \right) - \right.$$
$$\left. - \frac{q^2}{16} \left[1 - \frac{4\lambda_k}{\pi} \arctan\left(\frac{1}{\lambda_k} \right) \right] \right\} \quad (8)$$

For DVB-T channel, where the concatenated Reed-Solomon - convolutional code is used, the parameters λ_k and q are calculated as

$$\lambda_k = \sqrt{\frac{\bar{\gamma}}{kp + \bar{\gamma}}} \quad \text{and} \quad q = 4\left(1 - \frac{1}{\sqrt{M}}\right), \quad (9)$$

where

$$p = \frac{2(M-1)}{\left(3 R_{RS} R_C \log_2 M\right)}. \quad (10)$$

The bit error rate at the output of channel decoder is determined from expressions (2) - (6) as BEP in the communication channel is equal to

$$P_{in} = \frac{P_{b,SC}(\lambda_k)}{\log_2(M) R_{RS} R_C}. \quad (11)$$

The following two figures (Fig. 3 and Fig. 4) show dependence of BER at the output of concatenated RS-convolutional decoder from CNR at demodulator input for the cases with two ($L = 2$) and four ($L = 4$) receive antennas. To obtaining this dependences, it is accepted that $k = 6$, $\bar{\gamma} = E_b/N_0$, $N_{pl} = 6048$, $N_{nz} = 6817$ and $T_\tau = T_s/32$.

The researches are conducted for the three modulations of OFDM subcarriers (QPSK, 16QAM and 64QAM), as in the figures only dependences for three code rates (1/2, 3/4, and 7/8) are shown.

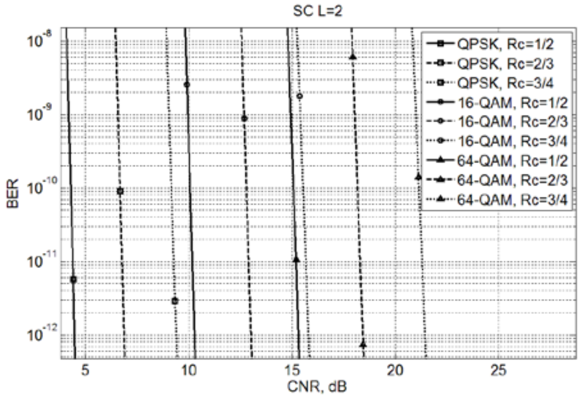

Fig. 3. BER characteristics of DVB-T channel when $L = 2$

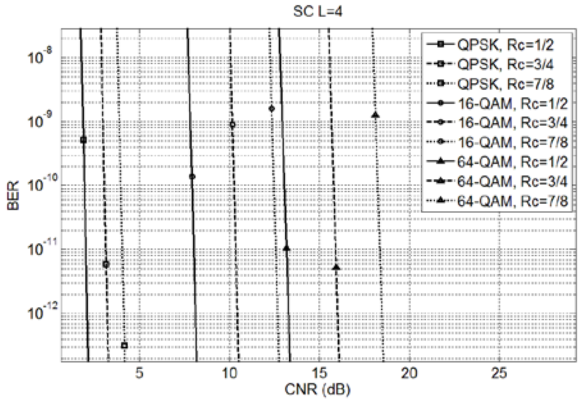

Fig. 4. BER characteristics of DVB-T channel when $L = 4$

The values of CNR, required for QEF reception when two and four diversity branches are used can be seen in Tab. II.

TABLE II
CNR VALUES WHEN COMBINING THE SIGNALS RECEIVED BY VARIOUS ANTENNAS

L	R_C	1/2	3/4	7/8
2	QPSK	4.4 dB	6.8 dB	9.3 dB
	16QAM	10.2 dB	12.9 dB	15.7 dB
	64QAM	15.2 dB	18.3 dB	21.3 dB
4	QPSK	2.1 dB	3.1 dB	4.1 dB
	16QAM	8.0 dB	10.4 dB	12.6 dB
	64QAM	13.2 dB	15.9 dB	18.3 dB

It is obvious, that for the given modulation of OFDM subcarriers and for a given code rate, by using of receive combining technique, it is possible to obtain the essential decrease of CNR values, which are necessary for QEF reception. The gain with respect to the parameter CNR compared to the case when only one receive channel is used is shown in Table III.

TABLE III
BENEFITS REGARDING THE PARAMETER CNR.

L	R_C	1/2	3/4	7/8
2	QPSK	3.8 dB	4.8 dB	6.1 dB
	16QAM	3.3 dB	4.4 dB	5.6 dB
	64QAM	2.9 dB	3.9 dB	5.3 dB
4	QPSK	6.1 dB	8.5 dB	11.3 dB
	16QAM	5.5 dB	6.8 dB	8.7 dB
	64QAM	4.9 dB	6.3 dB	8.3 dB

The conducted researches show, that using of more than four diversity branches does not influence essentially values of CNR, that are required for BER = 10^{-11}. This is illustrated on Fig. 5.

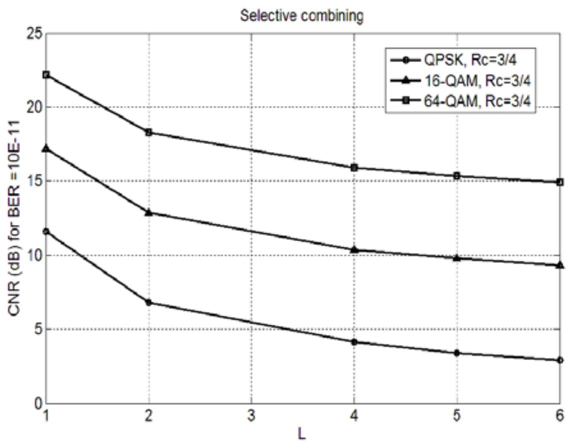

Fig. 5 Influence of number of diversity branches on CNR

It is important to mark, that in contrast to the convolutional code rate and the type of subcarrier modulation the diversity reception technique does not influence the spectral efficiency and its implementation is associated with increasing the system complexity.

V. CONCLUSION

The investigations carried out on BER characteristic of DVB-T channels allow to define the minimum acceptable values of CNR, which are required for achieve QEF reception, taking into account the code parameters, the size of OFDM symbol guard interval, the modulation type and the number of diversity branches.

Obtained results show, that when the signal is received by one antenna and the convolutional code rate is maximal, the values of CNR varies from 15.4 dB (QPSK) to 26.6 dB (64QAM). Using two diversity branches allows these values to be reduced by 6.1 dB (QPSK) and 5.3 dB (64QAM), and when using four diversity branches the achieved reduction is 11.3 dB (QPSK) and 8.3 dB (64QAM).

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