DESIGN OF RADIO CHANNEL FOR DVB-T SYSTEM

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Abstract

The paper deals with the influence of transmitter parameters, the distance between transmitter and receiver, the propagation losses, the channel coding and modulation on the quality of received video information in DVB-T systems. A мathematical model to determine the dependence of field strength from distance to DVB-T transmitter is presented. Expressions for calculating of minimum carrier-to-noise ratio (CNR) at the input of DVB-T receiver, necessary for quasi-error-free reception, are given. The dependence of minimum mean field strength at the receiver input from CNR is derived and the algorithm for determination of maximum distance to the transmitter is described.

1. INTRODUCTION

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. As is known, required quality of the received digital TV 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]. 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 evaluating the quality of received TV programs in DVB-T system, the three different criteria are used: the carrier-to-noise ratio (CNR) required for quasi-error-free reception, the available useful data rate and the field strength required for different reception modes. There are four reception modes, namely, fixed reception with rooftop antenna, portable outdoor and indoor reception and mobile reception. Specific for mobile reception is that receiver moves relative to the transmitter, this causes Doppler effect in communication channel.

The planning of digital terrestrial broadcasting systems can be divided into two main stages. The first step is to define the dependence of field strength from distance to transmitter antenna, taking into account conditions of signal propagation, requirements to percentage of coverage and percentage of time, during which the given reception quality is supported. The second stage of the planning is determination of minimum median field strength at the receiver input, required for quasi-error-free reception for different parameters of DVB-T signal and different reception conditions. After the minimum median field strength is calculated, the service zone of a given DVB-T transmitter can be estimated, using dependences from the first step of design.

The aim of this research is to derive relationships for determination of field strength at the receiver input that is required for quasi-error-free reception, considering the parameters of DVB-T transmitter and receiver and distance between them, the communication channel parameters, the modulation type and parameters of channel codes.

2. DEPENDENCE OF FIELD STRENGTH FROM DISTANCE TO TRANSMITTER

Dependences of field strength E (dBμV/m) against distance d (km) to transmitter antenna are given in form of tables and graphics in ITU-R recommendations. The values are obtained on the base of measurements and theoretical considerations and ensure that value of field-strength is exceeded for 50% of locations for time percentages 50%, 10% and 1% of system work. These dependences correspond to equivalent radiated power (ERP) of 1 kW in the direction of the reception point, or respectively, 1.637 kW equivalent isotropic radiated power (EIRP), and receiver antenna height 10 m above ground level. The recommendation contains dependence of E from d for different frequency bands, transmitter antenna heights and geographical zones.

When developing the algorithm of designing the DVB-T system, it is necessary to derive dependence of field strength from distance to transmitter. This requires the selection of an adequate model that describes losses in communication channel. Suitable for this purpose is semi-empirical Hata-Okumura model. Number of modifications of this model exists, as comparison suggests that the ITU-R P.529-3 model is the most suitable for general use and for frequencies above 500 MHz and is the most close to Okumura model [3].

Modified model ITU-R P.529-3 of Hata-Okumura model for determination of propagation losses L (in dB) has the following form:

$$L=69.82+6.16*\lg(f)-13.82*\lg(h_t)- \\ -\alpha(h_r)+\left[44.9-6.55*\lg(h_t)\right]\lg(d)^b, \quad (1)$$

where f is working frequency in MHz, h_t – transmission antenna height in m, $\alpha(h_r)$ – gain correction factor of receiver antenna, considering antenna height h_r, in dB, d – distance between transmitter and receiver in km.

For determination of receiver antenna correction factor, the following expression is used:

$$\alpha(h_r)=[1.1*\lg(f)-0.7]h_r- \\ -[1.56*\lg(f)-0.8]. \quad (2)$$

The value of power index b for $d \le 20$ km is 1, and for $d > 20$ km it is calculated with the following formula:

$$b=1+\left(0.14+1.87*10^{-4}*f\right)*d^{\Delta}+ \\ +\left(1.07*10^{-3}*h_t^{\Delta}\right)*d^{\Delta}, \quad (3)$$

where

$$d^{\Delta}=\left[\lg(d/20)\right]^{0.8} \text{ and} \quad (4)$$

$$h_t^{\Delta}=h_t/\left(1+7*10^{-6}*h_t^2\right)^{1/2}. \quad (5)$$

This model is suitable for use over the following ranges of input parameters:

$150 \text{ MHz} \le f \le 1500 \text{ MHz}$,

$30 \text{ m} \le h_t \le 200 \text{ m}$,

$1 \text{ m} \le h_r \le 10 \text{ m}$,

$1 \text{ km} \le d \le 100 \text{ km}$.

By known equivalent isotropic radiated power of transmitter (EIRP) in dBW, signal propagation losses from transmitter to receiver L in dB and radiated signal frequency f in MHz, the power flux density at receiving point Φ in dBW/m² can be found, as for the purpose following expression is used:

$$\Phi=EIRP-L+20\lg f-38.55 \quad (6)$$

The following formula is obtained to determine field strength at receiver point E is dBμV/m:

$$E=\Phi+120+10\lg(Z_{c0})=\Phi+145.76, \quad (7)$$

where Z_{c0} = 120π is free space wave impedance.

Dependences of field strength from distance to transmitter for three transmitter antenna heights are shown on Fig. 1. The dependences refer to the case, when EIRP = 32.15 dBW, and f = 600 MHz.

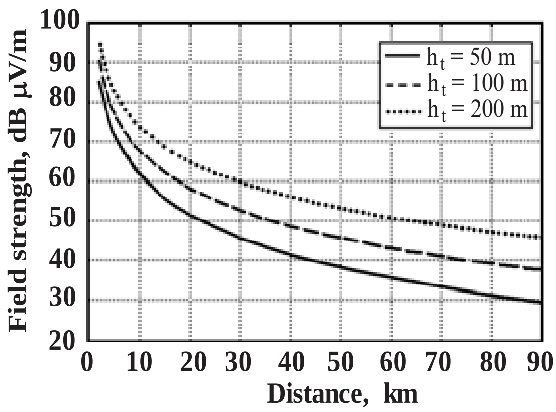

Fig. 1. Field strength for a given distance to receiver and transmitter antenna height

If the output transmitter power P_t in W is given, the following expression is used to calculate EIRP in dBW:

$$EIRP=10\lg(P_t)+G_t-L_{\Sigma} \quad (8)$$

where G_t is the gain of transmitter antenna in dBi and L_{Σ} is the transmitter feeder losses in dB.

3. ACCEPTABLE CNR AT THE INPUT OF DVB-T RECEIVER

To provide QEF reception, it is necessary BER at the output of channel decoder not to exceed 10^{-11}.

The value of BER depends on CNR at the input of DVB-T receiver, roll-off factor *α* of digital filter at the output of demodulator ($\alpha = 0.35$), code rates of Reed-Solomon code and convolutional code, modulation method (number of bits per symbol, m) and working mode of the system (2K or 8K).

In DVB-T systems the shorted Reed-Solomon code RS(204,188,8) is used with rate $R_{RS} = 0.92$. The convolutional code rate R_C can be 1/2, 2/3, 3/4, 5/6 and 7/8. For modulation of subcarriers the following methods are used: QPSK, 16QAM и 64QAM (value of m for these modulations are respectively 2, 4 and 6).

The two modes of work of DVB-T system differs in number of subcarriers in OFDM symbol, that is 1705 (2k) and 6817 (8k). In both modes the ratio of guard interval length (τ) and OFDM symbol length (T_U) can be τ/T_U = 1/4, 1/8, 1/16 and 1/32.

Also, the type of communication channel must be considered when determining the CNR. The channel is characterized with Rice fading when right path between transmitter and receiver exists, and when there is no right sight, the channel is characterized with Rayleigh fading and received radio signal is formed from reflected copies of transmitted signal. The channel with more complex conditions of signal propagation requires higher values of CNR ratio at the input of receiver.

In [4] are given expressions for determining the dependence of BER at the output of channel decoder from CNR at the input of DVB-T receiver, from covolutional code rate R_C and modulation type. These dependences are used to calculate the minimum CNR, required for QEF reception. Obtained values of CNR (in dB) for Rice and Rayleigh channels, when reception is fixed (FR), portable outdoor (PO), portable indoor (PI) and mobile (MO) are given in Table 1.

Table 1. Acceptable values of CNR

Modulation	R_C	Race channel	Rayleigh channel	
		FR	PO/PI	MO
QPSK	1/2	5,9	8,2	11,1
QPSK	2/3	7,9	10,2	13,2
QPSK	3/4	9,1	11,6	14,5
QPSK	5/6	10,3	12,8	15,8
QPSK	7/8	11,3	15,4	16,9
16-QAM	1/2	11,6	13,5	16,8
16-QAM	2/3	14,1	16,4	19,4
16-QAM	3/4	15,7	17,2	21,1
16-QAM	5/6	16,9	19,4	22,4
16-QAM	7/8	17,5	21,3	23,1
64-QAM	1/2	17,2	18,1	22,4
64-QAM	2/3	19,5	21,8	24,8
64-QAM	3/4	21,2	22,2	26,6
64-QAM	5/6	22,7	25,2	28,2
64-QAM	7/8	23,7	26,6	29,3

4. DEPENDENCE OF FIELD STRENGTH FROM ACCEPTABLE CNR

Large numbers of experimental and theoretical researches were conducted with purpose to find the dependence of field strength at the receiver input from minimum CNR, at which the QEF reception is provided. Obtained results for different conditions were described in detail and documented in resolutions of Regional Radio communication Conference (RRC-06) of ITU-R from 2006 year [5].

The following dependence was derived to determine the minimum field strength at receiving place E_{min} (in dBμV/m), necessary for QEF reception [5]:

$$E_{min} = P_{r\,min} - G_r - 10\lg\left(\frac{1.64\lambda^2}{4\pi}\right) + L_f\,, \qquad (9)$$

where $P_{r\,min}$ is acceptable minimum signal level at the DVB-T receiver input in dBW, G_r – receiver antenna gain related to half-dipole in dBi and λ – receive signal wave length in m, L_f – receiver feeder losses in dB.

The minimum level of receive signal is limited by acceptable values of CNR parameter and noise power P_n at receiver input:

$$P_{r\,min} = CNR + P_n\,. \qquad (10)$$

Values of CNR, which depend on type of communication channel, selected scheme of OFDM signal subcarrier modulation, convolutional code rate and receiving mode are given in Table 1. Levels of outer and inner noises at the input of DVB-T receiver are defined by formula:

$$P_n = 10\lg(k) + 10\lg(B_n) + \\ + 10\lg(T) + NF_r\,., \qquad (11)$$

where $k = -1.38.10^{-23}$, W/K.Hz is Boltzmann's constant, B_n – receiver noise bandwidth in Hz (for channel bandwidth 8 MHz $B_n = 7{,}61$ MHz), $T = 290$ K –

absolute temperature, NF_r – receiver noise figure in dB (according to ITU-R recommendations for DVB-T receivers NF_r = 7 dB).

Minimum mean field strength E_{med} at receiving place is used for design of DVB-T channel. Except E_{min}, it depends on the receiving mode and is calculated using following expressions:

$$E_{med} = E_{min} + P_{mmn} + C_l \quad \text{«FR»} \qquad (12)$$

$$E_{med} = E_{min} + P_{mmn} + C_l + L_h \quad \text{«PO»} \qquad (13)$$

$$E_{med} = E_{min} + P_{mmn} + C_l + L_h + L_b \quad \text{«PI»} \qquad (14)$$

Coefficients used in these expressions, whose values are given in dB, account influence of following factors: man-made noise (P_{mmn}); characteristics of area of receiver location (C_l); losses from changing the height of receiver antenna relative to reference value, that is accepted to be 1.5 m above ground level (L_h) and mean building entry loss (L_b).

Dependences of mean minimum field strength in receiving place E_{med} (in dBμV/m) from minimum CNR value at the input of receiver (in dB) for fixed reception with rooftop antenna, portable outdoor reception and portable indoor reception are shown on Fig. 2. To obtain these dependences it is accepted that f = 600 MHz, L_f = 4 dB G_r = 11 dBi, and recommended by ITU-R values of coefficients from (11) - (13), namely P_{mmn} = 0 dB, C_l = 13 dB, L_h = 17 dB and L_b = 8 dB.

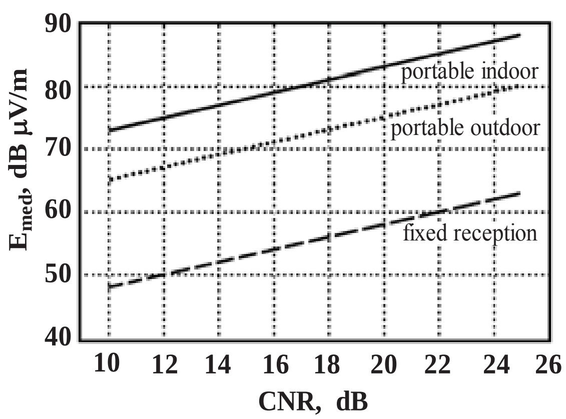

Fig. 2. Minimum median field strength corresponding to minimum CNR

Using obtained dependences easily can be found value of E_{med} necessary for minimum CNR and for QEF reception. For example, if modulation of subcarriers in OFDM symbol is 16QAM, convolutional code rate is R_C = 3/4, from Table 1 the following values of CNR are obtained: 15.7 dB (fixed reception) and 18.1 dB (portable indoor and outdoor reception). To ensure these values of CNR it is necessary field strength at receiving place E_{med} to be not less then 53.9 dBμV/m – for fixed reception (FR), 73.3 dBμV/m – for portable outdoor (PO) reception and 81.3 dBμV/m – for portable indoor (PI) reception.

5. SERVICE ZONE OF DVB-T TRANSMITTER

Service zone of DVB-T transmitter is characterized by field strength that is above minimum mean field strength E_{med}. As already explained, E_{med} depends on minimum acceptable C/N ratio at the input of receiver, radiated signal frequency f, receiver antenna gain G_r, noise parameters of receiver (B_n and NF_r) and selected above additional factors.

Minimum acceptable values of CNR parameter, taking into account modulation scheme, convolutional code rate and type of communication channel are given in Table 1. According to catalog data receiver antenna gain value typically varies in range from 5 to 40 dBi depending on number of its elements and its shape. Values of other parameters are chosen according to ITU-R recommendations for DVB-T systems.

To determine maximum acceptable distance between transmitter and receiver d_{max}, dependences given in the second section of the publication could be used, or graphical dependences from ITU-R recommendations, similar to those shown on Fig. 1. Accepting, transmitted EIRP is 32.15 dBW, radiated signal frequency f = 600 MHz and values of parameter E_{med} are 55.4 dBμV/m (for FR), 72.4 dBμV/m (for PO reception) and 80.4 dBμV/m (for PI reception). Then, to provide QEF reception for 95% of locations in service area for 50% of the time of transmitter work, it is necessary d_{max} not to exceed values given in Table 2.

Table 2. Maximum distance between transmitter and receiver in km

h_h, m	50	100	200
FR	15.7 km	25.2 km	43 km
PO	4.9 km	7.35 km	11.55 km
PI	2.7 km	4.2 km	6.25 km

6. CONCLUSION

Dependences for determination of field strength at receiving place, given in this publication, allow take into account parameters of DVB-T transmitter and receiver, conditions of radiated radio signal propagation and mode of its receiving. These dependences are used for development of software, used for resolving some important problems, related to construction of terrestrial television networks. These problems are: determination of output power, antenna gain and antenna system directional properties for DVB-T transmitters and its service zone, creating conditions for QEF reception, while changing radio signal propagation conditions and signal reception mode and other.

8. APPENDIX AND ACKNOWLEDGMENTS

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