Estimation of the Noise Immunity Characteristics of Telecommunication Network

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Abstract. The harmful impacts of various interference sources in the communication channel of data transmission systems and an increasing noise immunity in linear distortion conditions are important problems in the development of information transmission systems. To improve reliability and the data receiving accuracy, a mathematical model is developed, which allows to assessment of the survivability of telecommunication systems to interference at incoherent receiving. In this case is assumed that system impact the unintentional sources. The mathematical model considers the communication quality, spectral efficiency, coding method, and modulation principle used during the multimedia services. Presently, the development of the corporate multiservice communication networks is in conditions where the size of user and service traffic packets is rapidly increase. To ensure transmission reliability is promising of an implementation of the coherent modem. It will allow a decrease in the failures of such systems. To increase the transmission rate used coherent modem with noise-resistant characteristics. However, the communication quality in this case is decreased, due to more influence of the inter-symbol interference to the data quality receiving. The synthesis of optimal signals based on rectangular pulses with different shapes by the coherent modem for the data transmission system aims is solved by using of matching filter that has a pulse transient response. To obtain this the frequency limiter is used at the output of the channel digital demodulator. One of the ways to properly solve the problem noted above is by applying in the development of telecommunication multiservice networks the mathematical model with correction ability. This one can be developed based on the optimal signal-receiving theory.

Key-Words: - quality of communication, final signals, telecommunication systems, transmission systems, communication channel, mathematical model, spectral efficiency, communication network.

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1 Introduction

The quality control of the transmission and communication in a data transmission system (DTS) with a coherent modem (CM) in complex conditions are used by several means. These means provide adaptive protection from interference in real-time mode during the document and voice transmission. This allows us to minimize the interference sources' impact to CM. Due to this during the provision of the multimedia services there is cause of a delay of the useful and service traffic flow. The service traffic is developed to increase the operation efficiency of the multiservice telecommunication networks (MSTN). For the assessment of the noise immunity characteristics of the receiving of a DTS with a CM, it is necessary to consider the bit error probability P_{BER} and the data transfer rate (DTR) V_b of the CM in critical states. Further, we assume that interference created unintentionally is organized, and the different sources of interference are random, [1], [2].

2 Problem Statement

Considering the components of the noise immunity vector $R_{ö}(t, k_{nm})$ of data receiving at time t, and the transmission rate of the CM under the intentional interference influence can be described by the following expression:

$$R_{ö}(t, k_{nm}) = W[P_{BER}, V_b, SNR(E_b, k_{nm}), N_{nn}(t)], \quad (1)$$

Where $N_{nn}(t)-$ function that considers the intentional interference sources at time t; $SNR(E_b, N_0)-$ signal-to-noise ratio. It characterizes the complex communication quality (CQ) indicators with the CM considering the energy E_b of one bit signal and the spectral density of power of interference N_0.

Dependence (1) presents the essence of the approach, which considers the complex indicators of the CQ in DTS. Based on dependence (1) a mathematical model (MM) to assess the stability of CM to interference during the data receiving is proposed. During the use of this receiving model, is assumed that any $b_i, 1 \leq i \leq n$ parameter of the signal $u(t, b_i)$ carries information and this is a process with random characteristics. In the proposed approach, to effectively separate this parameter $S(t, b_i)$ from the time interval $[0, T_c]$ is required:

$$S(t, b_i) = N_{nn}(t) + b_i u_0(t) + (1 - b_i) u_1(t), \; 0 \leq t \leq T_c \quad (2)$$

An expression (2) can be used to analyse of the optimal realization of binary signals at the time interval, [3] and allows to decide on $u_0(t)$ or $u_1(t)$. The considered models are the main part of the noise-immunity problem of data receiving and binary signals processing in DTS with a CM. Let us consider the process of building the MM to assess the receiving noise immunity.

3 Solution of the Problem

The MM to assess the receiving noise immunity proposed to solve this problem includes the methods of discrete signals receiving, correction codes had large effectiveness, and amplitude modulation (AM) with quadrature law in a DTS using a CM. So as the noise immunity of receiving depends on random characteristics of the used modem that is approved by system analysis in, [4], [5], so quantitative assessment of it can be the operation failure probability of DTS. This probability is a monotonic function of the SNR at the input of the receiver and can be estimated based on the average erroneous receiving probability of a discrete signal:

$$E[P_{er}] = F[SNR(E_b, k_{nm}), V_b], \quad (3)$$

To increase the receiving noise immunity of the CM in a DTS, it is necessary to consider the main indicators which characterize the operating quality of the MSCN, [6], [7], [8]. As a criterion for the quality indicator of the studied communication network, is accepted its bandwidth, considering at the channel level the parameters of the system noise immunity under the intentional interference influence. The maximum bandwidth of the CM in a DTS is defined by the following expression:

$$C_{max}(E_b, V_b) = \Delta F_c \cdot \ell og_m[1 + SNR(E_b, k_{nm})], \quad (4)$$

where E_b - the energy to transmission of one bit of the discrete signal and defined as follow:

$$E_b = E_c / [R_k \cdot \ell og\, m], \; R_k = (k/n), \quad (5)$$

R_k – the rate of Reed-Solomon (RS) code; $R_k < 1$; ΔF_c - the bandwidth of the signal.

The expressions (4) and (5) is obvious following. The main parameter which determines the maximum bandwidth and CQ in DTS is a complex indicator of the SNR, which is determined as:

$$SNR(E_b, k_{nm}) = V_b \cdot E_b \cdot [\Delta F_c \cdot N_o]^{-1}, \quad (6)$$

The last expression characterizes the CQ of the receiving by coherent modem and shows of the signal power to noise level ratio in DTS. Expression (6) is also an energy indicator of noise immunity of receiving and describes the use of the CM in terms of power. Considering the limit value qtr of SNR in DTS, the preventing conditions of the degradation of the CQ can be defined by the following expression:

$$SNR \leq q_{tr.} \leq \min_{E_b}\{\alpha_{\kappa p}[SNR]\}, \quad (7)$$

where q_{tr} - is the limit value, the critical of the SNR value. It provides a preset quality of a DTS using a CM:

$$q_{tr} = \min_{E_b}\{\alpha_{\kappa p}[SNR(E_b, k_{nm})]\}, \quad (8)$$

where α_{kr} – a modem's resource coefficient, which considers the energy losses during the received signal processing in a real DTS relatively on ideal receiving ($\alpha_{\kappa p} \geq 1$).

The mathematical model is developed to assess of the noise immunity of receiving by using a CM in a DTS is used to solve this problem, [9], [10]. A mathematical interpretation of this can be expressed by the following function:

$$Q_P = W\{\underset{E_b, k_{nm}}{Argmax} R_{\ddot{o}}[SNR(E_b, k_{nm})]\}, \quad (9)$$

Under the following restrictions

$$C_{mak}(E_b, V_b) \geq C_{mak}^{bb.}(E_b, V_b),$$
$$P_{BER} \leq P_{BER}^{bb},$$

$$SNR(E_b, k_{nm}) \geq SNR^{bb}(E_b, k_{nm}), \quad (10)$$

The expressions (9) and (10) are the basis of the proposed approach, [11], [12], [13], [14]. The mathematical model developed based on it considers the indicators of CQ, energy effectiveness, coding, and modulation methods to assess the noise immunity of receiving. As well as expressions (9) and (10) are a simple analytical description of the function of noise immunity when assessing the operation quality of the DTS with a CM. Considering the formulation of the problem given above, let us study and assess the bit error probability during the discrete signals receiving. By the Neumann-Pearson (NP) criterion and the model to assess the noise immunity receiving, as the noise immunity characteristic of the given modem is accepted the discrete signal receiving probability at the output of the demodulator (DM), and the total power of an intentional interference which coming to the input.

As research result in, [4], to assess the discrete signal probability at the output of the DM proposed the following expression:

$$P_{qe} = 1 - \sum_{i=1}^{t} C_N^{N-i} \cdot (1 - P_{te})^{N-i} P_{te}^{i}, \quad (11)$$

where P_{te} - the data distortion probability of the traffic packets ransmitted them by the DTS; C_N^{N-i} - binomial coefficient; t - the correcting capacity of the RS code, expressed considering the code sequence length N and code rate, as follow:

$$t = 0{,}5N \cdot (1 - R_k) = 0{,}5(k + r)(1 - R_k) \quad (12)$$

R_k - the RS code rate, that determined as follows: $R_k = (k / N) < 1$.

The study aim is to use polynomial, where

$$d_{\min} \geq (2t + \sigma + 1)$$

is the minimum of code distance, $\sigma = \sigma_{er} -$ the number of errors in packet.

The total interference power p_{mn} at the input is determined based on the bandwidth ΔF_c of the signal, interference ΔF_n, and the average external interference power expressed by spectral density, as following way, [6]:

$$p_{og} = \eta_{cn}(F) \cdot N_n \cdot \Delta F_n, \quad (13)$$

where $\eta_{cn}(F)-$ matching coefficient of the interference and signal in frequency that defined as follow:

$$\eta_{cn}(F) = [(\Delta F_n) + (\Delta F_c)] / \Delta F_c, \quad (14)$$

Considering the (7), (8), and expression noted below

$$[E_b / N_{mn}] = [P_c / P_{mn}], \quad (15)$$

a bit error probability for the CM can be determined as, [6]:

$$P_{BER} = \frac{1}{2} erfc\left[\frac{k}{N} \cdot \frac{E_b}{N_{mn}} \cdot k_{nm}\right]^{0,5}, \text{ at M=2} \quad (16)$$

where $erfc(x)-$ an additional error function integral, that is defined as, [3]:

$$erfc(x) = (2/\sqrt{\pi}) \int_x^{\infty} \exp(-t^2) dt$$

k and N - the noise immunity parameters of the RS code (k - number of information bits include in the packet). Expression (16) is used to determine as main noise immunity indicator when applying M_RS modulation and RS code.

Modeling of the parameters of the modems in the DTS performed in MATLAB environment. Simulating of transmitting and receiving of signals used the Communications Toolbox, [7]. To determination of the dependency, the bit error probability and signal-noise ratio used the BERTool graphical package. The BERTool environment is allowed to calculate the values of $SNR(E_b, k_{nm})$ and modem's noise immunity for a given frequency range. The graphical curve for these dependents

$$P_{BER} = F[SNR(E_b, k_{nm})]$$

was built, which used to calculate of the theoretical value of the RS-code parameters and bit rate. The graphical curve is built by the BERTool on analytical expressions (14-16). The following values were obtained based on calculations:

RS code modulation performed according to the RS algorithm: at

$$R_k = 0{,}75;\ N = 32,\ d = 4,\ k = 24.$$

The bit error probability improved at

$$R_k = 0{,}75 < 1.$$

An analysis of results of performed calculations shows the following: an increase of $SNR(E_b, k_{nm})$ leads to a decreasing in the bit error probability. This matches with the requirements on the CQ and the noise immunity level of DTS tracts at the given rates for bit and code. Thus, the proposed mathematical model allows to assessment of noise immunity of the CM receiver when impacts of the unintentional interference. This MM considers the energy indicators of the modems, manipulation type at modulation, bit rate, and coding rate.

The results of research and analysis presented in the article can be used in a mathematical model for assessment of the noise immunity (NI) at incoherent receiving in DTS. These research results increase the reliability and accuracy of data receiving. To provide the CQ of DTS under the influence of unintentional interference, and to ensure noise immunity of DTS with the required quality of service (QoS) at the channel and physical levels, it is necessary to develop and apply the new receiving models. Regarding this, the problems of assessment of the noise immunity parameters during the design of DTS are urgent. Investigation results on the optimal receiving of discrete signals and determination of an error probability in coherent receiving were presented in, [4], [5]. The aim of this work is to develop a MM to assess of the noise immunity during the incoherent receiving in DTS that operate under the impacts of unintentional interference.

Let now us analyze the operating quality of the DTS, under the influence of unintentional interference sources.

At the channel and physical level in telecommunication system (TCS) Modularly Phase Shift Keying (M-PSK) modulation and the polynomial RS code $GF(N,k,d)$ are used. The parameters of the RS code are $N, k, d,$ [8]. The RS codes that used in the given system are directly cyclic codes, with an error correction set, which can be defined as presented in, [2]. As the main indicator to assess the quality of TCS during the impacts of interference, the average value of an error probability is accepted. Thus, the need of development a MM to improve the QC by applying effective coding and modulation algorithms, as well as for assessment of the noise immunity, is the actuality of the problem. So, if the noise immunity of receiving depends on the random parameters of the receiver, then it's the quantitative measure can be the malfunction probability of the system. This probability is assessed by the average probability, which shows of an erroneous receiving and depends on SNR at the input of the receiver, also is a monotonic function as:

$$E[P_{se}] = F\{R_k, SNR[(E_b, k_E(V_b)], M, V_b\}, \quad (17)$$

where R_k –is the Reed-Solomon coding rate, $R_k < 1$.

An energy transmitting coefficient $k_E(V_b)$ is determined considering the bit signal energy and the signal-to-noise ratio as follows:

$$k_E(V_b) = (E_b / E_{in}) \le 1, \quad (18)$$

where E_{in} – the bit signal energy is at the input.

Considering the above and expression (18), the mathematical statement of the given problem on the development of MM, the objective function to assess noise immunity of the TCS can be recorded as follow:

$$K_n(E) = W\{\underset{h_c}{Arg \min} E[P_{se}(h_c^2)]\}, \quad (19)$$

at the following restrictions

$$C_{max} \ge C_{max.bb.}, P_{BER} \le P_{BERbb}, \\ \eta_{SE}(\Delta F_c) \ge \eta_{CE.bb.}(\Delta F_c), \quad (20)$$

where C_{max} - maximum throughput for the given TCS during the multimedia services; P_{BER} – bit errors probability; $\eta_{SE}(\Delta F_c)$ – spectral efficiency of TCS at the incoherent receiving. which shows the using efficiency of the bandwidth ΔF_c of the binary signal; $C_{max.bb.}$, $P_{BER.bb.}$, $\eta_{CE.bb.}(\Delta F_c)$ – the admissible values respectively.

The last expression (20) also (21) is the basis of the new approach. Based on them a MM for assessment of the NI of a TCS was developed. This MM considers the CQ, coding methods, modulation scheme, and spectral efficiency, [14]. At the same time, obtained expressions allow us to analytically represent the NI function to assess the performance of the TCS enough simple. To implement the new approach used in constructing the MM, a scheme for the operation of an optical receiver with incoherent receiving is proposed. To perform the task by the method of random-phase incoherent receiving, it is necessary to study the paths of the transmission and receiving systems of discrete data. Then, by comparison with the threshold estimation DQ, a decision is made in favor of assumptions H_0 and H_1.

The limiting level is determined by the similarity criterion as follows:

$$\varPi(u_{1,0}) \underset{H_0}{\overset{H_1}{\gtrless}} \varPi(S) = \frac{p(u_1)}{p(u_0)}, \qquad (21)$$

For signals that have the same probability $\varPi_0 = 1$, then the expression for the similarity coefficient will take the following form:

$$\ell n I_0(2S_1/N_0) - \ell n I_0(2S_0/N_0) \underset{H_0}{\overset{H_1}{\gtrless}} \frac{E_1 - E_0}{N_0}, \qquad (22)$$

Expressions (21) and (22) determine the structure of the optimal receiver of a binary signal with an unknown initial phase in case of incoherent receiving. At the output of ZS and MS, the binary signal is essentially the energy of a discrete signal: {Π (0,1)}

$$E_{0,1} = \int_0^{T_c} u_{0,1}^2(t)\, dt = E \qquad (23)$$

Let's compare $S(\varPi_0)$ with the threshold signal at the considered moment T_c. Usually, in these cases, the value of the threshold signal is taken close to $(E/2) = S(\varPi_0)$. Let us analyze the average values of the probability of erroneous receiving of discrete signals obtained as a result of MM research. Based on similarity criteria (22) and (23), a formula is proposed to estimate the code packet receiving probability on the matched filter output based on the noise immunity estimation model:

$$P_{qe}(N, t_k) = 1 - \sum_{i=1}^{t_k} C_N^{N-i} \cdot (1 - P_{te})^{N-i} P_{te}^i, \qquad (24)$$

where P_{te} – the distortion probability of the packet data during transmission by the system; C_N^{N-i} - binomial coefficient from N to N-i; t_k – the correction ability of the RS coding, which, considering the code sequence length N. The code rate is determined as (12). RS code rate and defined as

$$R_k = (k/N) < 1.$$

In this case, the polynomial $GF(N,k,d) = GF(127, 64, 7)$ was used.

The expression (12) allows us to calculate the probability of packet loss due to various data distortions due to the lack of the recipient's ability to correct the code:

$$P_{ie}(t_k < t_{k.mp.}) = (k/N) \cdot P_{te} \cdot P_{qe}(N, t_k), \qquad (25)$$

On using the M-RSK modulation scheme, the aggregate nominal power of the unintentional interference at the receiver input is taken as a noise immunity characteristic. The total interference power P_{cmn} at the DM input is determined by the signal bandwidth ΔF_c and interference bandwidth ΔF_n, the spectral density of the average external interference power N_{cn}, as the following expression:

$$P_{cmn} = \eta_{cn}(F) \cdot N_{cn} \cdot \Delta F_n + P_{ш}, \qquad (26)$$

where $\eta_{cn}(F)$ – the matching coefficient of the interference and signal at a given frequency range, is defined as:

$$\eta_{cn}(F) = [(\Delta F_n) + (\Delta F_c)] / \Delta F_c, \qquad (27)$$

Considering the expressions (26) and (27), the SNR takes a complex form:

$$SNR(P_c / P_{cmn}) = E[B_c, P_{cmn}, \eta_{cn}(F), N_{cn}], \qquad (28)$$

where B_c – is the base of the received complex signal and, considering the entire bit arrival time T_b, is determined as follows:

$$B_c = T_b \cdot \Delta F_c = (1/V_b) \cdot \Delta F_c, \qquad (29)$$

Considering the obtained expressions (24)-(29) and

$$[E_b / N_{cmn}] = [P_c / P_{cmn}],$$

for the M-RSK modulation at M = 2, a bit error probability is determined by the following expression:

$$P_{BER} = \frac{1}{2} erfc\left(\frac{h_c}{\sqrt{2}}\right) = \frac{1}{2} erfc\left[R_k \cdot \frac{E_{in}}{N_{cmn}} \cdot k_E(V_b)\right], \qquad (30)$$

where $erfc(x) = 1 - erf(x)$ – a residual error function is determined as:

$$erfc(x) = 2(\pi)^{-0,5} \int_x^{\infty} \exp(-\delta^2)\, d\delta \cdot$$

Calculations and simulating of a noise-immunity of communication system during the receiving incoherent receiver are performed also using MATLAB Toolbox. The optimal transmitting and receiving algorithm is shown in Figure 1:

4 Conclusion

The decrease in the dynamic viscosity of oil using the developed reagent in the temperature range characteristic of oil transportation processes at a shear rate corresponding to starting loads was 55%.

The effectiveness of the ANA-10 reagent as an inhibitor of ASF formation in comparison with industrially produced analogs has been experimentally proven.

The technical and economic feasibility of using the developed reagent of complex action when collecting borehole fluid and transporting oil by pipeline transport is justified by a reduction in operating costs when using it by 10...15%, considering the commercial cost of chemicalization of the transportation process of 20 rub/m^3.

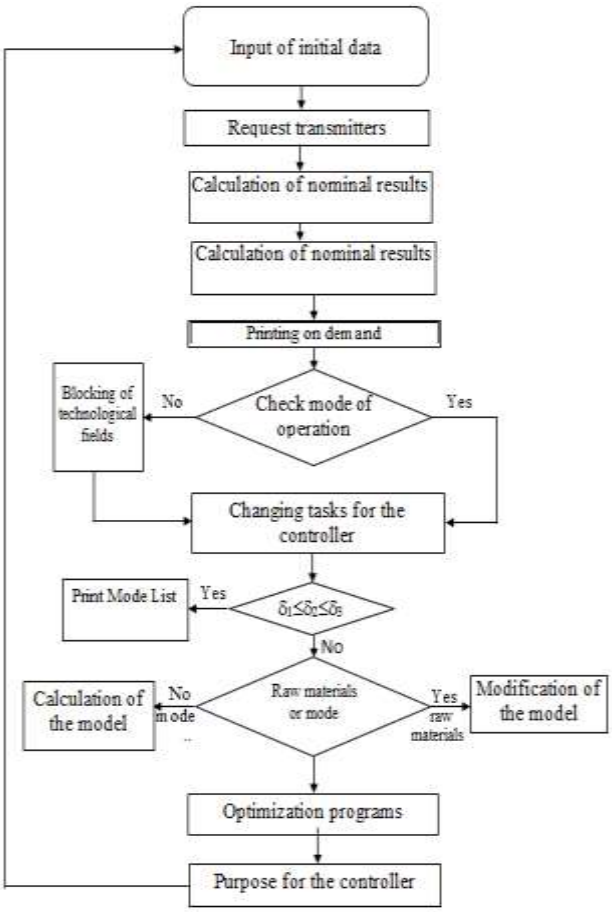

Fig. 1: Optimal transmitting and receiving algorithm

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Conflict of Interest

The authors have no conflicts of interest to declare.

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