METHOD OF ESTIMATING RELIABILITY OF INFORMATION TRANSMISSION IN WIRELESS NETWORKS CHANNELS INCREASE IN NOISE AND INTERFERENCE

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***Abstract**: This paper describes a method for estimating the reliability of information transmission in wireless networks operating in conditions of high noise and interference. The method is based on obtaining analytical relationships for calculating the reliability of information transmission based on nonlinear regression analysis and the use of log-likelihood function about transmitted bits in decision-making in the turbo decoder.*

Keywords: information technologies, a priori uncertainty, wireless networks, turbo codes

***ACM Classification Keywords**: H.4 Information system applications, H.4.3 Communications Applications and Expert Systems, G.1.6 Optimization, I.6 Simulation and Modeling, K.6.4 System Management*

Introduction

To increase the reliability of information transmission in the current wireless systems use codes noise-resistant: block codes, BCH codes, Reed-Solomon Reed-Muller codes concatenated convolutional codes, turbo codes (TC) and others. The most effective among these are TC, which are energy efficiency inferior to the theoretical Shannon limit is only 0.5 dB [Berrou, 1993].

Today, due to the increased energy efficiency of TC used in mobile communication systems of the third generation 3G (cdma2000, cdma2000 1xEV-DO, cdma2000 1xEV-DV, UMTS), the system LTE, CCSDS in communication systems for transmission of telemetry data from spacecraft, systems, satellite digital TV DVB-RCS [Holma, 2006- Ergen, 2009] and others.

A significant impact on reducing the reliability of information transmission in wireless networks have a powerful noise and intentional interference from, including jamming devices. To increase the reliability of information transmission on the physical layer of wireless systems today use adaptive-code signal structure using a signal multiposition and turbo codes. Development and implementation of adaptive methods for information exchange requires the establishment of effective procedures for monitoring and forecasting of states of channels and reliability of information transmission.

Analysis of research and publications

The basic methods and algorithms for the estimation of reliability of information transmitted over wireless networks presented in [Fengqin, 2003- Roshanzadeh, 2012].

In [Fengqin, 2003] to evaluate the reliability of the information used by the values of log-likelihood function of the transmitted bits in association with a dispersion of noise in the channel with additive white Gaussian noise. Calculated the likelihood function of the transmitted bits:

$$L(x_t) = \log_e \frac{\Pr\{x_t = +1 \mid z_t\}}{\Pr\{x_t = -1 \mid z_t\}} = \log_e \frac{f(z_t \mid x_t = +1)}{f(z_t \mid x_t = -1)} = \frac{2}{\sigma_m^2} z_t , \quad (1)$$

where x_t – the transmitted bits, z_t – accepted, $f(\cdot|\cdot)$ – probability density function, $t \in \overline{1,N}$, σ_m^2 – noise variance.

Is the mean value (1):

$$E\big[|L(x)|\big] = \frac{2}{\sigma_m^2} E\big[|z|\big], \quad (2)$$

$$E\big[|z|\big] = \sqrt{\frac{2}{\pi}} \sigma_m e^{-1/\left(2\sigma_m^2\right)} + erf\left(\frac{1}{\sqrt{2\sigma_m^2}}\right), \quad (3)$$

where $erf(\cdot)$ – the error function.

If $\sigma_m^2 < 0.2$, $E\big[|z|\big] \approx 1$, and therefore

$$\sigma_m^2 \approx \frac{2}{E\big[|L(x)|\big]}, \text{ when } E\big[|L(x)|\big] > 10 . \quad (4)$$

Evaluating the results presented it can be concluded that this evaluation method is suitable for small values of noise variance, i.e. for large signal-to-noise ratio.

In addition, the authors of [Fengqin, 2003] proposed to evaluate the use of error codes CRC, which are described by polynomials $D^{12} + D^{11} + D^3 + D^2 + 1$, $D^{16} + D^{15} + D^2 + 1$, $D^{16} + D^{12} + D^5 + 1$. Study the properties of CRC-codes are shown in [Castagnoli, 1990].

It should be noted that the CRC-codes have a low ability to detect errors that the large noise variance reduces the number of detected errors, and reduces the reliability of the transmitted information.

Studies on the use Reed-Solomon codes to detect errors in the received sequence shown in [Fadnavis, 2013].

Using additional error detection codes leads to the introduction of redundancy into the transmitted sequence, and to process complexity in a digital signal processing means to transmit information, which leads to an excessive use of computing resources systems.

Further analysis of [Fengqin, 2003- Roshanzadeh, 2012] leads to the conclusion that many modern methods for assessing the reliability based on the calculation of noise variance and the use of error detection codes. In the presence of strong noise in the channel, existing approaches will result in lower quality evaluation reliability of information transmission.

Therefore, there is a need to develop new, more efficient methods for assessing the reliability of the transmitted information channels for wireless data transmission systems with high noise levels.

Description transmission system

Figure 1 shows a block diagram of a data transmission system that operates at high noise and interference.

Data source generates a sequence $\overline{U}$ that enters the encoder TC. TC encoder produces a sequence of encoded bits $\overline{Y}$. In modulator, BPSK sequence $\overline{Y}$ converted into modulated signals $\overline{S}$. Frequency tuning is performed using a frequency synthesizer (FS) and a generator of pseudorandom sequence hopping (GPRS) in the pseudorandom modulator operating frequency (PRMOF). In the communication channel signals affect the fluctuation noise and jamming, the most commonly used noise barrage interference, noise interference in the part of the band polyharmonic interference and response interference. The received signal output from the receiver is supplied to a demodulator PRMOF, where due to the frequency synthesizer controlled by GPRS, the operating frequency jumps are eliminated. Character sequence after the BPSK demodulation and iterative decoding in the decoder TC is converted to a bit sequence received $\overline{U}'$. Furthermore, the information supplied to the decoding device reliability analysis.

In [Holma, 2006] is a block diagram of the encoder and iterative decoder TC with "soft" input and "soft" output.

Using a decoder with a "soft" input and "soft" output indicates that the data input and output of the decoder TC are of type real numbers, which significantly improves the quality of decoding [Berrou, 1993], in contrast to the "hard" option when using two-level decision making data and take only two integers "0" or "1".

TC encoder consists of two parallel recursive systematic convolutional codes (RSCC), separated pseudorandom interleaver. An interleaver in the turbo code encoder composition is used for shifting the information bits input to the second RSCC, to reduce the correlation of the first parity bit and second RSCC. Each RSCC performs encoding on an information sequence of its trellis diagram, the structure of which depends on the generator polynomial RSCC [Valenti, 2001]. TC iterative decoder consists of series-connected component decoders. One decoding iteration and decoder comprises two pseudorandom interleaving two devices (deinterleaving). Deinterleaving apparatus deinterleaving operation is performed. In the decoder circuit TC used $d = 2I$ component decoders, wherein *I* – the total number of iterations of the decoding, $d \in \overline{2, D}$, *D* – the total number of component decoders.

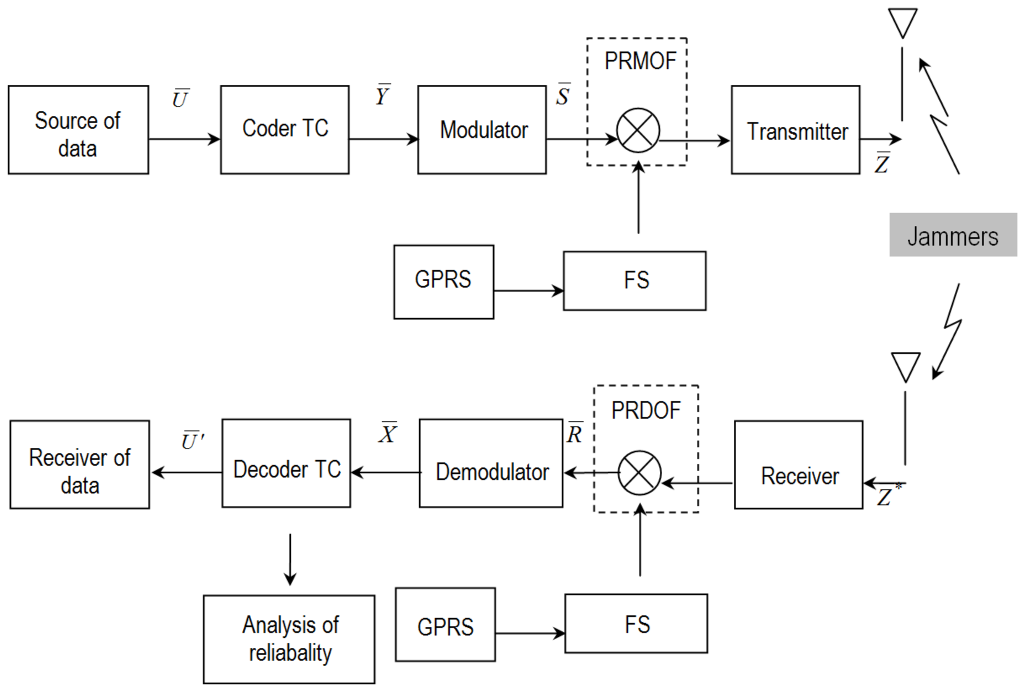

Figure 1.

Decoding of bits

Consider in more detail the operation of the decoder 1, 2 at the *j*-th decoding iteration decoding *t*-th bit, $j \in \overline{1, I}$, $t \in \overline{1, N}$, *N* – total number of transmitted bits in a data block. Let x_t – is *t*-th transmitted bit, and y_t – received *t*-th bit distorted by the influence of white Gaussian noise. As in channels with high noise levels at the receiver decisions under conditions of uncertainty, the "soft" decision or logarithmic ratio of the likelihood function (LRLF), distance decoder 1 in the *j*-th iteration is determined by the following expression [Valenti, 2001]:

$$L^{1,j}(x_t \mid y_t) = \ln \frac{P(y_t \mid x_t = +1)}{P(y_t \mid x_t = -1)} + \ln \frac{P(x_t = +1)}{P(x_t = -1)} = L_a^{1,j}(x_t) + L^{1,j}(y_t \mid x_t), \quad (5)$$

where $L^{1,j}(y_t \mid x_t)$ – LRLF, which is obtained by measuring y_t outlet channel interleave conditions that can be transmitted $x_t = +1$ or $x_t = -1$, a $L_a^{1,j}(x_t)$ – priori LRLF data bit x_t.

To simplify equation (1) can be rewritten as follows:

$$L^{1,j}(x_t) = L_c^{1,j}(y_t) + L_a^{1,j}(x_t) + L_e^{1,j}(x_t), \quad (6)$$

where $L_c^{1,j}(y_t)$ – the "channel reliability", $L_e^{1,i}(x_t)$ – posteriori LRLF data bit x_t.

The latter is calculated a posteriori LRLF data bit x_t $-L_e^{1,j}(x_t)$:

$$L_e^{1,j}(x_t) = L^{1,j}(x_t) - L_c^{1,j}(y_t) - L_a^{1,j}(x_t). \quad (7)$$

Interleaver converts posteriori LRLF $L_e^{1,j}(x_t)$ a priori LRLF $L_a^{2,j}(x_t)$: $L_a^{2,j}(x_t) = f_1\left(L_e^{1,j}(x_t)\right)$, which is supplied to the decoder 2. The decoder 2 performs the following calculation to obtain the posterior LRLF data bit x_t – $L_e^{2,j}(x_t)$:

$$L_e^{2,j}(x_t) = L^{2,j}(x_t) - L_c^{2,j}(y_t) - L_a^{2,j}(x_t). \quad (8)$$

After surgery, deinterleaving $L_a^{1,j+1}(x_t) = f_2\left(L_e^{2,j}(x_t)\right)$ value $L_a^{1,j+1}(x_t)$ is used as a priori for one iteration of the decoder. Further evaluation is carried out similar to (7) and (8).

After performing the required number of iterations, or in the case of a forced stop the iterative decoding procedure, submitted the "hard" decision on the decoded bits:

$$\tilde{x}_t^{\mathrm{C}} = \begin{cases} 1, & \text{if } L(x_t^{\mathrm{C}}) \geq 0 \\ 0, & \text{if } L(x_t^{\mathrm{C}}) < 0 \end{cases}. \quad (9)$$

Find of error area

To assess the quality of the decoding will use the following algorithm.

1. Formation of a matrix of values of systematic data bits X^{S} size $1 \times N$, produced by the encoder turbo code:

$$X^{\mathrm{S}} = \begin{bmatrix} x_1^{\mathrm{S}} & x_2^{\mathrm{S}} & \ldots & x_N^{\mathrm{S}} \end{bmatrix}. \quad (10)$$

2. Formation matrix *LA* size values of a priori information for the *i*-th decoder:

$$LA = \begin{bmatrix} L_a^i(x_1^{\mathrm{S}}) & L_a^i(x_2^{\mathrm{S}}) & \ldots & L_a^i(x_N^{\mathrm{S}}) \end{bmatrix}. \quad (11)$$

3. Formation of systematic information channel matrix samples Y^{S} size $1 \times N$:

$$Y^{\mathrm{S}} = \begin{bmatrix} y_1^{\mathrm{S}} & y_2^{\mathrm{S}} & \ldots & y_N^{\mathrm{S}} \end{bmatrix}. \quad (12)$$

4. Formation of the channel matrix of test samples $Y^{\mathrm{P}j}$ size $1 \times N$, $j \in \overline{1,K}$, where K – number of encoders (decoders turbo code):

$$Y^{Pj} = \begin{bmatrix} y_1^{\mathrm{P}j} & y_2^{\mathrm{P}j} & \ldots & y_N^{\mathrm{P}j} \end{bmatrix}. \quad (13)$$

5. Formation of the matrix size *LE* values "external" information for the *i*-th decoder.

$$LE = \begin{bmatrix} L_e^i(x_1^{\mathrm{C}}) & L_e^i(x_2^{\mathrm{C}}) & \ldots & L_e^i(x_N^{\mathrm{C}}) \end{bmatrix}. \quad (14)$$

6. Calculating $L^i(x_t^C)$, $i \in \overline{1,D}$, $t \in \overline{1,N}$ for the *i*-th decoder and bit block of *N* according to expression (6).

7. Formation matrix *L* size $1 \times N$ LRLF for the i-th decoder.

$$L = \left[L^i(x_1^C) \quad L^i(x_2^C) \quad \dots \quad L^i(x_N^C) \right]. \tag{15}$$

8. Formation matrix *LE* size for the *i*-th decoder.

$$L^* = \left[L^i(x_1^C)x_1^C \quad L^i(x_2^C)x_2^C \quad \dots \quad L^i(x_N^C)x_N^C \right]. \tag{16}$$

9. The loop: if $L^i(x_t^C)x_t^C < 0$, $t \in \overline{1,N}$, then $S_L = S_L + 1$.

Simulation was performed in the Borland C ++ Builder data transmission system using a turbo code with a two generator polynomial (1, 7/5) recursive systematic convolutional code, a pseudo-random interleaving algorithm, the decoding algorithm Map, no perforation 1, 2, 4 and 8 decoding iterations, the number of bits transmitted in a bit unit, for various values of the ratio of signal energy to noise power spectral density (signal-to-noise ratio - SNR). The simulation results were processed using a package of Matlab.

After tests, we obtain a distribution of errors, that is, the dependence of the normalized mean value of the number of errors $S_L^* = \frac{S_L}{Nn}$ the logarithmic likelihood ratio $L(x^C)$, as shown in Figures 2-5, where N – number of bits in a transmitted block, *n* - the number of blocks of size *N*.

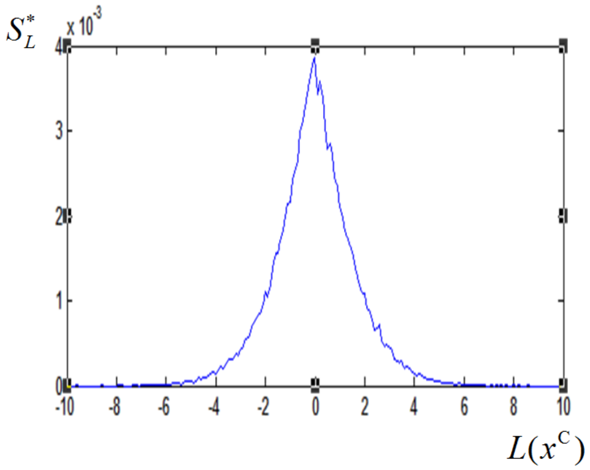

Figure 2 - Distribution of values of error (Iteration - 1, SNR – 0.3 dB)

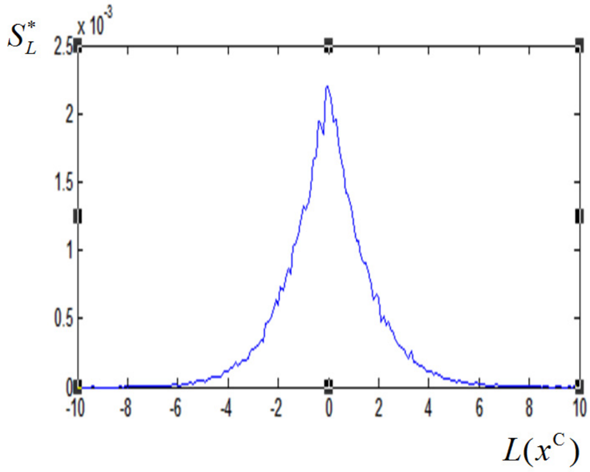

Figure 3 - Distribution of values of error (Iteration - 2, SNR – 0.3 dB

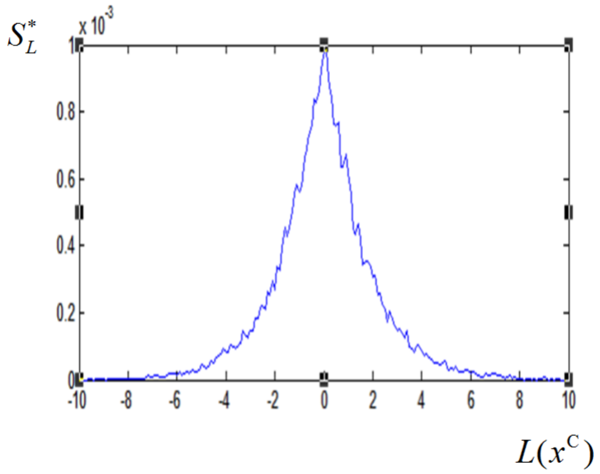

Figure 4 - Distribution of values of error (Iteration - 4, SNR - 0.3 dB)

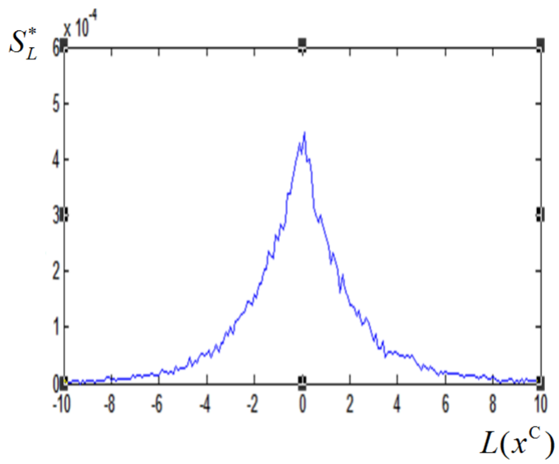

Figure 5 - Distribution of values of error (Iteration - 8, SNR - 0.3 dB)

As you can see, the distribution of the error values shown in Figure 1-4, describes a normal (Gaussian) distribution law of random variables

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \quad (17)$$

where μ – mathematical delay, σ – the standard deviation.

To find the area of the field error at a given value SNR need to find the integral of the function, which describes the distribution of values, and use the rule of three sigma. This will get 99.7% of the values, so we can say that will be evaluated for 99.7% of the area (Figure 6).

$$F(x) = \int_{-(3\sigma-\mu)}^{3\sigma+\mu} \frac{1}{\Delta\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \quad (18)$$

where Δ – range separating the abscissa with the graphical display of the distribution function on the graph.

On the basis of of the experiments, we assume that μ=0 and because the formula (18) is simplified:

$$F(x) = \int_{-3\sigma}^{3\sigma} \frac{1}{\Delta\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}}. \quad (19)$$

Let $a = \frac{1}{\sigma\sqrt{2\pi}}$, $c = \sqrt{2}\sigma$, then

$$f(x)=ae^{-\frac{(x-b)^2}{c^2}}, \tag{20}$$

$$F(x)=\int_{-3\sigma}^{3\sigma}\frac{a}{\Delta}e^{-\left(\frac{x-b}{c}\right)^2}. \tag{21}$$

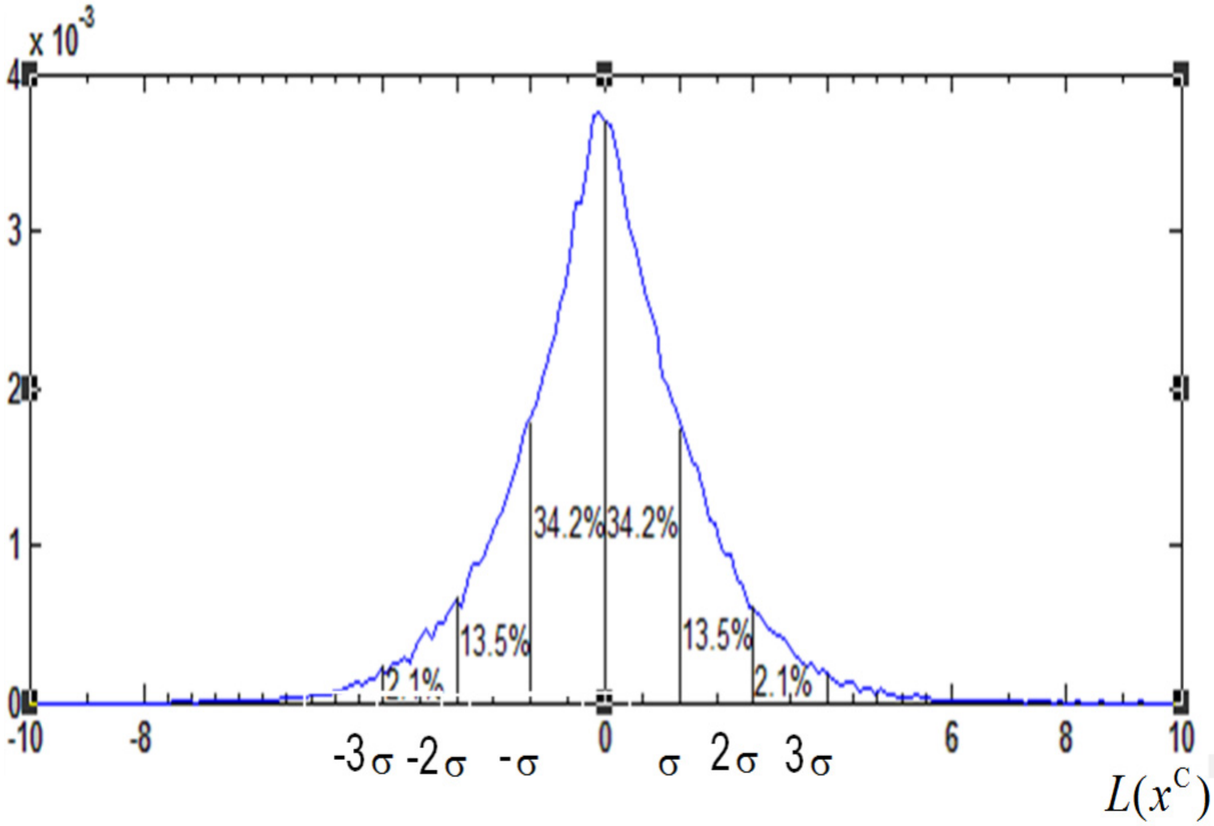

Figure 6 - Percentage of hitting errors in the range of values $L(x^{C})$ (Iteration - 1, SNR - 0.3 dB)

Regression analysis

Logarithm of both sides of equation (20), assuming that b = 0:

$$\ln(f(x))=\ln\left(ae^{-\frac{(x-b)^2}{c^2}}\right)=\ln(a)-\frac{x^2}{c^2}. \tag{22}$$

We introduce new variables and parameters: $b_0=\ln(a)$, $b_1=-\frac{1}{c^2}$, $Y=\ln(f(x))$, $X=x^2$.

Obtain the regression model, specified in the linear form:

$$Y=b_0+b_1X. \tag{23}$$

We find the parameters of the model using the least squares method. To do this, we write the system of normal equations for the linear model:

$$\begin{cases} nb_0 + b_1 \sum_{i=1}^{n} X_i = \sum_{i=1}^{n} Y_i \\ b_0 \sum_{i=1}^{n} X_i + b_1 \sum_{i=1}^{n} X_i^2 = \sum_{i=1}^{n} (X_i Y_i) \end{cases}, \tag{24}$$

where n - number of observations. System parameters are calculated by the formulas:

$$b_0 = \frac{\sum Y_i}{n} - b_1 \frac{\sum X_i}{n}, \tag{25}$$

$$b_1 = \frac{n \sum (Y_i X_i) - \sum X_i \sum Y_i}{n \sum X_i^2 - \left(\sum X_i\right)^2}, \tag{26}$$

To find the coefficients of the variables must be expressed: $a = e^{b_0}$, $c^2 = -\frac{1}{b_1}$.

For factors with which we will continue to determine the area of the field errors, we carry out a regression analysis using the data presented in Figures 7-10.

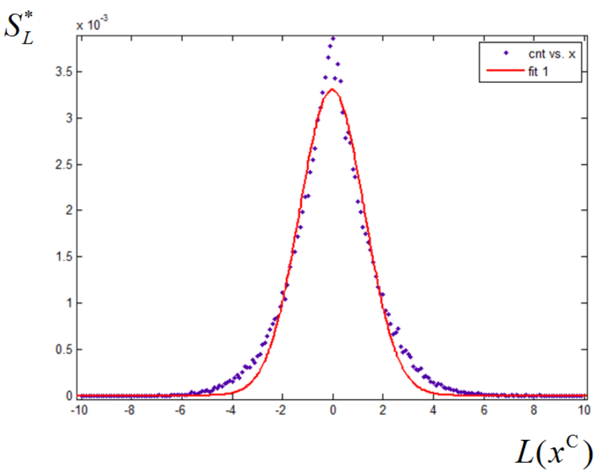

Figure 7 - Regression analysis for field errors (Iteration - 1, SNR - 0.3 dB)

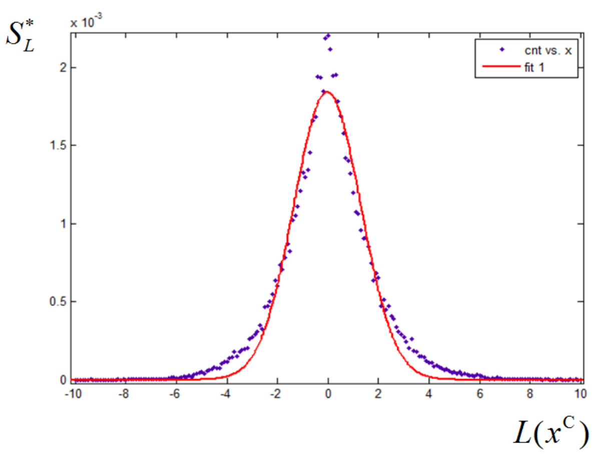

Figure 8 - Regression analysis for field errors (Iteration - 2, SNR - 0.3 dB)

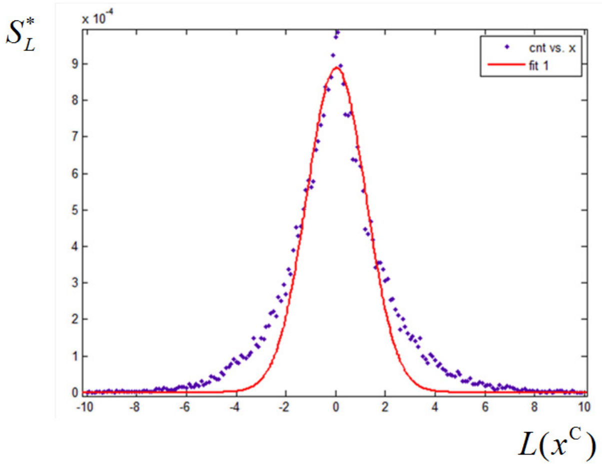

Figure 9 - Regression analysis for field errors (Iteration - 4, SNR - 0.3 dB)

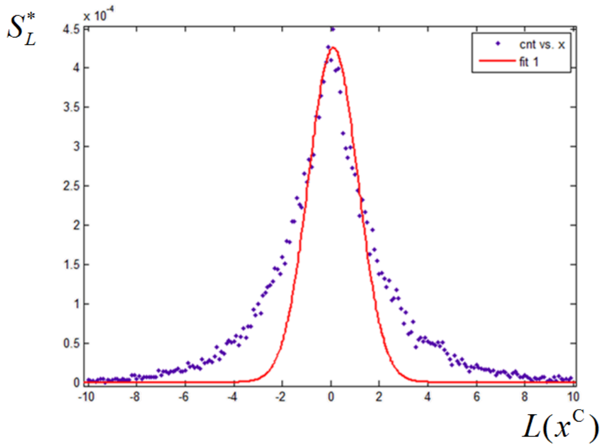

Figure 10 - Regression analysis for field errors (Iteration - 8, SNR - 0.3 dB)

Table 1 shows the results of finding the coefficients of the functions of normal error distributions a, b, c.

Table 1 - Results of finding the coefficients of the functions of a normal distribution of errors

SNR, дБ	Iterations			
	1	2	4	8
0	a = 0,004062, b = – 0,01998, c = 1,753	a = 0,002824, b = – 0,03997, c = 1,845	a = 0,002001, b = – 0.03508, c = 1,888	a = 0,001571, b = – 0,04475, c = 1,868
0,03	a = 0,003982, b = – 0,02925, c = 1,749	a = 0,002724, b = – 0.02381, c = 1,845	a = 0,001823, b = – 0.03427, c = 1,906	a = 0,001418, b = – 0,03458, c = 1,881
0,06	a = 0,003836, b = – 0,02161, c = 1,775	a = 0,002563, b = – 0,03255, c = 1,882	a = 0,001755, b = – 0.02994, c = 1,91	a = 0,001166, b = – 0,03461, c = 1,953
0,09	a = 0,003851, b = – 0,02754, c = 1,761	a = 0,002498, b = – 0,02888, c = 1,837	a = 0,001621, b = – 0,01116, c = 1,832	a = 0,001146, b = – 0,008424, c = 1,927

The coefficients obtained with a 95% confidence interval, the sum of squared errors SSE: 4,264e006, the value of determination R-square: 0,9873, the customized value of determination Adjusted R-square: 0,9873, the standard deviation RMSE: 8,452e-005. With the value of determination and rigged values of determination can say about the effectiveness and reliability of the selected coefficients of the selected function regression.

Let *L* - random variable whose values are the results of decoding the *i*-th decoder, namely the calculation of the transferred LRLF in an *n*-bit block length *N*: $L^i\left(x_{kt}^C\right),\ t \in \overline{1,N}\ ,\ k \in \overline{1,n}$. Expectation and variance of the random variable *L* is defined by the following expressions:

$$M_L = \frac{\sum_{k=1}^{n}\sum_{t=1}^{N} L^i\left(x_{kt}^C\right)}{nN}\ , \tag{27}$$

$$D_L = \frac{\sum_{k=1}^{n}\sum_{t=1}^{N}\left(L^i\left(x_{kt}^C\right) - M_L\right)^2}{(n-1)(N-1)}\ . \tag{28}$$

Thus, by analyzing the variance of transmitted bits LRLF can compute the coefficients of the normal distribution function to calculate the error and the accuracy of information transmission. The number of blocks n to calculate the expectation and variance calculated from the required values and a confidence level of the confidence interval [Иващенко, 1988].

Conclusion

This paper presents a method for estimating the reliability of information transmission in wireless systems that operate in channels with elevated levels of noise and interference. The method is based on the results of the decoding of turbo codes to determine the value of reliability of information transmission. The results of the simulation method for assessing the reliability of the transmitted information through statistical estimation of log-likelihood function of the transmitted bits, which are produced in an iterative turbo decoder code. The results make it possible to estimate the variance LRLF about bits transmitted and received using the coefficients to calculate the values of reliability of information transmission in the wireless channel. The results can be applied in the design and development of adaptive data transmission systems with given values of reliability.

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