Methodology of selecting optimal parameters of OFDM- SCC in conditions of selective stopping in radio path

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Abstract. Methodology of selecting optimal parameters of OFDM- SCC in conditions of selective stopping in radio path. In this article described technique in which the optimal parameters of OFDM-SCC determined in the case of transmitting information over a communications channel in terms of considering selective fading distortion signal in radio path. Rational SCC parameters for a specific channel defined state with a finite number of allowable options that can simplify the practical implementation of adaptive equipment modem radio communication systems.

Keywords: *communication channel, radio waves, signal, radio communication system, radio path*

Introduction. One of the main factors affecting the quality of radio communications is fading signal resulting from multipath propagation of radio waves, and nonlinear signal distortion in radio path. While transporting signals by multibeam channels, widely used method of orthogonal frequency division multiplexing (OFDM) [1-2]. The main advantages of this technology is the relatively high stability over selective fading, and high frequency efficiency.

In the construction of radio communication systems (RCS) with OFDM great attention paid to construction of signal-code constructions (SCC), which allow to increase the speed of information transmission with constraints of power and bandwidth frequency (to increase frequency efficiency of the system). Increasing of frequency efficiency of OFDM RCS by coordination forms transmitted signals and the type of modulation parameters of communication channel without additional expansion channel bandwidth and increasing the transmitter power is rather urgent task.

The main way to increase the speed of information transmission in RCS without compromising energy efficiency is the use of signal-code constructions [3], which represent a set of signal sequences derived from noiseimmunity codes and ensembles signals with the dense packing. As noiseimmunity codes can be used block and line codes [4]. The greatest efficiency of transmission of SCC achieved by using line codes ensembles in combination with AFM signals. Their energy gain in gaus channel is 3 ... 6 dB, depending on the complexity of the interconnected system modulation and coding.

Analysis of the effectiveness of radio communication systems shows that the use of multi-modulation allow to increase speed in comparison with the binary modulation, but you can not get closer to the capacity nor the frequency or for energy efficiency. The use of correcting codes with binary modulation allows to approach the bandwidth close to the border Shannon.

In real multipath channels except the additive noise occurs intersymbol interference (ISI) caused by memory of the channels. The channels reaction on sequence of input signals cause mutual imposition signals at the output channel. If normalize amplitude-frequency response of the channel by power, we can say that the ISI leads to a significant change of distance between the signals at the output channel and, most importantly, to reduce the minimum distance between them.

In process of synthesis of signals and codes for channels with ISI, this effect is usually not taken into account, so as input signals select such signals that coordinated with the ideal channel without ISI. However, ISI seek to take into account designing the optimal receiver (decoder). Widely known decision of this is the Viterbi algorithm and its modification, which takes into account line coding [5].

Lets take a look at the approach of encoding channels with ISI, based on the synthesis of signal-code constructions that have "warp" space signals in the transmission on real channel [6]. The basis for this approach is the possibility of converting channels with ISI in set with gaus channels without memory, so, without ISI, but diferents from each other with scalar transmission coefficient or the signal / noise ratio.

The essence of the technique is to construct signal-code structures with optimum(for the criterion of maximum frequency efficiency) parameters while limiting the value of the probability of erroneous signal receptions at selective fading and distortion.

Problem Statement. *Given:* options of transmitting device and communication channel $\Psi = \{\psi_i\},\ i = \overline{1,10}$, where $\psi_1 \ldots \psi_{10}$ – output signal, signal / noise ratio, modulation, information rate, bandwidth communication channel, dimension of signals, THD signal in radio path, code combination length, speed of adjustment code, code size range.

Required: build OFDM-SCC, that maximize frequency effectiveness of RCS β_F using constraints on the probability of erroneous reception signals $P_{\text{mis}} \le P_{\text{mish}}$.

Constraints: dimension of signals $2 \le M \le 256$; type of correcting code – line code with speed R = 0,5-0,9; probability of receiving false signals $P_{\text{пом}} \le 10^{-5}$.

The task of determining the parameters of SCC with maximum efficiency frequency reduced to a typical optimization problem. The system of equations for solving the optimization problem have the form:

$$\begin{cases} \beta_F = F_1(v_{\text{i}}, \Delta F, M, K_3, n, R, d) = \max; \\ P_{\text{mis}} = F_2(P_{\text{c}}, M, n, R, d) \le P_{\text{mis h}}, \end{cases} \tag{1}$$

where

n – code combination length,

P_{c} – signal power;

M – dimension of signals,

R – speed of adjustment code,

d – code size range.

Methods of coosing OFDM-SCC for radio systems consists of the following stages.

Data input. Input parameters of transmitter and communication channel $\Psi = \{\psi_i\}$, and the size of permissible value of probability signal P_{mish}.

Selecting the number of subcarriers. While passing a group of OFDM signal through nonlinear radio path of radio subcarriers orthogonality is disturbed, leading to their mutual influence and to reducing noise immunity of receiving signals.

Evaluation of transfer characteristic link. At this stage, using the method proposed in [7] evaluated the state of multipath channel.

Converting the channel with between the symbols distortions in set with gaus-channel without the memory. In real frequency-limited channels (except the additive noise) occurs intersymbol interference (ISI) caused by memory channels. The reaction of channel on input signals sequences cause mutual imposition signals at the output channel. If normalize the power in amplitude-frequency characteristic of the channel, we can say that the ISI leads to a significant change in the distance between the signals at the output channel and, most importantly, to reducing of the minimum distance between them.

In Gauss-channel with ISI (GCSCC) input and output of the channel associated in expression [6]

$$Z = K_h X + B, \tag{2}$$

where

X – samples of the transmitted signal at the input channel;

B – samples of white Gaussian noise (WGN);

K_h – matrix of the channel ($L_0 \times L$), elements of which are components of weight sequence $\{h_n\}_{n=0}^{l-1}$.

Parameter l determines the memory channel, as each count of input signal is a linear combination of l transferred samples. When duration (number of samples) of guard interval l_0 bigger or equals channel memory $l - 1$, then channel blocks overlap. So, the condition $l_0 \geq l$ is the absence between blocking interference. Block length on output bigger, then on input, and equals $L_0 = L + l - 1$.

For this channel the following statement is true. If WGN power output equals GCSCC P_{h}, and average signal power of output size is limited P_{avg}, then GCSCC capacity, his value $|K_0| \geq |K_1| \geq \ldots \geq |K_{L-1}|$, equals

$$C = v_0 \frac{1}{L} \sum_{i=0}^{M} \frac{1}{2} \log_2 \left[|K_i|^2 \frac{L}{M} \left(\frac{P_{\text{h}}}{P_{\text{avg}}} + \frac{1}{L} \sum_{m=0}^{M} \frac{1}{|K_m|^2} \right) \right]; \tag{3}$$

$$v_0 = \frac{L}{L_0} = \frac{1}{1 + l_0 / L},$$

where v_0 – the relative speed of transmitting, while inputting protective intervals between signal blocks; $M \leq L - 1$ – the largest number for output power

$$P_M = P_{\text{avg}} \frac{L}{M} + P_{\text{h}} \left[\frac{L}{M} \sum_{m=0}^{M} \frac{1}{|K_m|^2} - \frac{1}{|K_\mu|^2} \right] > 0.$$

If $L \to \infty$ GCSCC is transformed into a Gaussian channel without memory (GCWM), the entrance of which is a stationary random sequence $\{Z_K\}_{K \to -\infty}^{\infty}$, and output – stationary random sequence $\{\tilde{Z}_K\}_{K \to -\infty}^{\infty}$.

As a result of the above GCSCC-conversion is a set of independent parallel GCWM input and output of each channel related in expression $Z_i = K_i X_i + B_i, \quad i = \overline{0, L-1}.$

Parameters defining before distortion of signals. Lets take a look at the approach to encoding channels with ISI, based on the synthesis of signal-code constructions that consist "warp" in the transmission of signals in real channel.

For optimization of the signals group parameters with OFDM use inputting to the signal distortion in transmission $X_i = \frac{1}{|K_i|} \xi_i$ and correction at the reception $\xi_i = b_i Z_i$, where $b_i = e^{-j \arg K_i}$.

Determining the average power of the output signal at channel. If output channel has significant unevenness of amplitude-frequency characteristics in Nyquist rate, so channels could be quite different. The difference between subchannels characteristics should be taken into account in the process of signals construction and SCC.

Typically, parallel subchannels with distortion using different alphabets of signals with phase shift keying (PM) and quadrature amplitude modulation (QAM). But with the same minimum Euclidean distance d, which does not depend on the number of subchannel i. The need of considering of this option due to the possibility of building its base of effective signals and signal-code constructions [5].

Suppose $0 < m_1 < m_2 < m_3 < \ldots < m_Q \leq M_1$ – splitting numbers of subchannels. Then, in subchannel with the numbers from m_{j-1} till $m_j - 1$ ($m_0 = 0$) used alphabet KAM with 2^{q_j} symbols, $1 \leq j \leq Q$, and $q_1 > q_2 > \ldots > \quad > q_Q \geq 1$. This means, that alphabets with more number of points use in subchannels with higher signal / noise ratio or with large eigenvalues K_i.

The average power output of i-subchannel has the form

$$P_{\text{out}\,i} = P_{q_j} / |K_i|^2, \quad m_{j-1} \leq i \leq m_j - 1, \tag{4}$$

where $P_{q_j} = d_E^2 x(2^{q_j})$ – average power of output signal KAM subchannels with numbers m_{j-1} till $m_j - 1$, and

$$x(q) = \left\{ \begin{array}{l} (2^q - 1/2)/6,\ q = 2n - 1, \\ (2^q - 1)/6,\ q = 2n,\ n = 1, 2, \ldots \end{array} \right\}. \tag{5}$$

Average power of output of OFDM channel group size is limited by P_{avg}

$$\frac{1}{N} \sum_{i=0}^{M_1 - 1} P_{\text{out}\,i} \leq P_{\text{avg}}. \tag{6}$$

Putting (4) in formula (6), we can get an equation

$$d_E^2 \sum_{j=1}^{Q} x(2^{q_j}) \frac{1}{N} \sum_{i=m_{j-1}}^{m_j - 1} \frac{1}{|K_i|^2} \leq P_{\text{avg}}. \tag{7}$$

Note that

$$\frac{1}{L}\sum_{i=m_{j-1}}^{m_j-1}\frac{1}{|K_i|^2} = f_m(m_j) - f_m(m_{j-1}),$$

where $f_L(M) = (1/L)\sum_{i=0}^{M-1} 1/|K_i|^2$, we are getting

$$d_E^2\sum_{j=1}^{Q} x(2^{q_j})\left[f_L(m_j) - f_L(m_{j-1})\right] \le P_{\text{avg}}. \qquad (8)$$

Calculation of the maximum rate in each channel. The maximum speed of each channel with fixed q_j determined as:

$$v(q_j, P_{qj}/P_{\text{h}}) = v(q_j, d_E^2\varphi(2^{q_j})/P_{\text{h}}) \qquad (9)$$

Determination of the maximum rate of group signal. The total rate in the channel of the OFDM could be calculated by expression

$$v = v_0\frac{1}{N}\sum_{j=1}^{Q} s_j v(q_j, d_E^2 x(2^{q_j})/P_{\text{h}}), \qquad (10)$$

where $s_j = m_j - m_{j-1}$, $m_0 = 0$ – number of subchannels with the same alphabet KAM.

Optimization of this variant considered by the speed with limited average power at the input channel comes down to choosing the optimal partitioning GCWM on groups at the same rate, the optimal choice of alphabets and minimum range *d*.

The maximum speed for OFDM-channel with distortions and random alphabets in each parallel subchannels provided that the minimum distance in all alphabets is constant and equal d, is given by expression

$$v_{\max} = \max_{d>0}\ \max_{s_j=1,2,\ldots}\ \max_{q_j=1,2,\ldots} v_0\frac{1}{N}\sum_{j=1}^{Q} m_j v\left(q_j, \frac{d_E^2 x(2^{q_j})}{P_{\text{h}}}\right) \qquad (11)$$

with restrictions described above, the permissible average power at the input OFDM-channel, and $s_j = m_j - m_{j-1}$, $m_0 = 0$, $0 < m_1 < m_2 < \ldots < m_Q \le M_1$ – partition of subchannels into groups with v_j parallel channels, each one using same alphabet KAM with average power

$$P_{qj} = d_E^2 x(2^{q_j}).$$

So, we got stepped structure in which transmitted block (as a result of virtual transformations) on transmitting and receiving side turns system in N – parallel channels, from which m_1 modulated KAM-2, m_2-signals modulated KAM-4, m_3- signals modulated KAM-8 and so on. The last m_q – signals modulating KAM-2^q.

Now to this signal structure we can "impose" correcting code and receive SCC.

We can use every known block or radio path SCC. Required only fairly simple modification of the SCC, which takes into account the difference in successive alphabets characters. The result is a so-called stepped SCC, which is encoded and decoded in a single block of converting signals.

In proposed method, optimal parameters of OFDM-SCC determined in case of information transmitting over a communications channel in terms of considering selective fading distortion signal in radio path. Rational SCC parameters for a specific channel defined with a finite number of allowable options, that can simplify the practical implementation of adaptive equipment of radio communication systems.

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