Improving the efficiency of multichannel systems based on the coordination of channel signals

G S Voronkov¹, P E Filatov¹, A Kh Sultanov¹, R V Kutluyarov¹, I L Vinogradova¹ and I V Kuznetsov¹

¹Ufa state aviation technical University, Karl Marks str. 12, Ufa, Russia, 450008
e-mail: voronkov.gs@net.ugatu.su

Abstract. A method for improving the energy efficiency and noise immunity of multichannel systems, based on the overall coordination of channel signals, is described. To coordinate the signals, a coordinating matrix is used, whose elements are the cross-correlation coefficients of signals from different channels. The possibility of reducing the dynamic range of channel signals while maintaining the quality of communication is shown. The possibility of synthesizing invariant (with an unlimited transfer ratio in separate channels) of coordinated group DPCM codecs with channels of the same type is shown.

1. Introduction
The development of wireless technologies is inherently associated with the increase in the speed of data transmission in communication channels. This, in turn, requires a corresponding increase in the signal-to-noise ratio at the reception, which negatively affects the power consumption of the transmitters. To reduce the growth rate of energy consumption, it is necessary to introduce technologies in communication technology that increase its energy efficiency. In this case, a measure of energy efficiency is proposed to consider the ratio of the transmission rate to the power consumed by the transmitter, necessary to ensure the specified speed [1].

One of the ways to solve this problem is the use of coordinated group codecs of differential pulse code modulation (DPCM) [2]. The main idea of their use is to use a common coordinated predictor (extrapolator) across all channels of a multichannel system. In works [1-4], the synthesis of coordinated group DICM converters based on solving optimization problems was considered. Despite the achieved results (reduction of the dynamic range of the signals), group DIKM-converters of this type have disadvantages. First of all, it is necessary to pay attention to the complexity of the analytical design of predictors, which requires factorization and separation operations. In these papers, solutions were obtained for a small (not exceeding 4) number of channels. Its increase leads to a sharp increase in computational complexity.

As an alternative to the described methods, it is proposed for systems with channels of the same type to consider the method of synthesizing DPCM-converters with a coding matrix, based on an assessment of its stability (without solving an optimization problem).

2. The structure of the coordinated multi-channel DPCM-codec and the formulation of the problem
The block diagram of a multichannel system with the number of channels n, using coordinated DPCM codecs, is shown in figure 1.
Figure 1. The structure of group DPCM codec including coding matrix.

There are input actions \( u_i(t) \), where \( i = 1..n \) on the system input (\( n \) - the number of channels). These actions form the input action vector \( \vec{U} = [u_1, ..., u_n]^T \) (\( T \) is the transposition index). The extrapolated
signals \( \tilde{u}(t) \) are fed to the second inputs of the comparison elements. Prediction errors (difference signals) \( e_i(t) \) (forming a vector \( E = [e_1, \ldots, e_n]^T \)), defined as \( e_i(t) = u_i(t) - \tilde{u}_i(t) \) are being transmitted in the channel. The extrapolator represents the dynamic part of the system, consisting of blocks of analog-digital and digital-analog conversion, filters and other elements), which will be described by the transfer function \( W_p(s) = m \cdot W(s) \), where \( m \) – known static transfer ratio for channel \( i \), determined based on the noise level in this channel, \( W(s) \) – equivalent transfer function of predictor dynamic part. The encoding matrix \( K \) is a structure \( n \times n \) in which static coefficients of channel \( k_{ij} \) (\( i \) is the channel number) are located on the main diagonal, and the remaining positions are determined based on the mutual correlation of the channels with the corresponding numbers \( i \) and \( j \):

\[
K = \begin{bmatrix}
 k_{11} & k_{12} & \cdots & k_{1n} \\
 k_{12} & k_{22} & \cdots & k_{2n} \\
 \vdots & \vdots & \ddots & \vdots \\
 k_{1n} & k_{2n} & \cdots & k_{nn}
\end{bmatrix},
\]

where \( k_{ij} \) is the coefficient of linear correlation for channels number \( i \) and \( j \) (\( i \neq j \)):

\[
k_{ij} = \frac{1}{\sigma_i \sigma_j} \cdot \frac{1}{N} \sum_{i=1}^{N} (u_{i,n} - u_i)(u_{j,n} - u_j).
\]

So, the main task is to determine the coefficients on the main diagonal of the matrix.

3. The solution

The solution was found using the stability theory. The characteristic polynomial of the transmitting part of the system can be defined as:

\[
d(s) = \det \begin{bmatrix}
 1 + k_{11}mW(s) & k_{12}mW(s) & \cdots & k_{1n}mW(s) \\
 k_{12}mW(s) & 1 + k_{22}mW(s) & \cdots & k_{2n}mW(s) \\
 \vdots & \vdots & \ddots & \vdots \\
 k_{1n}mW(s) & k_{2n}mW(s) & \cdots & 1 + k_{nn}mW(s)
\end{bmatrix},
\]

to simplify the subsequent solution, we introduce an additional condition:

\[
k_{11}m_1 = k_{22}m_2 = \ldots = k_{nn}m_n = k,
\]

so the problem will be solved for the only variable. Then the characteristic equation of the system transmitting part can be represented as:

\[
d(h, \Phi, k) = 1 + \frac{h_2}{k^2} \Phi^2(s) + \frac{h_3}{k^3} \Phi^3(s) + \ldots + \frac{h_n}{k^n} \Phi^n(s) = 0,
\]

where

\[
h_m = \sum_{i,j=1}^{m} \gamma_{ij} \frac{\det |K_{ij}|}{\Delta},
\]

\[
\gamma_{ij} = \begin{cases}
 0, & i = j, \\
 1, & i \neq j.
\end{cases}
\]

The obtained characteristic equation corresponds to closed-loop control systems with subsystems of the same type. Therefore, to study the stability of the system, we apply the frequency stability criterion of Ilyasov-Kabalnov [5]. By this criterion, we consider the new equation

\[
1 + \frac{h_2}{k^2} \eta^2 + \frac{h_3}{k^3} \eta^3 + \ldots + \frac{h_n}{k^n} \eta^n = 0,
\]

where \( \Phi(s) = \eta \).
According to the Ilyasov-Kabalnova criterion, for the stability of a system, it is necessary to choose $k$ such that the hodograph of the amplitude-phase characteristic, (of a stable subsystem) does not cover more than one of the roots of this equation.

Using a conformal mapping of the form \( \eta = \frac{1 - \lambda}{1 + \lambda} \), we’ll get the equation:

\[
1 + \frac{h_2}{k^2} \left( \frac{1 - \lambda}{1 + \lambda} \right)^2 + \frac{h_3}{k^3} \left( \frac{1 - \lambda}{1 + \lambda} \right)^3 + \ldots + \frac{h_n}{k^n} \left( \frac{1 - \lambda}{1 + \lambda} \right)^n = 0,
\]

or

\[
(1 + \lambda)^n + \frac{h_2}{k^2} (1 - \lambda)^2 (1 + \lambda)^{n-2} + \frac{h_3}{k^3} (1 - \lambda)^3 (1 + \lambda)^{n-3} + \ldots + \frac{h_n}{k^n} (1 - \lambda)^n = 0.
\]

Then, for the stability of the transmitting part (assuming the stability of single-type subsystems) of the coordinated DPCM system, it is sufficient that all the roots of the characteristic equation for the complex variable $\lambda$ lie in the left part of the half-plane, $\text{Re}\{\lambda_i\} < 0, i = 1, n$. Further, using the algebraic stability criteria, it is easy to obtain the range of parameter $k$ values.

4. Simulation

The simulation was performed for a system of three correlated channels. The channels were obtained from the channels of the chroma image taken from the UAV. As all together these channels are combined in one picture, they are well-correlated. The simulation was performed in the MatLab system. The source image is given in figure 2.

![Figure 2. The source image.](image)

The main purpose of simulation was to approve the decreasing of signals dynamic range and to test the system noise immunity. For this purpose, three channels (red, green and blue) were generated from the source image. Then for these three channels first was simulated the transmission by channel with white noise (AWGN-channel), and the picture #1 (figure 3) was restored from the received signal. Then three source signals were coded with the encoding matrix and transmitted through the AWGN-channel with the same SNR. From this signal picture #2 was restored.

On image #2 there is still possible to find the road edges, while figure #1 is undetermined. Also, bit error ratio and dynamic range decreasing were counted for each channel. The results are given in table 1.
5. Conclusion
The new method of coordinated differential transformation of signals was described. The essence of this method is in synthesizing the coordinated extrapolator transfer function by solving the stability theory. The method proposed provides the decreasing of dynamic range for correlated signal and increases the channel noise immunity, that was proved by the simulation.

6. References
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