Signals and messages differential transformation research for increasing multichannel systems efficiency

G S Voronkov¹, P E Filatov¹, A Kh Sultanov¹, A V Voronkova¹, I L Vinogradova¹ and I V Kuznetsov¹

¹Ufa State Aviation Technical University, K. Marx st. 12, Ufa, Russia, 450000

e-mail: voronkov-gr@yandex.ru, filatovpe@gmail.com, tks@ugatu.ac.ru

Abstract. The problem of differential transformation for multichannel systems efficiency increasing is described. Examples for low-frequency and high-frequency circuits are given; different circuits’ advantages are described. The achieved results on the energy efficiency increasing due to the differential transformation of the primary signals and OFDM band signal for the case of the AWGN-channel are given. Different telecommunication implementation and further research directions are described.

1. Introduction

Mobile radio systems are being developed rapidly nowadays. For example, there are more than 1.453 billion subscribers of LTE-networks worldwide according to GSA (Global Mobile Suppliers Association) [1]. The draft of 5th generation mobile radio network was published by 3GPP [2], and the first commercial 5G-network launch is planned in 2020 [3]. Satellite Earth remote sensing systems are also being developed. During the year 2016, 95 new space vehicles of remote sensing for various classes and destinations were put into orbit, and in the first quarter of 2017 97 spacecrafts were put into orbit [4], and all of them are required high-speed data transmission channels. The same may be said also about pilotless vehicles.

It may be noticed, that for all systems described it is very important to ensure their autonomous operation for as long as possible with limited battery capacity, or, in another words, to increase their energy efficiency. This feature allows to combine such devices into a separate class of energy-deficient communication systems.

Methods of differential processing of signals and messages may be suggested as one of the directions for solving the problem of ensuring energy efficiency. Their essence lies in the transmission of the difference between the original signals and their extrapolated values (difference signal). This allows either the band signal dynamic range or peak factor reducing. This decreases telecommunication system power consumption (without losing connection quality), increases the system noise immunity and information security (due to the difficulty of detecting signals in the air) [5]. The described effects are achieved due to the modernization of structural solutions in both the part of the primary processing of messages and at the level of band signal forming.

2. Differential signal processing methods structures

2.1. Group Codecs of Differential Pulse Code Modulation (DPCM)

Group coordinated DPCM codecs [6, 7] may be considered as the implementation of the differential signal processing method at the layer of the primary signals forming. The generalized scheme of these
codecs is shown in figure 1. Structures may be different depending on the method of forming the coordinated signals, for example, in [8] the summing and difference schemes were described, and other types of schemas may be suggested also.

![Figure 1. Group DPCM codec structure: \( s_i \) – signal of channel number \( i \), \( e_i \) – its difference signal.](image)

During the research, a group DPMC codec was modeled for a three-channel system. For the case of stepped actions at the system inputs, the decrease in the dynamic range of signals due to their extrapolation was 7.3 dB. With a harmonic input signal, the dynamic range reduction was 10.7 dB, for random input signal – 13.07 dB [9]. The simulation results for step and random input signals are shown in figure 2.

### 2.2. Differential transformation of OFDM signals

In the radio frequency layer, the possibility of applying differential transformation to the signals of OFDM-systems was researched. There were investigated structures of extrapolators based on the mathematical apparatus of Kalman-Bucy and Wiener-Hopf linear optimal filtration theory. The generalized structure of the OFDM signal codec is shown in figure 3.

The OFDM signal generation path is supplemented by a coordinated extrapolator synthesizing the signal based on the known spectral characteristics of channel noise and in-phase and quadrature components signals of the OFDM signal complex envelope. The initial values of these signals are compared with the extrapolated ones, and the result of their comparison (difference) is used as a modulating signal. In this case, the differential transformation can be carried out both “by the input” and “by the output”. The received signal after down conversion is restored by addition with the signal synthesized by the extrapolator. Special attention should be paid when considering the scheme to allocate the possibility of synchronizing the extrapolators of the receiving and transmitting units using the submultiplexing [10, 11] (that also increases system spectral efficiency).

The suggested method simulation was firstly performed for the data transmission channel of microsatellite “UGATU-SAT 2”, designed for the Earth remote sensing (ERS). The following transmission system parameters were adopted. Channel bandwidth is 8 MHz, the number of OFDM subcarriers is 16, the modulation on subcarriers is QPSK. The channel was considered as AWGN (additive white Gaussian noise) channel, SNR (signal-to-noise ratio) was 22 dB. The model did not take into account multipath propagation and fading in the communication channel or other non-linear effects. ERS system snapshot was used as the message. Image parameters were the following: size 512x512 pixels in BMP format without compression, color scheme – shades of gray.
Figure 2. Group DPCM codec simulation results, (a) – for step signal input, (b) – for random signal input.

The image was divided into 32x32 pixel fragments, then each of the resulting 256 fragments was converted to a binary format, after which the QPSK symbols were generated. These symbols were subjected to inverse fast Fourier transform, which allows to obtain the first type of band-pass signal (signal 1). The signal generated was convoluted with the extrapolator impulse response, the difference between the original signal and its extrapolated value was calculated, thus, a second type of band
signal was generated – a signal compressed according the differential scheme (signal 2). In-phase and quadrature signal shapes before up conversion for one of the fragments are given in figure 4. Signal 1 and signal 2 average powers were calculated after that. Third type of signal (signal 3) was formed with decreasing signal 1 amplitude until this signal power be equal signal 2 power. Transmission along the AWGN channel was simulated after that. The received band signal was transformed using fast Fourier transform. Since 3 variants of the band signal had been previously obtained, it was possible to compare QPSK signal constellations obtained by processing different band signals and to estimate the symbol error ratio. The received signal constellations for one of the fragments transmission case are shown in Fig. 5, from left to right: a signal constellation for signal 1, signal 2 and signal 3.

Figure 3. Differential transformation of OFDM signal.

Figure 4. Signal shapes before upconversion. Blue – uncompressed signal; Red – extrapolated signal; Green – their difference.
Since the original image was divided into 256 fragments, there were obtained 256 power gain values for the differential transformation using as a result of modeling. The histogram of compression levels is shown in figure 5. The horizontal axis shows the compression ratios, dB, vertical axis - the number of information parcels.

According to the results of the simulation, the differential conversion made it possible to reduce the power of the band signal by 1.6 dB to 3.5 dB with the mean value 2.49 dB relative to the original signal. A corresponding reduction in transmitting power without extrapolation leads to an increase in the symbol error. For the uncompressed signal and for the signal subjected to differential transformation, the average symbol error ratio was about 0.000947 s⁻¹, while for the signal with a reduced power the average symbol error ratio was about 0.0638 s⁻¹. The result can also be interpreted in a different way: the use of differential transformation makes it possible to reduce the required signal-to-noise ratio at reception by an average of 2.49 dB without degrading the communication quality.

3. Differential transformation for informational security increasing

As it was shown, differential transformation may decrease the band signal dynamic range without communication quality decreasing. This obviously may reduce the transceivers power consumption. But at the same time transmitting power reduction may help to reach an additional advantage. OFDM technology in modern wireless systems not only increases their spectral efficiency, but also leads to a broadening of the signal spectrum, bringing it closer to a noise-like signal. This allows to increase the energy secrecy of the system. By energy secrecy, this means a reduction in the probability of unauthorized signal detecting in the air by its energy. The detection probability of transmission by a receiver sniffer (radio intercept) is the higher, the more the signal-to-noise power ratio (SNR) at the input of this receiver is provided during the radio interception [5] So band signal differential transformation also leads to telecommunication system energy secrecy increasing.

Let us estimate the reduction of signal detection probability. In accordance with the expressions given in [5], the detection probability may be find through the Markum Q-function in dependence of SNR for low probability of false triggering. The dependency graph of detection probability from signal to noise ratio (for channel bandwidth 8 MHz) is given in figure 6.

As it was shown, the minimum transmitting power reduction reached in simulation is equal 1.6 dB, the average value is 2.49 dB, maximum – 3.5 dB. As it may be seen from the graph, SNR reducing from 22 dB to 20,5 dB may reduce the detection probability to 0,15. For average and maximum value the detection probability may be reduced up to 0.001.

4. Conclusion

The proposed solutions can be used in various areas of communication to achieve various objectives. In the radio channel, the developed methods increase the energy efficiency and security of
communication channels. In wired systems (xDSL, PLC), the proposed schemes increase the noise immunity of the channels. It is also interesting to combine suggested method with methods of compression described in [13]. In optical systems, reducing the dynamic range of channel signals will reduce the influence of nonlinear effects, thereby increasing the spectral efficiency of communication systems. In addition, it should be noted that in optical transmission systems it is possible to organize a secondary compaction channel based on spatial multiplexing of signals [14].

For farther research is very important to solve the problem of extrapolator synthesis for non-linear and many-dimensional channels (for example, for MIMO systems). Another direction is the creation of intelligent (including so-called invariant) systems that adapt to the type of messages transmitted and signal propagation conditions, which will significantly expand the functionality of communication systems.

![Figure 6. Dependency graph of detection probability from signal-to-noise ratio.](image)

### 5. References

[1] GSA confirms LTE connects 1 in 5 mobile subscribers worldwide: Q2 (Access mode: https://gsacom.com/press-release/gsa-confirms-lte-connects-1-5-mobile-subscribers-worldwide-q2-2016/) (20.11.2017)

[2] Draft new Report ITU-R M.[IMT-2020.TECH PERF REQ] - Minimum requirements related to technical performance for IMT-2020 radio interface(s) (Access mode: https://www.itu.int/md/meetingdoc.asp?lang=en&parent=R15-SG05-C-0040 (20.11.2017)

[3] Doug I 2017 Japan, China Plan Commercial 5G Networks by 2020 Radio technology leader (Access mode: http://www.radiomagonline.com/around-the-world/0020/japan-china-plan-commercial-5g-networks-by-2020/38939) (20.11.2017)

[4] Satellite photogram world industry in the results of launching Earth remote sensing satellites in 2016 (Access mode: http://new.scanex.ru/company/news/mirovaya-otrasl-kosmicheskoy-semki-v-itogakh-zapuskov-sputnikov/) (20.11.2017)

[5] Bekkiev A Y and Borisov V I 2014 Basic principles of noise-protected radio communication systems designing Theory and Technique of Radio Communication 1 5-18

[6] Kuznetsov I V, Filatov P E and Gimaev A N 2015 Research and Development of Clustered DPCM Signals for Multichannel power-short data transmitting systems Radioengineering 2 87-92

[7] Kuznetsov I V, Sultanov A Kh, Filatov P E and Smirnova E A 2017 The group codec with differential pulse modulation on the basis of the differential scheme of transformation of the remains of a prediction design Radioengineering 2 23-30

[8] Kuznetsov I V and Filatov P E 2016 Aspects of creation of the group codec with differential pulse code modulation of signals for multichannel communication systems T-Comm: Journal of Telecommunications and their Application in Transport Industry 10(2) 34-39
[9] Filatov P E 2016 Efficiency increasing of energy-deficient multi-channel information transmission systems based on coordinated signal conversion VI International distance scientific and technical conference “Information technologies. Radioelectronics. Telecommunications” 274-278

[10] Kuznetsov I V, Voronkov G S, Sultanov A Kh and Antonov V V 2016 Differential OFDM-converter for energy deficient communication system based on coordinated signal predictor design Radioengineering 12 59-63

[11] Voronkov G S 2017 The possibility of submultiplexing in systems with orthogonal frequency multiplexing International scientific and technical conference proceedings “Future information technologies” 12 65-66

[12] Voronkov G S, Kuznetsov I V and Sultanov A Kh 2017 Increasing the energy efficiency of OFDM systems using differential signal conversion CEUR Workshop Proceedings 1901 259-263

[13] Gashnikov M V, Glumov N I, Kuznetsov A V, Mitekin V A, Myasnikov V V and Sergeev V V 2016 Hyperspectral remote sensing data compression and protection Computer Optics 40(5) 689-712 DOI: 10.18287/2412-6179-2016-40-5-689-712

[14] Kutluyarov R V, Bagmanov V Kh, Antonov V V, Sultanov A Kh and Lyubopytov V S 2017 Increase of nonlinear signal distortions due to linear mode coupling in space division multiplexed systems International Multi-Conference on Engineering, Computer and Information Sciences (SIBIRCON) 282-286

Acknowledgments
This work is supported by the Ministry of Education and Science of Russian Federation under the Basic part of the State assignment for higher education organizations.