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Prospects of using the UFMC technology in 5g / Imt-2020 networks

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ABSTRACT

The article considers the technology of frequency multiplexing with universal filtering UFMC, planned to be introduced in the fifth generation of mobile communication networks, which allows maximizing the rate of decay of the side lobes of the multifrequency signal spectrum that cause out-of-band emissions. As a method of investigation, a computational experiment was chosen. The parameters of the OFDM and UFMC signals were compared to determine the gain of the UFMC technology in the occupied bandwidth of the signal spectrum, as well as the number of arithmetic operations, required to generate a data symbol compared to the OFDM technology, on the basis of which, conclusions were made about the practical application of UFMC technology in networks mobile communication of the fifth generation. The conducted analysis can help to select the optimal number of sub-channels in groups in order to minimize the amount of computations during the UFMC symbol generation process.

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1. INTRODUCTION

The development of information technology has led to significant changes in all areas of human activity, which in turn leads to a continuous increasing in traffic volumes [1, 2]. Moreover, it is planned that a significant part of this traffic will be the exchange of data of inter-machine interaction. Taking into account all the new tasks that arise in the field of telecommunications, it becomes evident the need to move to new standards in mobile communication networks [3, 4]. And now, the standard of communication networks of the fifth generation is already at the stage of certification. The approval of this standard is planned to be implemented in 2020, after agreement the frequency bands at the World Radiocommunication Conference and obtaining a positive decision from the International Telecommunication Union. However, even now it is possible to get acquainted with the draft copy of this standard published on the ITU website. According to the data presented in the draft IMT-2020 standard, the speeds of the downstream and upstream digital streams will be 10 and 20 Gbit/s respectively, the downstream and upstream speeds of 100 and 50 Mbit / s are declared for the end user. At the first stage, the organization of fifth-generation networks is planned on the basis of the existing architecture of the fourth-generation networks, which will be gradually supplemented with the latest developments of radio access [5]. In existing fourth-generation wireless access networks for data transmission, orthogonal frequency multiplexing OFDM technology is used. Despite the indisputable advantages of this technology, we should note a number of disadvantages, for example: the need for highprecision synchronization in time and frequency, sensitivity to the Doppler effect, high values of the peak factor. It should also be noted a fairly broad frequency band in which incidental radio emissions of the OFDM signal are observed above a predetermined level. At the same time, increasing the spectral efficiency is quite a challenge. However, there are already several solutions that, along with classical OFDM, are included in the basis of data transmission in the fifth generation communication networks. In this article, one of such technologies will be considered: universal filtered multicarrier (UFMC).

2. SPECTRAL COMPONENTS

The principle of UFMC technology is to maximize the decay rate of the side lobes of the multifrequency signal spectrum at the output of the Fourier transform block with the help of filters with finite impulse response (FIR filters), the weight coefficients of which correspond to the Dolph-Chebyshev window function [6-9]. An expression describing in general the principle of forming the i-th OFDM symbol on the transmitting side is:

$$\dot{x}^{i}_{\text{cp}} = \frac{1}{\sqrt{N}} \boldsymbol{A}\boldsymbol{W}^{H}\dot{\boldsymbol{X}}^{i} = \boldsymbol{A}\dot{x}^{i},$$

where $\dot{\boldsymbol{X}}^{i}$ – i-th complex data frame of duration N, $\boldsymbol{W}^{H} = (\boldsymbol{W}^{T}) - N \times N$ – matrix of the inverse discrete Fourier transform (IDFT), arg* – complex conjugate operator, $\dot{x}^{i}$ – sequence N-point (IDFT), $\dot{\boldsymbol{X}}^{i}$, $\boldsymbol{A} = \left[\frac{0_{M\times N-M} | \boldsymbol{I}_{M}}{\boldsymbol{I}_{N}}\right]$ – the block matrix for adding a cyclic prefix, by copying the last M samples $\dot{x}^{i}$ in the time window between the sequences $\dot{x}^{i-1}$ and $\dot{x}^{i}$. Then symbol $\dot{x}^{i}$ enters the digital-to-analog converter, where the OFDM signal is generated:

$$x^{i}(t) = Re\left(\sum_{n=1}^{N} x^{i}_{n} \cdot h_{\text{ЦАП}}(t - n\Delta t)\right)\cos(2\pi f_{\text{н}} t),$$

where $h_{DAC}(t)$ – impulse response DAC.

The symmetry property of the IDFT matrix elements should be noted. $\omega^{*}_{m,n} = exp\left(2\pi i \frac{m\cdot n}{N}\right)$, where m,n=0…N-1 – row and column number of matrix $\boldsymbol{W}^{H}: Re(\omega^{*}_{m,n}) = Re(\omega^{*}_{N-m,n}),\ Re(\omega^{*}_{m,n}) = Re(\omega^{*}_{N-m,n})$ для $\forall m = 1 \ldots \left(\frac{N}{2}\right) - 1$. The symmetry property is also valid for n. Thus, in order to organize the transmission by N subcarriers, it is necessary to increase the size of the matrix $\boldsymbol{W}^{H}$ up to 2N, which allows, nevertheless, to form the real signal at the output of the IDFT block due to the Hermitian expansion of the complex data frame: $\dot{\boldsymbol{X}}^{i}_{N-n} = (\dot{\boldsymbol{X}}^{i}_{n})^{*}$, для $\forall n = 1 \ldots \left(\frac{N}{2}\right) - 1$. An example of the OFDM symbol for N = 256 and M = N / 8 and its spectrum is shown in Figure 1.

As can be seen from Figure 1, the level of spectral components, that go beyond the bandwidth allocated for transmission and which affect the signal transmission in adjacent channels, is quite high.

In the UFMC technology discussed in this article, the QAM N sub-channel signals are divided into G groups. The complex data frame of each such group at the positions of QAM signals that do not fall within the frequency range of this group contains zero elements. Complex frames of these groups are fed to separate blocks N of a point IDFT, at the output of which FIR filters with impulse characteristics described by the expressions [7] are installed:

$$h^{i}_{g} = \left(\sum_{k=0}^{l} \frac{(-1)^{l}(L-k-2)!\,ch(arch(10^{\alpha})/N)}{(L-l-k-1)!\,k!\,(l-k)!}\right)\cos\left(\frac{2\pi N\cdot g\cdot l}{G\cdot L}\right),$$

where g – the number of the subcarrier group 0 ... G-1, L – the length of the filter (odd), selected within the range 0.07 ... 0.1 of the N value, which is commensurable with the length of the cyclic prefix.

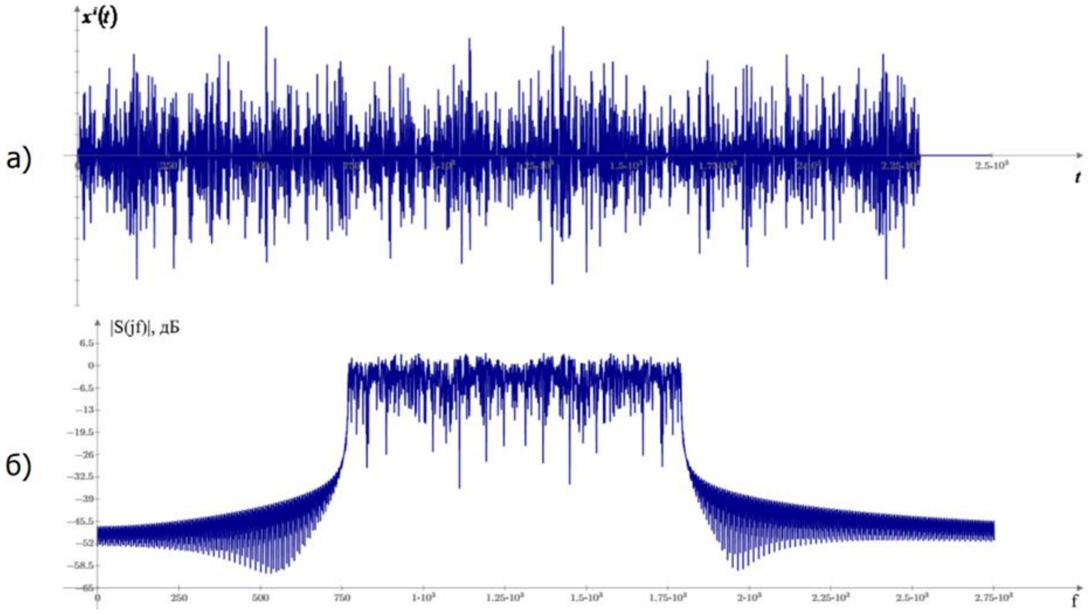

Figure 1. The level of spectral components: a) the OFDM symbol,
b) the amplitude spectrum of the OFDM signal

In Figure 2 the impulse response of FIR filters for 0.7 and 15 groups for G = 16, as well as their spectral characteristics for L = 17, N = 256, insertion damping of the side lobes - 80 dB, are shown.

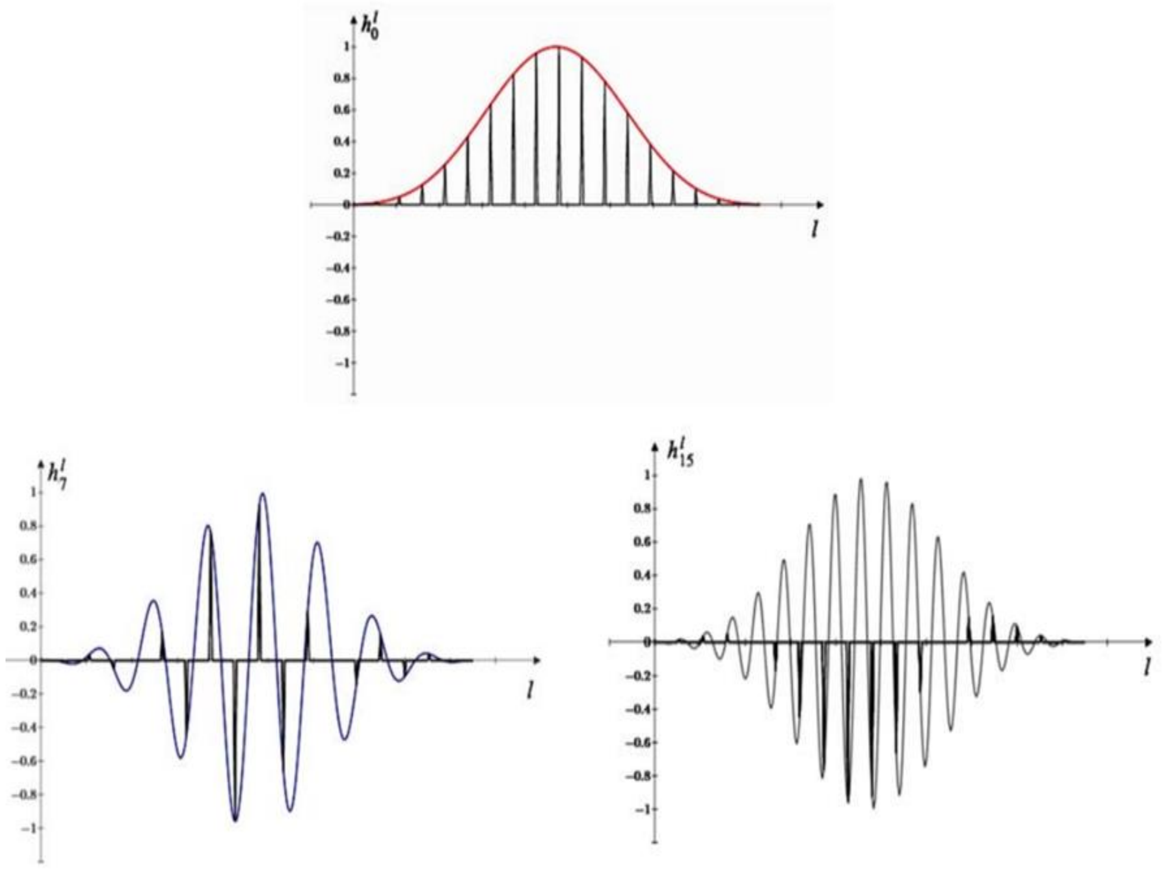

Figure 2. Impulse characteristics of FIR filters for groups g = 0, 7, 15

The formation of the i-th data symbol UFMC as a function of discrete time can be described by the following expression:

$$\dot{x}^{i}_{UFMC} = \frac{1}{\sqrt{2N}}\sum_{g=0}^{G-1} \boldsymbol{H}_g \boldsymbol{W}^H \boldsymbol{D}_g \dot{\boldsymbol{X}}^i = \sum_{g=0}^{G-1} \dot{x}^{i}_{g}$$

where $\boldsymbol{D}_g = diag\{d_0, d_1, \dots, d_{2N-1}\}$ – matrix of forming a complex data frame of the group, where d_n=1, if n is one of the sub-channel numbers of the given group, and d_n=0,otherwise. $\boldsymbol{H}_g$ - $(2N + L - 1) \times 2N$ a matrix of an aperiodic convolution of the signal from the output of the IDFT block and the counts of the Dolph-Chebyshev window function, $\dot{x}^{i}_{g}$ is the data symbol of the group g. The UFMC data symbol is then fed to the DAC and a frequency converter that carries the UFMC signal spectrum to the high-frequency range. In Figure 3 shows the spectral characteristics of FIR filters for groups.

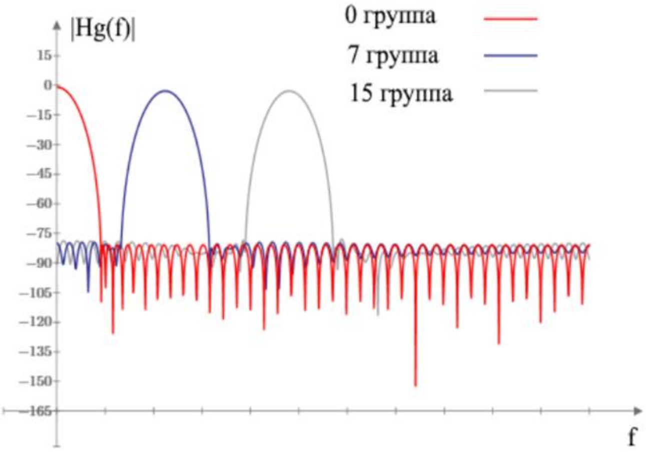

Figure 3. Spectral characteristics of FIR filters for groups g = 0, 7, 15

In Figure 4 the amplitude spectrums of the corresponding groups at the output of the frequency converter are shown.

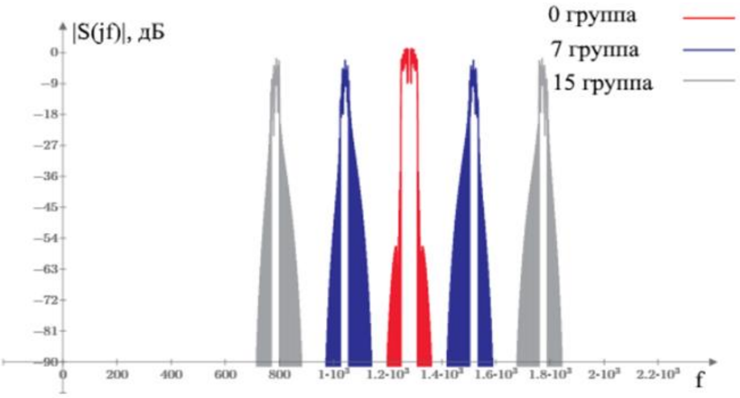

Figure 4. Amplitude spectrums of groups at the output of the frequency converter

In Figure 5 shows the amplitude spectrums of OFDM and UFMC signals formed from a single complex data frame are shown.

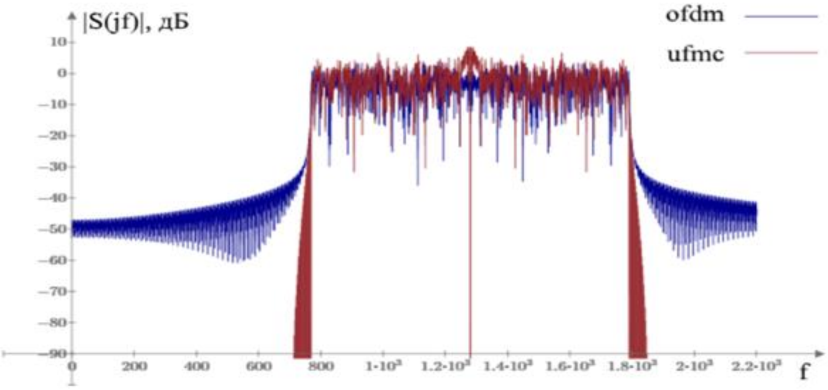

Figure 5. Amplitude spectrums of OFDM and UFMC signals

From Figure 5 it's obvious that UFMC technology effectively eliminates out-of-band emissions. So, if we determine the width of the occupied frequency band of the signal spectraum by the out-of-band radiation level -40 dB, then the UFMC gain over the occupied frequency band is more than 1.2.

3. VOLUMES AND SPEED OF CALCULATIONS

At the same time, it is worth to pay attention to the number of calculations required for the formation of OFDM and UFMC symbols. If for the formation of the OFDM symbol in practice it is necessary to perform the IFFT procedure, which takes into account the Hermitian symmetry$N\log_2(2N)$ operations of complex multiplication and $2N\log_2(2N)$ complex addition, then for the formation of the UFMC symbol, the IFFT procedures are required in G times larger and, therefore, in G times more calculations. The subsequent convolution of the real output sequence of the IFFT block with the impulse response of the FIR filter of the group of length L requires $G(2N+L-1)L$ multiplications and $G(2N+L-1)(L-1)$ additions [10-15]. As well as, it will be necessary to perform $G(2N+L-1)$ operations of adding symbol counts of these groups.

In Figure 6, a graph that shows the dependence of the number of arithmetic operations required for the formation of OFDM and UFMC symbols on the number of sub-channels N is presented. Calculations of the UFMC symbol were made for the case of 16 sub-channels in the group and the filter length L = 0.07 (2N).

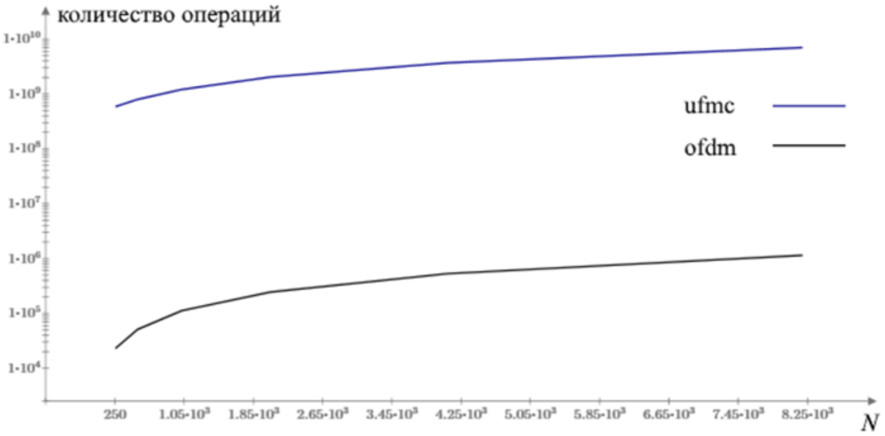

Figure 6. Dependence of the number of arithmetic operations required for the formation of OFDM and UFMC symbols, on the number of sub-channels N

As can be seen from the graphs, the number of arithmetic operations required to generate a UFMC symbol is at least four orders greater than the number of operations required to generate an OFDM symbol.

4. CONCLUSION

In the course of this work, the UFMC technology for data transmission in the standards of 5G / IMT-2020 networks were considered. And also it was compared with the OFDM technology, used in the networks of the fourth generation. It can be concluded that, despite the advantages in terms of economy of the bandwidth used for transmission, UFMC technology requires incommensurably large amounts of computation, which can significantly complicate the practical implementation of this technology, especially taking into account the transmission speeds that are planned to be provided to the final users.

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