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PROCEDURE FOR FORMATION OF FREQUENCY PLANS FOR COGNITIVE RADIO NETWORKS

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Abstract**:** *During the research, the algorithm of frequency ensemble frequency plans formation based on the QOFDM method was developed and simulation of the procedure of formation of frequency ensembles of signal ensemble depending on different values of parameters of frequency plans was performed. The simulation results are presented graphically.*

The work is devoted to the study of the properties of complex signals based on quasiorthogonal Frequency Division Multiplexing (QOFDM).

The QOFDM method significantly increases the bandwidth of the wireless communication network due to the nonlinear allocation of subcarrier frequencies.

An algorithm for ensemble formation was developed taking into account different values of subchannel width in the corresponding frequency plans.

Graphically, the form of frequency plans with different bandwidth and the dependence of the maximum emissions of CCF frequency plans, taking into account the number of subfrequencies and the width of the subchannels.

For statistical analysis, a simulation model of a radio channel was constructed, the results of statistical analysis of intercorrelation properties of frequency plans are graphically presented, properties based on quasi-orthogonal access at high frequencies are investigated, correlation properties of complex signals based on QOFDM are investigated.

Applying quasi-orthogonal access at high frequencies will increase the bandwidth of the communication system and the speed of information transmission due to the nonlinear distribution of high frequencies.

INTRODUCTION

Modern scientific and technological progress is accompanied by the rapid growth of the amount of information needed for various branches of human activity. The transmission of information at a distance is one of the greatest achievements of mankind. The purpose of communication is to disseminate scientific, economic, cultural knowledge and, ultimately, to meet the human need for communication.

The increasing demand of various radio services for an additional spectrum of frequencies is leading to a more complex radio spectrum management environment. To address this challenge, innovative spectrum management techniques are needed to ensure efficient use of bandwidth by services, as well as to enable the sharing of limited spectrum resources and their deployment in telecommunications systems. In certain circumstances, the use of dynamic spectrum access approaches may help to address this challenge. However, in order to realize it, there are a number of complex problems involved in controlling the use of radio frequency spectrum [2, 3]. This research is aimed at solving the problem of increasing the frequency resource utilization in the cognitive radio network. To solve this problem, it is proposed to use the method of determining the coincidence of frequency subcarriers based on the method QOFDM.

The Aim of the scientific research is to analyze the results obtained when modeling the dependence between different values of the bandwidth, the number of subcarrier frequencies in the frequency plan and the correlation coefficient. The procedure for determining the coincidence of positions of subcarrier frequencies when paired comparing frequency plans will improve the procedure of forming frequency plans in cognitive radio networks.

THE MAIN PART

The quasiorthogonal frequency division method of QOFDM channels is based on the already existing OFDM method [2]. Each subcarrier frequency is modulated according to a conventional modulation scheme (e.g., quadrature-amplitude modulation) at a low symbolic rate while maintaining the overall data rate as in conventional one-subcarrier modulation schemes in the same bandwidth. In practice, OFDM signals are obtained using the inverse FFT (Fast Fourier Transform). The main difference between the proposed QOFDM method and the existing method is precisely the orthogonality of the frequency subcarriers.

The difference between QOFDM (Quasiorthogonal frequency division multiplexing) with the previous methods is that this method allows increasing the subscriber capacity of the cognitive radio network due to the simultaneous use of different subscribers of the same network with the same variants of the same network. in different frequency plans. The QOFDM method is based on the use of individual distribution of subcarrier frequencies for each ensemble frequency plan.

The features of quasiorthogonal frequency modulation on subcarrier frequencies include:

- $N_1 \neq N_2 \neq \ldots \neq N_i \neq N_k$, where N_1 - the number of subcarrier frequencies in the *1-st* frequency plan of the ensemble, N_k - the number of subcarrier frequencies in the *k-th* band of the ensemble);
- for individual channels, a separate modulation with individual subcarrier frequencies distribution is assigned: $\Delta f_1 \neq \Delta f_2 \neq \ldots \neq \Delta f_i \neq \Delta f_k$, where Δf_1 - the interval of distribution between the ensembles raised in the *1-st* frequency plan, Δf_k - the interval of distribution between the ensembles raised in the *k-th* frequency plan);
- the signals are transmitted in the same frequency band ΔF.

A system consisting of four QOFDM signals is presented in the form of the graph shown in Fig. 1. Each of the four frequency plans shown in Fig. 1 has a different value for the interval between the subcarrier frequencies. For all frequency plans, the bandwidth value ΔF is 5 MHz.

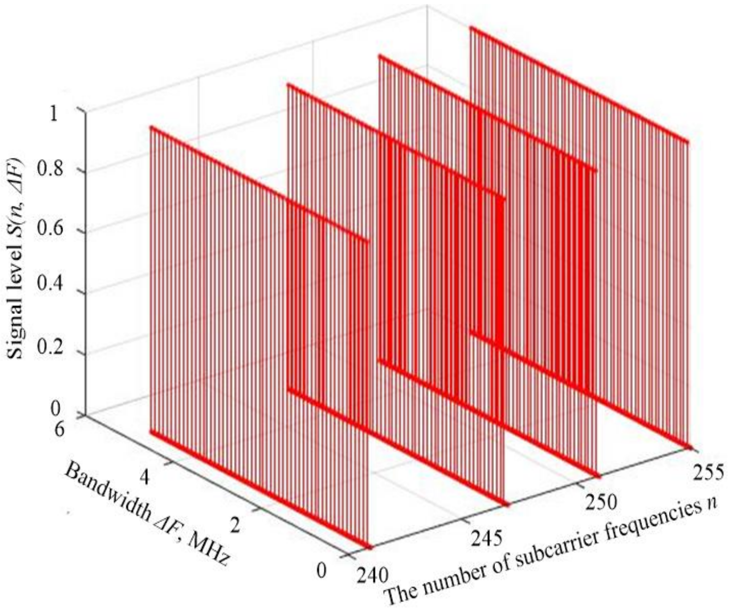

Fig. 1 A view of a system consisting of four QOFDM signals

The principle of zero orthogonal access at subcarrier frequencies is based on the principle of zero orthogonality between frequency positions [4]. One of the problems in signal generation using the proposed method of quasiorthogonal access at subcarrier frequencies is the task of determining the frequency positions that coincided when paired comparisons of frequency plans. As a result of unequal variants of distribution of subcarrier frequencies the task of determining the coincidence of positions in different frequency plans of the ensemble arises. To solve this problem, we propose to use the algorithm described in previous publications. Due to the large number of subcarrier frequencies in each band of the ensemble, these frequencies can overlap, so, obviously, certain positions of the subcarrier frequencies may coincide. It is necessary to determine the places of coincidence of frequency positions between different signals of the same ensemble, which coincided when comparing frequency plans with each other. The coincidence coefficient [5] is defined as the integral over the interval of the frequency band F_i to F_j of the product of the *i-th* and *j-th* frequency plans with a sampling step Δ_j. The coefficient of coincidence will be calculated by the formula (1):

(1) $$B_{ij}(\Delta f) = \int_{F_1}^{F_2} S_i(\Delta f_i) \cdot S_j(\Delta f_i - \Delta_j) d\Delta f$$

where Δ_j - the sampling frequency step in the *j-th* frequency plan.

The following condition (2) must be fulfilled:

(2) $$B_{ij}(\Delta f) \le \frac{1}{\sqrt{N_i \cdot N_j}}$$

Consider the method of determining the location of the coincidence of frequency positions in different ensemble signals.

Matched frequency positions are determined in pairs by expression (3)

(3) $$F_{ij} = \sum_{k=1}^{n_i} \Delta f_{ik} = \sum_{m=1}^{n_j} \Delta f_{jm}$$

where F_{ij} - the frequency position that coincided with the pairwise comparison of the *i-th* and *j-th* frequency plans; k - the number of subcarriers in the *i-th* frequency plan; m - the number of subcarriers in the *j-th* frequency plan; $\sum_{k=1}^{n_i}\Delta f_{ik}$ - the sum of the frequency intervals of the *i-th* frequency plan to the subcarrier, which coincided with the subcarrier *j-th* frequency plan; $\sum_{m=1}^{n_j}\Delta f_{jm}$ - the sum of the frequency intervals of the jth frequency plan to the subcarrier, which coincided with the subcarrier *i-th* frequency plan.

The system of equations (4) must be solved for four signals. Frequency positions will coincide when the equations are the same. Let $k = a$ and $m = b$. Then the expression (4) for the paired plans will look like (5):

$$\begin{cases} F_{12} = \sum_{k=1}^{n_i}\Delta f_{1k} = \sum_{m=1}^{n_2}\Delta f_{2m}, \\ F_{13} = \sum_{k=1}^{n_i}\Delta f_{1k} = \sum_{m=1}^{n_3}\Delta f_{3m}, \\ F_{14} = \sum_{k=1}^{n_i}\Delta f_{1k} = \sum_{m=1}^{n_4}\Delta f_{4m}, \\ F_{23} = \sum_{k=1}^{n_2}\Delta f_{2k} = \sum_{m=1}^{n_3}\Delta f_{3m}, \\ F_{24} = \sum_{k=1}^{n_2}\Delta f_{2k} = \sum_{m=1}^{n_4}\Delta f_{4m}, \\ F_{34} = \sum_{k=1}^{n_3}\Delta f_{3k} = \sum_{m=1}^{n_4}\Delta f_{4m}. \end{cases} \quad (4)$$

$$\begin{cases} a\cdot\Delta f_{1a} = b\cdot\Delta f_{2b} = F_{12}, \\ a\cdot\Delta f_{1a} = b\cdot\Delta f_{3b} = F_{13}, \\ a\cdot\Delta f_{1a} = b\cdot\Delta f_{4b} = F_{14}, \\ a\cdot\Delta f_{2a} = b\cdot\Delta f_{3b} = F_{23}, \\ a\cdot\Delta f_{2a} = b\cdot\Delta f_{4b} = F_{24}, \\ a\cdot\Delta f_{3a} = b\cdot\Delta f_{4b} = F_{34}. \end{cases} \quad (5)$$

From expression (5) we express the numbers of coincident frequency subcarriers a of the first frequency plan in the pair being compared – expression (6) and coincident frequency subcarriers b of another frequency plan in a pair that is compared (7):

$$\begin{cases} a = \dfrac{b\cdot\Delta f_{2b}}{\Delta f_{1a}}, \\ a = \dfrac{b\cdot\Delta f_{3b}}{\Delta f_{1a}}, \\ a = \dfrac{b\cdot\Delta f_{4b}}{\Delta f_{1a}}, \\ a = \dfrac{b\cdot\Delta f_{3b}}{\Delta f_{2a}}, \\ a = \dfrac{b\cdot\Delta f_{4b}}{\Delta f_{2a}}, \\ a = \dfrac{b\cdot\Delta f_{4b}}{\Delta f_{3a}}. \end{cases} \quad (6)$$

$$\begin{cases} b = \dfrac{a\cdot\Delta f_{1a}}{\Delta f_{2b}}, \\ b = \dfrac{a\cdot\Delta f_{1a}}{\Delta f_{3b}}, \\ b = \dfrac{a\cdot\Delta f_{1a}}{\Delta f_{4b}}, \\ b = \dfrac{a\cdot\Delta f_{2a}}{\Delta f_{3b}}, \\ b = \dfrac{a\cdot\Delta f_{2a}}{\Delta f_{4b}}, \\ b = \dfrac{a\cdot\Delta f_{3a}}{\Delta f_{4b}}. \end{cases} \quad (7)$$

This way you can determine the frequency positions that match the different signals. To illustrate the operability of the proposed method, an example is presented, which presents the simulation results for which 50 frequency plans included in the signal ensemble were selected. The calculations were performed with the values of the bandwidth parameter ΔF = 15 MHz and 20 MHz with the subchannel width Δs = 15 kHz. The number of frequency subcarriers varies from 23 to 512. The frequency plans are paired in comparison. Thus, the value of the correlation coefficient r_{ij} of the two compared frequency plans was calculated. On the basis of the obtained results, those frequency plans that gave the worst values in the calculation of the correlation coefficient, namely $r_{ij}> 0{,}1$, were removed. The Fig. 2 presents a plot of the correlation of the pairwise comparison of frequency plans on the number of frequency subcarriers in each frequency plan and on the bandwidth before removing the frequency plans from the ensemble. The Fig. 2 shows that before removing frequency plans from the ensemble, the highest values of the correlation coefficient are the frequency plans with the value of the number of frequency subcarriers in the range from about 100 to 350 and exceeding the limit value, which is equal to 10% of the maximum level (i.e. 0.1).

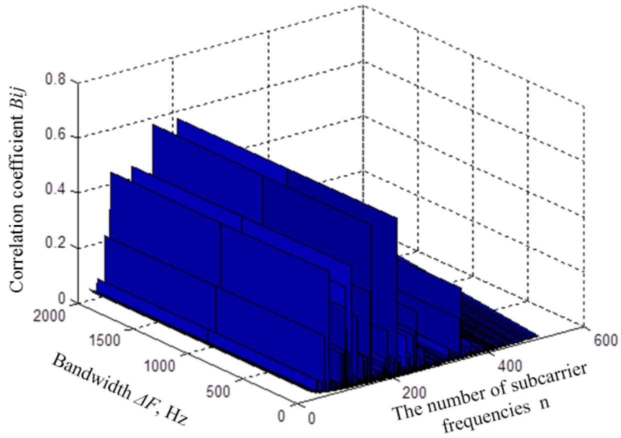

Fig. 2 Graph of correlation coefficient of pairwise comparison of frequency plans on number of frequency subcarriers and on bandwidth before removal of frequency plans from ensemble

In Fig. 3, the correlation coefficient does not exceed the allowable value. This is achieved by removing frequency plans from the ensemble.

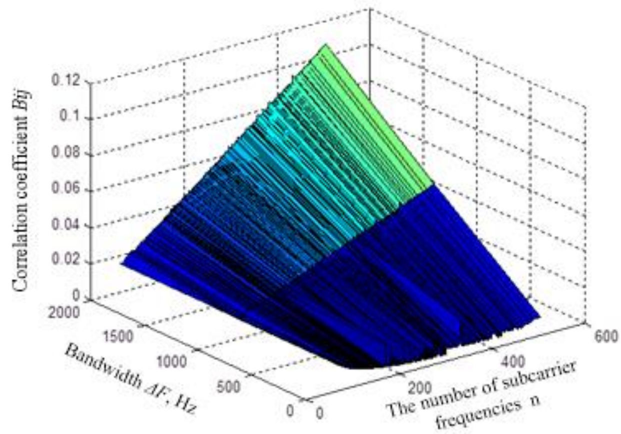

Fig. 3 Graph of correlation coefficient of pairwise comparison of frequency plans on the number of frequency subcarriers and on the bandwidth *ΔF* = 20 MHz before removal of frequency plans from the ensemble

The Fig. 4 illustrates the slightly worse results of the correlation coefficient after removing the frequency plans compared to the previous figures.

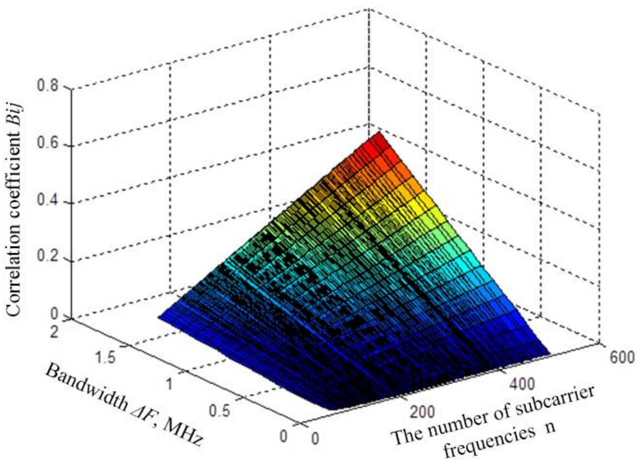

Fig. 4 Graph of correlation coefficient of pairwise comparison of frequency plans on the number of frequency subcarriers and on the bandwidth *ΔF* = 15 MHz after removal of frequency plans from the ensemble

The simulation was performed with a bandwidth value *ΔF* = 15 MHz. With this in mind, the maximum value of the correlation coefficient reaches a mark of 0.4.

CONCLUSIONS

Thus, we can conclude that the minimum similarity of the two compared plans is achieved when the value of the bandwidth *ΔF* = 20 MHz at a value of subchannel width of 15 kHz. Due to the exclusion of frequency plans with unsatisfactory characteristics from the list adopted for the formation, the ensembles of frequency plans that meet the requirements for mutual influences given in [4] are obtained.

The method of determining the frequency positions that coincide when paired comparing frequency plans allows to simplify the process of formation of frequency plans and to reduce the level of intra-system interference that occur when multiple users use the same frequency bands in cognitive radio systems. This makes it possible to increase the capacity of the cognitive radio network.

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