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THE STUDY OF THE CROSS-CORRELATION PROPERTIES OF COMPLEX SIGNALS ENSEMBLES OBTAINED BY FILTERED FREQUENCY ELEMENTS PERMUTATIONS

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ABSTRACT

Context. The relevance is to study the cross-correlation properties of the developed complex signals ensembles of large volume with a low level of multiple access interference, thereby increasing the efficiency of using a limited radio frequency range. The Object of Research is a method of bandpass filtering with permutations, which allows forming complex signals ensembles of large volume.

Objective. The Objective is to determine the optimal cross-correlation properties for the formation of complex signals ensembles of large volume with a low level of multiple access interference.

Method. The work has the study results of cross-correlation properties of complex signals ensembles obtained by applying the filtered elements permutation method. The formation of complex signals ensembles is based on pseudo-random sequences with improved cross-correlation properties in the time domain. Bandpass filtering is applied to such sequences, and the number of filter bands is determined based on the calculation of the frequency spectrum utilization coefficient. The filter band optimal width determination is based on a comparison of the maximum emissions of the side lobes values of the of cross-correlation function of signals from the elements number in the involved sequences. The signals obtained by frequency bands allocating are characterized by a difference in form in the minimal similarity condition. In order to reduce the multiple access interference impact, the frequency components transfer obtained by spectral filtering to the common frequency range is carried out. After that, the signals are transferred using the full search method. As a result, it was obtained all possible combinations of signal pairs permutations. The use of permutations in the complex signals ensemble formation can significantly increase the ensemble volume. The signals generated by frequency filtering, to which the transfer to the common frequency band and their subsequent permutation was applied, are subjected to correlation analysis based on the calculation of the maximum emissions values of the side lobes of the cross-correlation function.

Comparative characteristic of cross-correlation properties of developed signals with known signals prove that signals generated based on pseudo-random sequences with improved cross-correlation properties have a much larger ensembles volume, are formed on the basis of simple algorithms that don't require significant computing resources and have satisfactory cross-correlation characteristics. The use of bandpass filtering method with permutation allows the formation of large-volume ensembles whose signals differ in form, and the combination of different frequency bands reduces the vulnerability to multiple access interference.

Results. Due to the software implementation of the bandpass filtering method with permutations, the comparison of cross-correlation properties of nonlinear sequences, M-sequences, multiphase signals and developed signals based on sequences with improved cross-correlation properties was performed.

In estimating the levels of maximum emissions of side lobes of the cross-correlation function, it was found that the generated signals obtained by bandpass filtering with permutations deteriorate cross-correlation characteristics by increasing the pulse duration proportional to the decrease in signal frequency band, but their value satisfies the minimal similarity condition, used in cognitive telecommunications systems.

Conclusions. The study of the signals cross-correlation properties proves the effectiveness of the developed bandpass filtering with permutations method. The generated signals have cross-correlated characteristics no worse than ensembles based on known signals. At this level of maximum emissions of the side lobes of the cross-correlation function of the developed signals is 7–12% less than the known signals. Thus, the method of bandpass filtering with permutations can be used to increase the efficiency of radio frequency resource use of both existing and advanced cognitive telecommunication networks of wireless access based on systems with code division multiplexing.

KEYWORDS: complex signal, cross-correlation function, multiple access interference, signal base, signal spectrum width, filter band, low energy interaction, ensemble volume.

ABBREVIATIONS

CCF is a cross-correlation function;

MAI is a multiple access interference.

NOMENCLATURE

s_i is a i-th signal;

s_j is a j-th signal;

Δf is a filter band;

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Δ is a integration step;

B is a signal base;

$F_н$ is a lower limit of the frequency range;

$F_в$ is a upper limit of the frequency range;

ΔF is a width of the pseudo-random sequence spectrum main lobe with low interaction in time domain;

K_{ij} is a random pair of frequency elements;

$s(t)$ is a signal obtained by frequency filtering;

X is a frequency spectrum of the signal;

$\omega_0\tau$ is a phase shift;

E_i is a energy of the i-th signal;

T is a sequence duration;

τ is a sequence pulse duration;

t is a time;

N is a symbols number in the sequences;

R_{max} is a maximum emission of the side lobes of CCF.

INTRODUCTION

Increasing the number of users and the quality of their service in modern cognitive telecommunication systems and radio networks, provided multiple access to various information resources and technologies, is possible with using by ensembles of complex signals with large volumes.

Increased volume signals realization is possible with the use of pseudo-random sequences with improved cross-correlation properties. The advantages of such sequences are low energy interaction in the time domain, low level of cross-correlation, ensuring a low MAI level and compliance with the condition of minimal similarity. However, in the study of signal ensembles based on such sequences, it was found that the number of forming sequences limits their volume. Therefore, the urgent task is to form such signals ensembles that have mutually correlated properties close to the signals with minimal interaction in the time domain [1–3].

One of the main directions of research of complex signals ensembles is correlation characteristics definition. However, code division multiplexing is based on correlation processing. In this case, the main criterion for evaluating the characteristics of complex signals ensembles based on sequences with improved cross-correlation properties obtained by bandpass filtering with permutations and subsequent transfer to a common frequency range can be considered analysis of cross-correlation characteristics of the studied signals.

Pseudorandom sequences with improved cross-correlation properties are signals with a large base, have a low level of cross-correlation, provide a low level of multiple access interference and meet the condition of minimal similarity [6].

The use of signals based on sequences with improved cross-correlation properties obtained by bandpass filtering with permutations in cognitive telecommunication systems allows reducing the level of MAI by decreasing the values of the maximum emissions of the side lobes of the CCF received signals.

Estimation of the volume and analysis of cross-correlation characteristics of complex signals ensembles, which are formed on the basis of this method, will determine the feasibility of further use of such signals in telecommunication systems of cognitive radio communication with code division multiplexing.

The object of study is the method of bandpass filtering with permutations, which allows forming complex signals ensembles of large volume in order to increase the number of simultaneously served subscribers and the quality of their service in modern cognitive telecommunication systems with limited frequency resource.

The subject of study is a process of studying the cross-correlation characteristics of the formed complex signals ensembles obtained by applying the method of bandpass filtering with permutations.

The purpose of the work is to determine the optimal cross-correlation characteristics for the formation of complex signals ensembles of large volume with a low level of multiple access interference.

1 PROBLEM STATEMENT

Suppose an ensemble of complex signals consisting of 50 output sequences with N = 23 – 512, $T \approx$ 1,2 ms, τ_i = 10 ns. Δf was selected between 200 kHz and 450 kHz in 50 kHz increments.

The task is to calculate the values of R_{max}, based on the selection of optimal signal parameters, in order to determine the correlation properties of the signals. This takes into account the limitation on the number of filter bands k_s and the criterion of minimum similarity $R_{ij\ max}$, which will form ensembles of complex signals of large volume with a low level of multiple access interference and apply them in cognitive telecommunications systems.

2 REVIEW OF THE LITERATURE

Known complex signals classes are usually formed based on video pulses sequences formed by a certain rule. Such sequences include M-sequences, Gold, Kasami sequences, nonlinear sequences, multiphase signals and others [6, 9].

The structure of the signals used as subscribers determines the value and MAI pattern and, accordingly, the noise immunity of the system, the effectiveness of the frequency spectrum and the maximum number of active subscribers [7, 8, 10, 11]. Implementation of transmission systems, the signals of which overlap in frequency, is possible due to the use as information carriers of individual subscriber signals.

In transmission systems, the characteristics of the customer service quality and the transmitted information reliability are rigidly interrelated. Due to the presence of information in the system, the information transmission reliability depends on the number and activity of subscribers, as well as on the power of the signals emitted by them. Thus, to increase the noise immunity of the system it is necessary to reduce the number of simultaneously working subscribers, which is impractical in modern conditions of cognitive telecommunication systems development.

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Another way to improve the service quality is the use of signals with improved cross-correlation properties [9, 12], which are estimated using the values of the maximum emissions of the side lobes of the CCF depending on the number of pulses in the sequences.

The use of such signals allows developing ensembles of the large volume complex signals, which allows significantly increasing the number of simultaneously served subscribers and improve the quality of transmission.

3 MATERIALS AND METHODS

To determine the optimal values of frequency characteristics in this method of bandpass filtering with permutations in order to form ensembles of complex signals of large volume, pseudo-random sequences with low energy interaction in the time domain are used, which are described in [1, 2]. Bandpass filtering is applied to such sequences. Estimation of the number of bands is due to the coefficient of frequency spectrum k_s use, defined as [3]:

$$k_s = \frac{\Delta F}{\Delta f}. \quad (1)$$

The determination of the optimal width of the filtration band is based on a comparison of the values of the maximum emissions of the side lobes of the CCF signals from the number of elements in the involved sequences.

The comparison coefficient value of the maximum emissions of the side lobes of the CCF signals is determined by the expression [9]:

$$R_{ij\max}(\Delta f) = \int_{F_н}^{F_в} s_i(\Delta f) \cdot s_j(\Delta f - \Delta) d\Delta f. \quad (2)$$

The obtained values must meet the condition of minimal similarity [6]:

$$R_{ij\max} \le \frac{1...5}{\sqrt{B}}. \quad (3)$$

As a result of the application of such filtering, frequency bands were isolated from the spectrum of pseudo-random sequences with minimal energy interaction in the frequency domain. Signals obtained by allocating frequency bands are characterized by a difference in form in the condition of minimal similarity of signals (3).

In order to reduce the multiple access interference impact, the frequency transfer of the components obtained by filtering the spectrum of sequences with minimal energy interaction to the common frequency range is performed.

The analytical expression of the frequency transfer is [4]:

$$F^{-1}\{X(\omega - \omega_0)\} = s(t)e^{-j\omega_0\tau}. \quad (4)$$

In expression (4), the signal delay leads to a change in the phase-frequency characteristic, which shows the ratio of the harmonic components: $sin(\omega)/cos(\omega)$, so the frequency spectrum of the signal obtained by frequency filtering is difficult to phase shift. As a result, it is possible to significantly improve the frequency selectivity compared to known signals generated based on devices with direct amplification.

Signals permutation occurs by means of a full search method that is defined by a formula:

$$\sum_{i=1}^{n} K = \frac{K^2 - K}{2}. \quad (5)$$

To explain this method, we ask a set of four frequency elements K_1, K_2, K_3 and K_4, obtained by applying bandpass filtering at different intervals of the spectrum to sequences with improved cross-correlation properties. As a result, we obtain all possible combinations of permutations: K_{12}, K_{13}, K_{14}, K_{23}, K_{24} and K_{34}.

The use of permutations in a complex signals ensemble formation allows you to reduce the level of minimal similarity of signals at an acceptable level, while increasing the signals ensemble volume.

The cross-correlation properties of the signals generated by frequency filtering, to which the transfer to the common frequency band is applied and their subsequent permutation are analyzed by calculating the values of the maximum emissions of the side lobes of the CCF.

The calculation of the values of the maximum emissions of the side lobes of the CCF is in accordance with the docking function [5]:

$$R_{ij}(\tau) = \int_{-T}^{T} s_i(t) s_j(t - \tau) dt. \quad (6)$$

The energy of the signals obtained by the method of bandpass filtering with permutations will be different, therefore, to estimate correctly the maximum emissions values of the side lobes of the CCF by expression (6) it is necessary to normalize the signal energy [5]:

$$s_{i\,norm}(t) = \frac{s_i(t)}{\sqrt{E_i}}. \quad (7)$$

According to the calculations results of all possible variants of pairs of the received signals leave only those which will satisfy a condition of the minimal similarity (3).

Comparative characteristics of cross-correlation properties of developed signals with known signals prove that signals generated based on pseudo-random sequences with improved cross-correlation properties have a much larger volume of ensembles, are formed on the basis of simple algorithms that don't require significant computational resources and have better cross-correlation characteristics.

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The application of the method of bandpass filtering with permutations allows forming ensembles of large volume, the signals of which differ in form, and the combination of different frequency bands reduces the vulnerability to MAI.

4 EXPERIMENTS

The method of bandpass filtering with permutations is implemented as a software product created in the Matlab modeling environment, due to which there is a practical confirmation of the obtained theoretical results.

To form a complex signals ensemble, pseudo-random sequences with improved cross-correlation properties are used, to which band filtering is applied. The choice of the optimal bandwidth of the filter band is based on the analysis of the signal correlation properties produced by selecting the frequency elements obtained from different frequency bands, the number of which is determined by calculating the frequency spectrum utilization factor. According to the analysis results, the optimal value $\Delta f = 350$ kHz, and the number of filter bands is 4. To reduce the influence of the MAI to such signals isolated from the common frequency band of pseudo-random sequences with improved correlation properties, frequency transfer to the common frequency range is used. The obtained signals differ in form and satisfy the condition of minimal similarity of signals.

Then the permutation of signals is performed by the method of full search, the result is all possible combinations of permutations: K_{12}, K_{13}, K_{14}, K_{23}, K_{24} and K_{34}. The process of permutations in the formation of a complex signals ensemble allows reducing the level of minimal similarity of signals to an acceptable level, with a significant increase in the ensemble volume, the calculation of which is discussed in detail in [3].

Analysis of the cross-correlation properties of the signals generated by frequency filtering, to which the transfer to the common frequency band was applied and their subsequent permutation is based on the calculation of the values of the maximum emissions of the side lobes of the CCF.

The energy of the signals obtained by the method of bandpass filtering with permutations from different frequency ranges will be different, therefore, for correctly estimating the values of the maximum emissions of the side lobes of CCF by expression (6) it is necessary to normalize the signal energy. After alignment, the analysis of cross-correlation properties of the received signals is carried out and their models are built, based on which the maximum emissions of the side lobes of the CCF for all possible variants of signals are determined. When forming a complex signals ensemble, only those pairs of signals are used that will satisfy the requirements for the established restrictions.

Because of obtaining the data, a comparative characterization of the cross-correlation properties of the developed signals with known signals is carried out. The characterization proves that the signals formed based on pseudo-random sequences with improved cross-correlation properties outweigh the known signals in the volume of the ensemble, are formed on the basis of simple algorithms that don't require significant computational resources and have better cross-correlation properties.

5 RESULTS

The calculation results of the correlation properties of the signals obtained by frequency filtering with transfer to a common frequency range and permutations depending on the bandwidth are shown in table 1. The following notations were used: *Sftp200* (t) – *Sftp450* (t) – bandwidth signal from 200 to 450 kHz, $K_{12} – K_{34}$ – combinations of permutations of signal pairs. Figure 1 graphically shows the dependences of the calculation of the maximum emissions of the side lobes of the CCF on the number of pulses in sequences with improved correlation properties at different values of the bandwidth of the bandpass filters [14].

The obtained results testify to the correspondence of the signals to the signals with minimal energy interaction and satisfy the condition of minimal similarity. The optimal value of $\Delta f = 350$ kHz, as the formed complex signals ensemble has the optimal volume [3], and the levels of maximum emissions of the side lobes satisfy the selected constraint.

Table 2 presents the results of calculating the values of the maximum emissions of the side lobes of CCF nonlinear sequences, M-sequences, multiphase signals and developed signals based on sequences with improved cross-correlation properties.

Figure 2 shows a comparative characteristic of the values of the maximum emissions of the side lobes of the CCF signals based on different sequences.

As a result of the study, when estimating the levels of maximum emissions of side lobes of the CCF found that the generated signals obtained by bandpass filtering with permutations have worse cross-correlation properties, relative to signals obtained by permutation of time intervals of sequences based on a centered series due to increasing pulse duration in accordance with the reduction of the signal frequency band. However, their value satisfies the condition of minimal similarity and such signals can be used in cognitive telecommunication systems.

6 DISCUSSION

The data is in the calculating the correlation properties of signals (table 1) show that the study can be used to solve the problem of forming complex signals ensembles based on sequences with improved cross-correlation properties by bandpass filtering with subsequent transfer to the common frequency range and permutations of frequency elements.

The results of calculating the cross-correlation properties of the signals obtained by frequency filtering with transfer to the common frequency range and permutations are presented in Figure 1 and limited to $N = 150$ in order to better perceive the displayed values of maximum emissions of side lobes of CCF.

It should be noted that even when the value of Δf decreases to the level of 200 kHz, increasing the pulse duration does not violate the minimal similarity condition of the developed signals.

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The applied method of signal frequency elements permutation using full search allows receiving all possibilities of permutations combinations that from the point of view of optimum use of system computing resources creates additional loading.

Comparison of signals cross-correlation properties based on different sequences proves the effectiveness of the developed method of bandpass filtering with permutations. The formed complex signals ensembles have cross-correlation properties not worse than ensembles based on known signals, and the level of maximum emissions of the side lobes of the CCF of the developed signals is 7–12% lower than the indicators of known signals. Thus, the method of bandpass filtering with permutations can be used to increase the efficiency of radio frequency resource use in cognitive telecommunication networks based on systems with code division multiplexing.

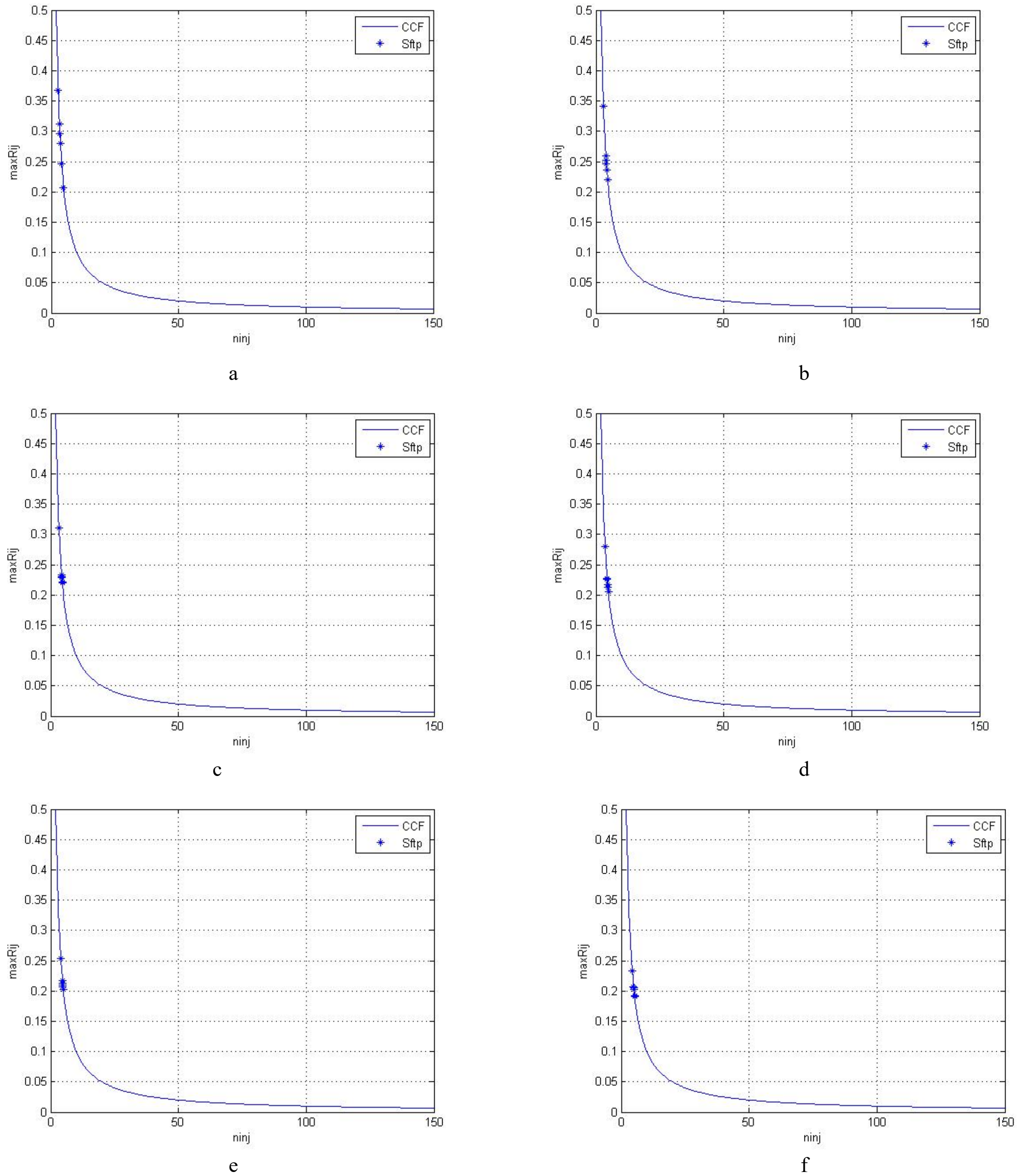

Figure 1 – The calculation results of the signals cross-correlation properties obtained by frequency filtering with permutation to the common frequency range and permutations:
a – when using the filter band width is equal 200 kHz, b – when using the filter band width is equal 250 kHz, c – when using the filter band width is equal 300 kHz, d – when using the filter band width is equal 350 kHz, e – when using the filter band width is equal 400 kHz, f – when using the filter band width is equal 450 kHz

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Table 1 – The calculation results of the signals correlation properties obtained by frequency filtering with permutation to the common frequency range and permutations within the filter bands width

	R_{12}	R_{13}	R_{14}	R_{23}	R_{24}	R_{34}
Sftp200(*t*)	0.3128	0.2795	0.3677	0.2464	0.2068	0.2958
Sftp250(*t*)	0.2601	0.2523	0.3416	0.2358	0.2195	0.2462
Sftp300(*t*)	0.2217	0.2193	0.3101	0.2284	0.2298	0.2329
Sftp350(*t*)	0.2120	0.2049	0.2796	0.2176	0.2265	0.2276
Sftp400(*t*)	0.2024	0.2027	0.2542	0.2104	0.2122	0.2178
Sftp450(*t*)	0.1901	0.2052	0.2336	0.2021	0.1917	0.2076

Table 2 – The calculation results of the values of the maximum emissions of the side lobes of the CCF signals based on different sequences

	The values of the maximum emissions of the side lobes of the CCF					
N	Nonlinear sequences	M- sequences	Multiphase signals	Sequences with low interaction in the time domain	The signals are obtained by permutation the time intervals of the sequences based on the centered series	Signals based on sequences with improved cross-correlation properties obtained by bandpass filtering with permutations
		$(1.9...6)/\sqrt{N}$	$(1...3)/\sqrt{N}$	$1/\sqrt{n_i n_j}$	$(1...3)\sqrt{B}$	$(1...5)\sqrt{B}$
40	0.092	0.341	0.058	0.0321	0.0729	0.256
100	0.0797	0.2354	0.041	0.0114	0.0507	0.182
256	0.0626	0.1186	0.0207	0.004	0.0221	0.11
512	0.0612	0.0863	0.0123	0.0031	0.019	0.079

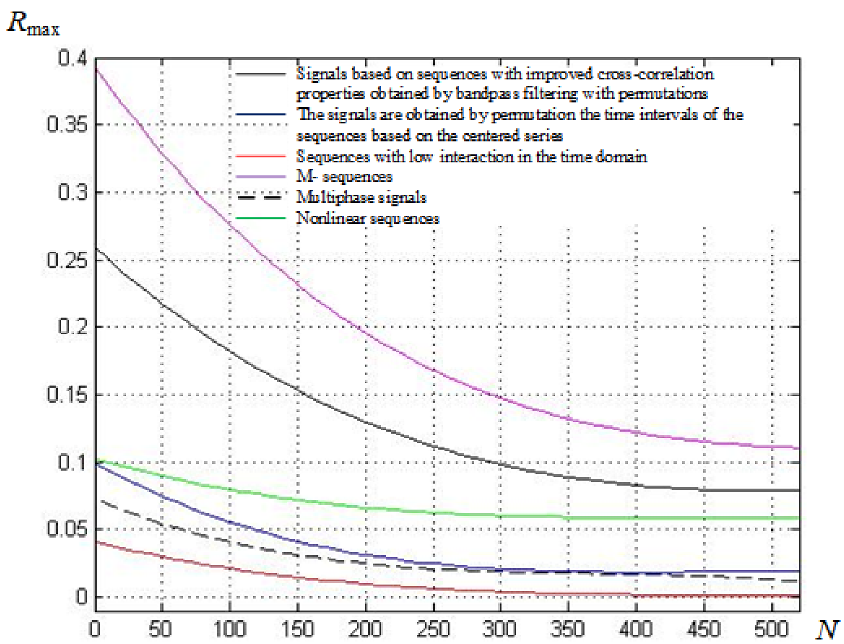

Figure 2 – Comparative characteristic of the values of the maximum emissions of the side lobes of the CCF signals based on different sequences

CONCLUSION

The main criterion for evaluating the properties of complex signals ensembles based on sequences with improved cross-correlation properties obtained by bandpass filtering with transfer and subsequent permutation to a common frequency range can be considered the analysis of cross-correlation properties of the studied signals. Analysis of the cross-correlation properties of complex signal ensembles based on pseudo-random sequences with improved cross-correlation properties allows the formation of complex signal ensembles of much larger volume than ensembles based on known signals.

The scientific novelty of the obtained results lies in the further development of the method of forming complex signals ensembles based on sequences with improved cross-correlation properties obtained by bandpass filtering with permutations, realized based on selection from sequences spectrum of equal bands with using the subsequent permutation. It allows increasing the complex sig-

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nals ensembles volume at a given level of multiple access interference.

The practical significance of the obtained results is in the possibility of using complex signals obtained by bandpass filtering with permutations in cognitive telecommunication systems, which are available to multiple access ensembles.

Prospects for further research are to improve the selective capabilities of the frequency elements permutation process, the choice of the optimal conversion when transfer selected frequency bands to a common frequency range and further study of the correlation and ensemble signals properties.

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ДОСЛІДЖЕННЯ ВЗАЄМОКОРЕЛЯЦІЙНИХ ВЛАСТИВОСТЕЙ АНСАМБЛІВ СКЛАДНИХ СИГНАЛІВ, ОТРИМАНИХ ШЛЯХОМ ПЕРЕСТАНОВОК ВІДФІЛЬТРОВАНИХ ЧАСТОТНИХ ЕЛЕМЕНТІВ

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АНОТАЦІЯ

Актуальність. Полягає у дослідженні взаємокореляційних властивостей розроблених ансамблів складних сигналів великого об'єму із забезпеченням низького рівня завад множинного доступу, за рахунок чого забезпечується підвищення ефективності використання обмеженого радіочастотного діапазону. Об'єктом дослідження є метод смугової фільтрації з перестановками, який дозволяє сформувати ансамблі складних сигналів великого об'єму.

Мета роботи. Полягає у визначенні оптимальних взаємокореляційних властивостей для формування ансамблів складних сигналів великого об'єму із забезпеченням низького рівня завад множинного доступу.

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Метод. У роботі наведено результати дослідження взаємокореляційних властивостей ансамблів складних сигналів, отриманих за рахунок застосування методу перестановок відфільтрованих елементів. Формування ансамблів складних сигналів відбувається на основі псевдовипадкових послідовностей з покращеними взаємокореляційними властивостями в часовій області. До таких послідовностей застосовується смугова фільтрація, причому кількість смуг фільтрації визначається на основі розрахунку коефіцієнта використання частотного спектра. Визначення оптимальної ширини смуги фільтрації відбувається на основі порівняння значень максимальних викидів бічних пелюсток функції взаємної кореляції сигналів від кількості елементів у задіяних послідовностях. Сигнали, отримані за допомогою виділення смуг частот, характеризуються відмінністю за формою при виконанні умови мінімальної подоби. З метою зменшення впливу завад множинного доступу здійснюється частотний перенос складових, отриманих у результаті фільтрації спектру, до спільної області частот. Після цього виконується перестановка сигналів за допомогою методу повного перебору. У результаті отримуємо усі можливі комбінації перестановок пар сигналів. Застосування перестановок при формуванні ансамбля складних сигналів дозволяє значно збільшити об'єм ансамбля. Сигнали, сформовані за рахунок частотної фільтрації, до яких застосовувався перенос в спільну смугу частот та їх подальша перестановка, піддаються кореляційному аналізу на основі розрахунку значень максимальних викидів бічних пелюсток функції взаємної кореляції. Порівняльна характеристика взаємокореляційних властивостей розроблених сигналів з відомими сигналами доводить, що сигнали, сформовані на основі псевдовипадкових послідовностей з покращеними взаємокореляційними властивостями мають значно більший об'єм ансамблів, формуються на основі простих алгоритмів, що не потребують значних обчислювальних ресурсів та мають задовільні взаємокореляційні характеристики. Застосування методу смугової фільтрації з перестановками дозволяє формувати ансамблі великого об'єму, сигнали яких відрізняються за формою, а комбінування різних частотних діапазонів зменшує вразливість до завад множинного доступу.

Результати. Завдяки програмній реалізації методу смугової фільтрації з перестановками виконано порівняння взаємокореляційних властивостей нелінійних послідовностей, М-послідовностей, багатофазних сигналів та розроблених сигналів на основі послідовностей з покращеними взаємокореляційними властивостями.

При оцінці рівнів максимальних викидів бічних пелюсток функції взаємної кореляції виявлено, що у сформованих сигналів, отриманих шляхом смугової фільтрації з перестановками, погіршуються взаємокореляційні характеристики, за рахунок збільшення тривалості імпульсів пропорційної зменшенню смуги частот сигналу, але їхнє значення задовольняє умову мінімальної подоби і такі сигнали можуть застосовуватися в когнітивних телекомунікаційних системах.

Висновки. Виконане дослідження взаємокореляційних властивостей сигналів доводить ефективність розробленого методу смугової фільтрації з перестановками. Сформовані сигнали мають взаємокореляційні характеристики не гірші ніж ансамблі на основі відомих сигналів. При цьому рівні максимальних викидів бічних пелюсток функції взаємної кореляції розроблених сигналів на 7–12 % менше показників відомих сигналів. Таким чином метод смугової фільтрації з перестановками може бути застосований для підвищення ефективності використання радіочастотного ресурсу як існуючих, так і перспективних когнітивних телекомунікаційних мереж безпроводового доступу на основі систем з кодовим розділенням каналів.

КЛЮЧОВІ СЛОВА: складний сигнал, функція взаємної кореляції, завада множинного доступу, база сигналу, ширина спектру сигналу, смуга фільтрації, низька енергетична взаємодія, об'єм ансамблю.

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ИССЛЕДОВАНИЕ ВЗАИМОКОРРЕЛЯЦИОННЫХ СВОЙСТВ АНСАМБЛЕЙ СЛОЖНЫХ СИГНАЛОВ, ПОЛУЧЕННЫХ ПУТЕМ ПЕРЕСТАНОВОК ОТФИЛЬТРОВАННЫХ ЧАСТОТНЫХ ЭЛЕМЕНТОВ

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АННОТАЦИЯ

Актуальность. Заключается в исследовании взаимокорреляционных свойств разработанных ансамблей сложных сигналов большого объема с обеспечением низкого уровня помех множественного доступа, за счет чего возможно повышение эффективности использования ограниченного радиочастотного диапазона. Объектом исследования является метод полосовой фильтрации с перестановками, позволяющий формировать ансамбли сложных сигналов большого объема.

Цель работы. Состоит в определении оптимальных взаимокорреляционных свойств для формирования ансамблей сложных сигналов большого объема с обеспечением низкого уровня помех множественного доступа.

Метод. В работе приведены результаты исследования взаимокорреляционных свойств ансамблей сложных сигналов, полученных за счет метода полосовой фильтрации с перестановками. Формирование ансамблей сложных сигналов происходит на основе псевдослучайных последовательностей с улучшенными взаимокорреляционными свойствами во временной области. К таким последовательностям применяется полосовая фильтрация, причем количество полос фильтрации определяется на основе расчета коэффициента использования частотного спектра. Определение оптимальной ширины полосы фильтрации происходит на основе сравнения значений максимальных выбросов боковых лепестков функции взаимной корреляции сигналов от количества элементов в задействованных последовательностях. Сигналы, полученные посредством

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выделения полос частот, характеризуются отличием по форме при выполнении условия минимального подобия. С целью уменьшения влияния помех множественного доступа производится частотный перенос составляющих, полученных в результате фильтрации спектра, в общую область частот. Далее производится перестановка сигналов с помощью метода полного перебора. В результате получаем все возможные комбинации перестановок пар сигналов. Использование перестановок при формировании ансамбля сложных сигналов позволяет значительно увеличить объем ансамбля. Сигналы, сформированные за счет частотной фильтрации, к которым применялся перенос в общую полосу частот и последующая их перестановка, подвергаются корреляционному анализу на основе расчета значений максимальных выбросов боковых лепестков функции взаимной корреляции. Сравнительная характеристика взаимокорреляционных свойств разработанных сигналов с известными сигналами доказывает, что сигналы, сформированные на основе псевдослучайных последовательностей с улучшенными взаимокорреляционными свойствами, имеют значительно больший объем ансамблей, формируются на основе простых алгоритмов, не требующих значительных вычислительных ресурсов и обладают лучшими взаимокорреляционными свойствами. Применение метода полосовой фильтрации с перестановками позволяет формировать ансамбли большого объема, сигналы которых отличаются по форме, а комбинирование различных частотных диапазонов уменьшает уязвимость к помехам множественного доступа.

Результаты. Благодаря программной реализации метода полосовой фильтрации с перестановками выполнено сравнение взаимокорреляционных свойств нелинейных последовательностей, М последовательностей, многофазных сигналов и разработанных сигналов на основе последовательностей с улучшенными взаимокорреляционными свойствами.

При оценке уровней максимальных выбросов боковых лепестков функции взаимной корреляции обнаружено, что у сформированных сигналов, полученных путем полосовой фильтрации с перестановками, ухудшаются взаимокорреляционные свойства за счет увеличения длительности импульсов пропорциональной уменьшению полосы частот сигнала, но их значение удовлетворяет условию минимального подобия и такие сигналы могут использоваться в когнитивных телекоммуникационных системах.

Выводы. Проведенное исследование взаимокорреляционных свойств сигналов доказывает эффективность разработанного метода полосовой фильтрации с перестановками. Сформированные сигналы обладают взаимокорреляционными свойствами, которые не хуже, чем ансамбли на основе известных сигналов. При этом уровень максимальных выбросов боковых лепестков функции взаимной корреляции разработанных сигналов на 7–12% меньше показателей известных сигналов. Таким образом, метод полосовой фильтрации с перестановками может быть применен для повышения эффективности использования радиочастотного ресурса как существующих, так и перспективных когнитивных телекоммуникационных сетей на основе систем с кодовым разделением каналов.

КЛЮЧЕВЫЕ СЛОВА: сложный сигнал, функция взаимной корреляции, помеха множественного доступа, видеоимпульс, база сигнала, ширина спектра сигнала, полоса фильтрации, низкое энергетическое взаимодействие, объем ансамбля.

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