AEROSPACE SYSTEMS FOR MONITORING AND CONTROL

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METHOD FOR SELECTING THE OPTIMAL DURATION OF OFDM SYMBOLS PREFIX IN SATELLITE COMMUNICATION CHANNELS OF AIR NAVIGATION SYSTEM

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Abstract

To study the method of selecting the optimal duration of the prefix OFDM-symbols in satellite communication channels, the original model of the communication line "Aircraft satellite-ground station" was built. The adaptive modulation model consists of an information source, an aircraft transmitter, an uplink / downlink, a satellite transponder, and a ground station receiver. OFDM technology for combating the effects of multipath is considered. The method of combating intersymbol interference based on the use of OFDM technology has been improved.

Keywords: satellite communication, OFDM, cyclic prefix, OFDM symbol, multipath time

1. Indroduction

Aviation telecommunications is developing dynamically due to the development of communication characteristics and principles of signal processing in communication between satellite and aircraft. The use of satellite communications in aviation is associated with the ability to connect to a large number of aircraft regardless of distance, the independent cost of communication from the distance between aircraft, the small impact of the atmosphere and the location of ground stations on the reliability of communication.

The principle of operation of aviation satellite telecommunication systems is based on the use of satellite transponders, which are used to communicate between aircraft and ground stations.

Issues related to the operation of aviation satellite communications are very important. Even a small degradation of the parameters affects the data rate or coverage, which immediately affects flight safety and operating costs. It is important to know how to maintain optimal channel settings.

That is why it is important to develop real models of aviation satellite communication channels and to explore ways to correct channel parameters in critical situations.

2. Analysis of research and publications

Known methods of generating OFDM signals [1-4] allow signal modulation in modern radio systems. In these methods, to protect against the phenomenon of intersymbol interference, as noted earlier, uses a protective interval of constant duration *Tg*. However, the question of adaptively changing the duration of this prefix in the above methods was not considered.

3. The purpose of the work

The purpose of this work is: to develop a method of adaptive change of the duration of the cyclic prefix of OFDM symbols.

4. Orthogonal frequency division multiplexing (OFDM)

This type of multiplexing with orthogonal frequency division attracts more attention to satellite communication systems.

The transmission of information using OFDM signals has become the standard for many modern radio systems due to a number of advantages - high spectral efficiency, low inter-symbol interference, high quality transmission in frequency-selective attenuation. At the same time, OFDM systems are sensitive to carrier instability. It is especially important to ensure energy efficiency of information transmission in aviation complexes with strict limitation of space-frequency parameters for on-board electronic equipment.

In most cases, radio communication is conducted in the presence of direct visibility, but in the conditions of reflection and multipath propagation of radio waves. Under these conditions, there may be more than one way of propagating radio waves between a satellite and terrestrial mobile stations. Radio waves arrive at the point of reception as a result of repeated reflection from buildings and other objects. The route of radio waves is usually not stationary, which is associated with the movement of mobile stations and other moving objects, in addition, it can be very different within the service areas, which may cover large areas with different nature, terrain, atmospheric parameters etc. The propagation of radio waves in such conditions is characterized by the following main effects [5-7]: fading associated with multipath; shading (or shielding); time scattering; Doppler scattering and propagation losses.

In such channels, the signal at the receiving point is the sum of a large number of elementary signals with different amplitudes and random delay time [5]. Individual rays can be delayed relative to each other by a significant amount, which causes multiple-source interference (MSI). Depending on the degree of distortion of the pulse shape, there are large (Fig. 1) and small (Fig. 2) intersymbol interference.

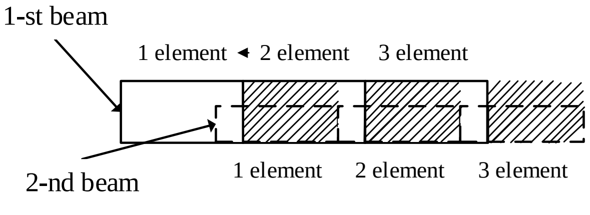

Fig.1. Large inter-character obstacles

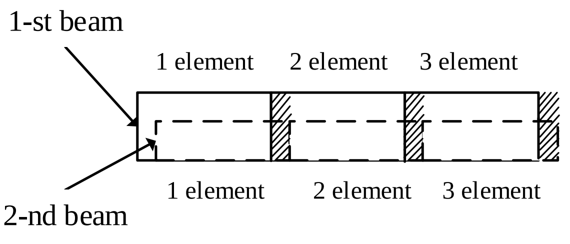

Fig.2. Small inter-character obstacles

This phenomenon is called time signal scattering.

The main characteristics of time scattering are the upper limit of time scattering and the root mean square value of time scattering.

The degree of distortion of the shape of the pulses when superimposing signals depends on the difference in the propagation time of radio waves in different ways. Usually the difference in propagation time along the maximum and minimum paths is called the multipath time (t_{mp}). For normal communication distances, the value is in the range of 0.2-0.5 μs. If the pulse duration (τ) is less than the multipath time, then there are large intersymbol interference. If the pulse duration is much longer than the multipath time, the intersymbol interference has little effect on the reception, because in this case only a small part of the element is affected by the interference.

In addition, as a result of repeated reflection of radio waves from different objects during the operation of the transmitter in the mode of continuous radiation, a complex interference pattern is created, which leads to signal fading [8, 9].

Freezing on the track can be divided into long-term (average) and short-term (fast). If we average the rapid fading associated with multipath, there remains nonselective shading. The reason for this phenomenon is the peculiarities of the terrain along the route of radio waves.

In real frequency-limited communication channels, intersymbol interference (ISI) is caused by channel memory [10]. The response of the channel to the sequence of input signals causes mutual overlap of signals at the output of the channel. If we normalize the power amplitude-frequency characteristic of the channel, we can say that the MSI leads to a significant change in the distances between the signals at the output of the channel and to a decrease in the minimum distance between them.

OFDM technology is used to deal with the problems outlined above.

OFDM (Orthogonal frequency-division multiplexing) – multiplexing with orthogonal frequency division multiplexing, is a digital modulation scheme that uses a large number of closely spaced orthogonal subcarriers. Each subcarrier is modulated by a conventional modulation scheme (e.g., quadrature amplitude modulation) at a low symbol rate, maintaining the overall data rate, as in conventional modulation schemes of one carrier in the same bandwidth. This method is quite effective in distributing a sequence of data symbols on a parallel stream with increasing duration of each symbol.

In OFDM, the data symbols $x_{m,k}$ in modern wireless networks are taken from the alphabets discussed below, the so-called *m* modulation schemes (m-position) Phase-Shift Keying (PSK), Binary Phase-Shift Keying (BPSK), Quadrature Amplitude Modulation (QAM-16), QAM-64, etc. [11]. These characters are transmitted sublime, spaced apart $\Delta f = \frac{1}{T_s}$ Hz, where is T_s – the duration of the symbol, which ensures their orthogonality in the rectangular shape of the modulating video pulses, despite the random phases due to data modulation. The choice of another form of envelope modulating video pulses makes it possible to obtain a more compact spectral power density, but causes a violation of the orthogonality of the sublime, and increase the probability of errors [10].

The principle of forming OFDM signals is as follows. The transmitted sequence of data characters $x_{m,k}$ is divided into blocks of *N* characters. Each block of *N* consecutive characters will be converted into a block of *N* parallel characters lasting each. The resulting symbols are modulated by *N* corresponding sublime frequencies.

The complex envelope of the OFDM signal at interval *T* can be represented in the form

$$s_m(t) = A \cdot \sum_{k=0}^{N-1} \left[x_{m,k} \cdot \exp\left\{ j \cdot \frac{2 \cdot \pi}{T} \cdot \left(k - \frac{N-1}{2} \right) \cdot t \right\} \right]$$

where: m – the number of the data block;
A – amplitude;

$f_k = f_0 + \frac{k}{T}$ – elevated frequency.

5. Adaptive change of duration of cyclic prefix of OFDM symbols

In wireless systems, the duration of the protection interval can usually be 1/4, 1/8, 1/16 or 1/32 of the duration of the OFDM symbol *Ts* [12].

This duration is determined by the equipment manufacturer and is constant throughout the life of the system using OFDM technology. However, the rays of the radio signal can go quite a different way, so they can be significantly delayed and overlap. The multipath time t_{mp} in this case depends on the lengths traveled by each beam of the radio signal separately. The duration of the guard interval T_g must be chosen from the condition $T_g > t_{mp}$, but must be as short as possible to increase the effective bandwidth of channels using OFDM.

It should be noted that the proposed methods do not allow to adaptively change the duration of the protection interval. This does not allow full use of OFDM channel bandwidth, while eliminating the effect of intersymbol interference. Therefore, the task of the method of adaptive change of the duration of the cyclic prefix is to eliminate the disadvantage, which does not allow to adaptively adapt to external conditions, changing the duration of the cyclic shift. This will allow more efficient use of channel bandwidth using OFDM signals.

In fig. Figure 3 illustrates the dependence of the multipath time t_{mp} on the difference between the distances between the direct and reflected rays on the logarithmic scale.

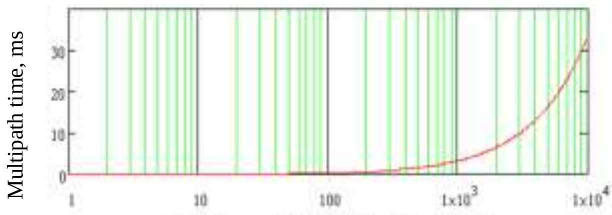

Fig. 3. The dependence of the multipath time on the difference between the distances between direct and reflected rays

Analyzing Fig.3, we can roughly understand what should be the value of the cyclic prefix for different distances between direct and reflected rays.

By choosing the duration of the cyclic prefix from the condition *Cyclic Prefix Duration* > *Multipath Time* (it should be greater than the maximum delay of radio signal propagation), it is possible to avoid the mutual influence of adjacent symbols of adjacent frequencies. The use of a cyclic prefix allows you to eliminate both multichannel noise and MSI (because the prefix is both a protective interval).

Preventing the occurrence of MSI and multichannel noise, the cyclic prefix is one of the ways to increase the noise immunity of the connection through the use of temporal redundancy.

Thus, the useful length of the symbol (T_u) s inversely proportional to the diversity of the elevated Δf. Then the length of the cyclic prefix is equal to ($T_g = G * T_u$), where G is the ratio (T_g/T_u). The selection of G is made according to the parameters of the channel. The total length of the OFDM symbol consists of the useful symbol length and the length of the cyclic prefix ($T_{OFDM} = T_g + T_u$).

The main goal of the communication system is to achieve high data rates with minimal Bit Error Rate (BER). The maximum data rate can be written as:

$$R = \frac{N_{data} \times b}{T_g + T_u} \quad , \qquad (1)$$

where, b - the number of bits per symbol based on the modulation scheme used. Obviously, changing the length of the cyclic prefix from 3% of the symbol length to 25%, significantly reduces the amount of information transmitted. As the length of the cyclic prefix increases to overcome intersymbol interference and inter-channel interference, this reduces the overall energy efficiency. The signal-to-noise ratio lost on the transmitter side can be specified as follows:

$$SNR_{loss} = -10 \log_{10} \left(1 - \frac{Tg}{Tof\,dm}\right). \qquad (2)$$

On the receiver side, the receiver energy does not change as a result of deleting the cyclic prefix. Minimizing power loss is very important because the mobile terminal must run on battery power. Because the useful length of OFDM is fixed, minimizing power loss can be accomplished by changing the length of the cyclic prefix.

Thus, as is known on the receiving side, the level of the received signal must be not less than the sensitivity of the receiver.

In this case, taking into account the signal-to-noise ratio lost on the transmitter side, the expression for the sensitivity of the receiver can be written as follows:

$$P_{sens} \geq P_{tr} - PL - SNR_{loss} \,. \qquad (3)$$

Then:

$$SNR_{loss} \geq P_{tr} - PL - P_{sens} \,. \qquad (4)$$

Substitute in this expression the relationship (1.2 and 1.4):

$$-10 \log_{10}\left(1 - \frac{Tg}{Tofdm}\right) \geq P_{tr} - PL - P_{sens} \qquad (5)$$

So:

$$\left(1 - \frac{Tg}{Tofdm}\right) \geq 10^{-\frac{(P_{tr} - PL - P_{sens})}{10}} \,,$$

$$\frac{Tg}{Tofdm} \leq -10^{-\frac{(P_{\mathrm{tr}} - PL - P_{\mathrm{sens}})}{10}} + 1 \qquad (6)$$

Substitute expression (1.6) and obtain:

$$\frac{Tg}{Tg + Tu} \leq -10^{-\frac{(P_{\mathrm{tr}} - PL - P_{\mathrm{sens}})}{10}} + 1,$$

$$\frac{G \cdot Tu}{G \cdot Tu + Tu} \leq -10^{-\frac{(P_{\mathrm{tr}} - PL - P_{\mathrm{sens}})}{10}} + 1. \qquad (7)$$

Thus, the value of the cyclic prefix must meet the following condition:

$$G \leq \frac{-\left(1 + 10^{-\frac{(P_{\mathrm{tr}} - PL - P_{\mathrm{sens}})}{10}}\right)}{10^{-\frac{(P_{\mathrm{tr}} - PL - P_{\mathrm{sens}})}{10}}}. \qquad (8)$$

Since the following cyclic prefix durations are possible in satellite communication technologies: $T_g = 1/4T_s, 1/8T_s, 1/16T_s, 1/32T_s$ (Ts - duration of OFDM symbol without cyclic prefix), this causes a decrease in the effective transmission rate data $T_s/(T_s - T_g)$: 1,33; 1,142; 1,07; 1,032 for each duration of the cyclic prefix, respectively.

In this situation, in order to prevent a significant reduction in the data rate over the network, it is necessary to choose the optimal duration of the cyclic prefix to provide subscribers with the fastest access to network resources depending on specific communication conditions (distance between transmitter and receiver, number and nature of interference radio signal, etc.).

The multipath time depends on the lengths traveled by each beam of the radio signal separately. The length of the route covered by each radio signal can be determined by the following formula:

$$d = \sqrt{\frac{P_T \cdot \lambda^2}{4 \cdot \pi \cdot p(d)}} \,.$$

Since there is information on the receiving side about the power emitted by the transmitter antenna and the ability to measure the power of the received signal, you can find the distance from the transmitter to the receiver, which was covered by each individual ray:

$$d_i = \sqrt{\frac{P_T \cdot \lambda^2}{4 \cdot \pi \cdot p(d_i)}}.$$

Then you need to find the minimum and maximum values of distances d. Finding their difference, you can determine the largest difference in the path length of electromagnetic waves. Knowing this information, you can determine the time of multipath:

$$t_{бп} = \frac{d_{\max} - d_{\min}}{c} \,,$$

where *c* is the speed of light in vacuum.

Thus, this algorithm [13, 14] allows you to change the duration of the cyclic prefix OFDM symbol, as close as possible to it defined in the previous step of the multipath time.

Based on the developed model, it is possible to develop an algorithm for adaptive change of the cyclic prefix OFDM symbol, which will maximize the useful bandwidth of channels, while providing adequate protection against intersymbol and inter-channel interference.

Fig. 4 presents an algorithm for changing the duration of the cyclic prefix for a specific example, in particular, for satellite communication systems [15].

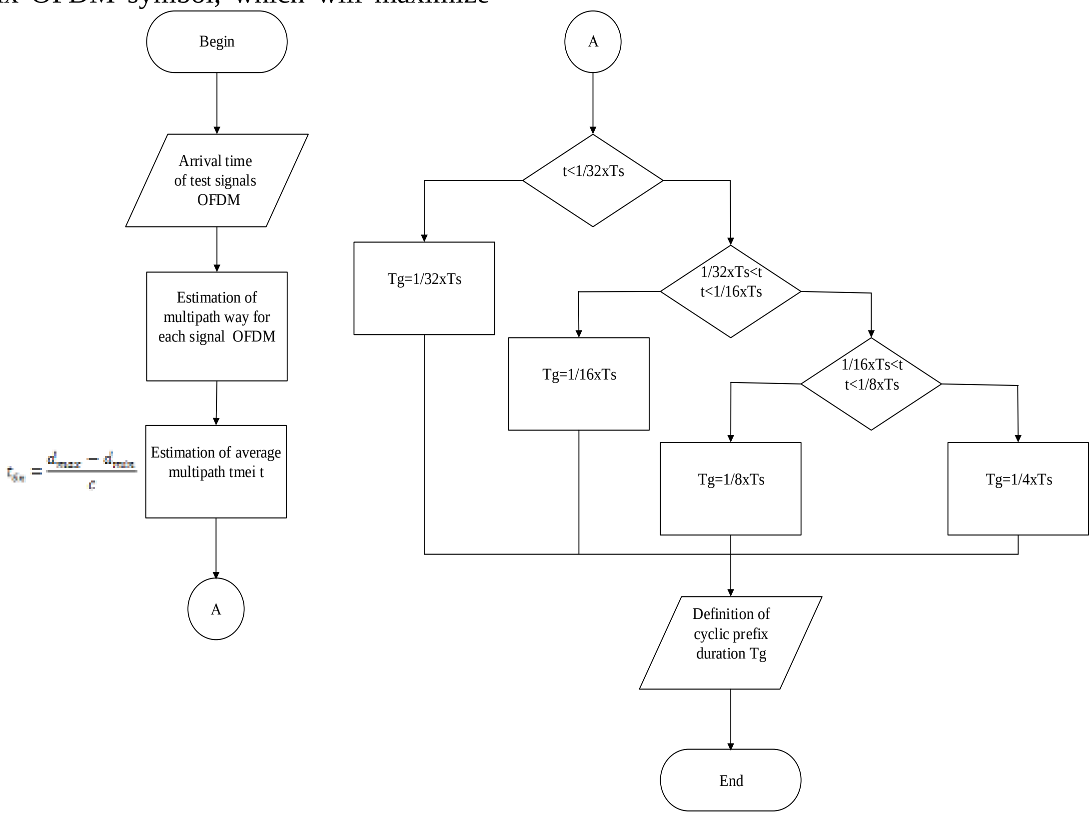

Fig. 4. Block diagram of the algorithm for adaptive change of the cyclic prefix OFDM symbol in the satellite communication channel

Not all steps are detailed, they indicate more the order of action when determining the optimal value of the duration of the cyclic prefix.

6. Conclusions

Effective use of anti-character interference techniques can increase the bandwidth of satellite communication channels. Therefore, OFDM technology to combat the effects of multipath was considered in this paper.

As a result of the research, the following results were obtained. In particular, the method of combating intersymbol interference based on the use of OFDM technology has been improved. An algorithm has been proposed that allows using statistical analysis of the data collected by the mobile station on the power of the received signals to determine the optimal duration of the cyclic prefix OFDM symbols.

The proposed method allows you to choose the shortest prefix that will provide the maximum allowable effective data rate at a given level of service quality.

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Метод вибору оптимальної тривалості префіксу OFDM символів в супутникових каналах зв'язку аеронавігаційної системи

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Для дослідження методу вибору оптимальної тривалості префіксу OFDM-символів в супутникових каналах зв’язку була побудована оригінальна модель лінії зв'язку «Літак-супутник-наземна станція» за допомогою програмного забезпечення MATLAB Simulink. Модель з адаптивною модуляцією складається з джерела інформації, літального передавача, висхідної / низхідної лінії зв'язку, супутникового транспондера та приймача наземної станції. Розглянуто технологію OFDM для боротьби із наслідками багатопроменевості. Удосконалено метод боротьби із міжсимвольною інтерференцією на основі використання технології OFDM.

Ключові слова: супутниковий зв'язок, OFDM, циклічний префікс, символ OFDM, час багатопроменевості

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Метод выбора оптимальной продолжительности префикса OFDM символов в спутниковых каналах связи аэронавигационной системы

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Для исследования метода выбора оптимальной продолжительности префикса OFDM-символов в спутниковых каналах связи была построена оригинальная модель линии связи «Самолет-спутник-наземная станция» с помощью программного обеспечения MATLAB Simulink. Модель с адаптивной модуляцией состоит из источника информации, летательного передатчика, восходящей / нисходящей линии связи, спутникового транспондера и приемника наземной станции. Рассмотрена технология OFDM для борьбы с последствиями многолучевости. Усовершенствован метод борьбы с Межсимвольные интерференцией на основе использования технологии OFDM.

Ключевые слова: спутниковая связь, OFDM, циклический префикс, символ OFDM, время многолучевости

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