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Investigation of the peculiarities of radio wave propagation in aeronautical satellite channels

The general establishments of radio wave propagation in aeronautical satellite channels are considered. The principle of operation of aviation satellite systems is offered. Mathematical models are also given.

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 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.

Orthogonal frequency division multiplexing (OFDM) attracts more attention to satellite communication systems. 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 level of intersymbol interference, high quality transmission in frequency-selective attenuation. At the same time, OFDM systems are sensitive to carrier frequency 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. However, issues related to the estimation of OFDM satellite channel parameters have not yet been studied in detail.

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 [1-3]: fading associated with multipath; shading (or shielding); time scattering; Doppler scattering and propagation losses. Fig. 1. illustrates the multi-beam nature of the propagation of radio waves between base and mobile stations.

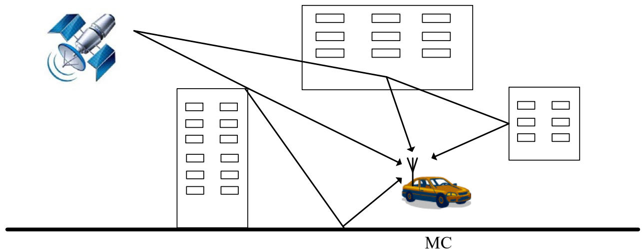

Fig. 1. The multibeam nature of the propagation of radio waves between satellite and mobile stations

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 [1]. Individual rays can be delayed relative to each other by a significant amount, which causes MSI (intersymbol interference). Depending on the degree of distortion of the pulse shape, there are large (Fig. 2) and small (Fig. 3) intersymbol interference.

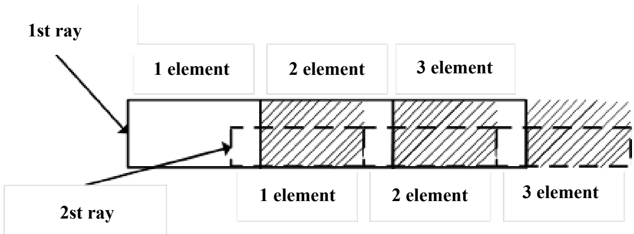

Fig.2. Large inter-character obstacles

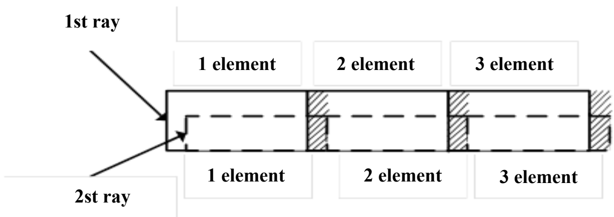

Fig. 3. Small intersymbol obstacles

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 *($t_{бn}$)*. 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 large intersymbol interference occurs. If the pulse duration far exceeds the multipath time, then 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 [4, 5].

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 [6]. 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.

In the synthesis of signals and codes for channels with MSI, this effect is usually not taken into account, ie as input signals are selected those that are consistent with the ideal channel without MSI. However, MSI tend to take into account in the synthesis of the optimal receiver (decoder). A well-known solution of this kind is the Viterbi algorithm and its modification that takes into account convolutional coding [6, 7].

A wide class of real channels can be represented as a linear model consisting of a linear filter and an adder with additive noise [6]. The input and output of such a channel are associated with the expression:

$$\bar{Z}(t) = \int_0^\infty h(\tau) \cdot Z(t-\tau) d\tau + \gamma(t) \tag{1}$$

where $h(\tau)$ – the impulse response of the channel (response to δ - function);

$\gamma(t)$ - additive noise.

Additive noise and input signal *Z(t)* are generally complex.

If the power of the additive white Gaussian noise at the output of the Gaussian channel from the MSI is $\sigma_{ш}^2$, and the average signal power at its input is limited to the value P_1, the bandwidth of the Gaussian channel from the MSI with the channel matrix K_{km}, the singular values of which $\rho_0 \geq \rho_1 \geq \ldots \geq \rho_{N-1} \geq 0$, is equal to [6]:

$$C = \rho_0 \cdot \frac{1}{N} \cdot \sum_{i=0}^{M} \frac{1}{2} \cdot \log_2 \left[\rho_i \cdot \frac{N}{M} \cdot \left(\frac{P_1}{\sigma_ш^2} \cdot \frac{1}{\rho_0} + \frac{1}{N} \cdot \sum_{\rho=0}^{M} \frac{1}{\rho_\rho} \right) \right] \quad (2)$$

where $M \le N+1$ – the largest number for which the following equation holds:

The latter expression makes it possible to estimate the bandwidth of channels with intersymbol interference, but does not contain any information about the properties of the channel, except for noise and signal power, the channel matrix. Therefore, it is important to develop a model that would help to comprehensively assess the state of the satellite channel between the transmitter and receiver of the radio signal.

Thus, in modern satellite communication systems, significant signal fading and distortion can occur. This can have negative consequences associated with reduced data transfer speeds, disconnections, and poor service delivery.

Thus, summarizing the above, we can say that the process of implementing satellite communication technologies for the CNS/ATM system in Ukraine and around the world is rapidly evolving, but still there are many problems associated with the planning of radio access networks. This is due to the complex nature of radio wave propagation, the high demands placed on the quality of service and the speed of data transmission.

The complexity of planning satellite channels is greatly influenced by the complex multi-beam nature of the propagation of radio waves in the event of possible interference and fading. The developed mathematical models allow to estimate a condition of such channels, definition of their basic characteristics, throughput. However, they do not allow a comprehensive assessment of the parameters of the satellite communication channel, taking into account a large number of external factors that may affect it.

OFDM systems are used to combat the phenomena of intersymbol interference and increase the bandwidth in the channels of satellite communication systems. Within the use of these technologies there are a number of unsolved problems. For OFDM, the question of determining the optimal duration of the cyclic prefix for OFDM symbols is unresolved, which does not always allow to maintain the maximum effective data rate at a given probability of bit errors.

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