Increasing the efficiency of satellite communication channels when outputting moving objects into the terminal space

V Kharchenko[1], I Ali[1,3], R Odarchenko[1] and T Dyka[1]

[1] Department of Air navigation, National Aviation University, 1 Liubomyra Huzara ave., Kyiv 03058, Ukraine
[2] Department Telecommunication systems, National Aviation University, 1 Liubomyra Huzara ave., Kyiv 03058, Ukraine

[3] E-mail: ismail.pilot1981@gmail.com

Abstract. Aviation telecommunications is developing dynamically to develop the characteristics of communication and the principles of signal blocks 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, independent communication costs from the distance between aircraft, low influential atmospheres and the location of ground states on the reliability of communication. In this, a significant influence on the data transmission process in satellite air navigation channels is the propagation of radio waves, as well as the multi-beam nature of propagation. Orthogonal frequency division multiplexing (OFDM) technology is widely used to combat the phenomenon of intersymbol interference. To use this technology, it was found that reduces the power of the radio signal, creates influential weather conditions, introduces cyclic prefixes to OFDM signals, which can mean a measure of the bandwidth of communication channels. Therefore, it was proposed to improve the method of changing the radiated power of radio transmitting devices by controlling the loss of radio signal power due to adverse weather conditions and other parameters of the radio propagation path, which may allow a practically unique necessary reduction in data rate to artificial satellites of the Earth and to avoid resolving communication interruptions for critical air navigation communications.

1. Introduction

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.

At the same time, a significant role in advanced air traffic control (ATS) systems is assigned to satellite communication technologies [1]. There are high requirements for the use of these systems in civil aviation, quality of operation and, in particular, to such characteristics as communication reliability, efficiency, stability and reliability of the transmitted information. These systems use modern methods of data transmission, but they are not without drawbacks.

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 speed of data transfer 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. 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 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.

Also, during the operation of modern satellite communication channels, there may be problems with data transmission related to the level of radio signal power on the receiving side. Since the operation of radio channels is always affected by different types of fading, which is a major obstacle to quality and reliable transmission of radio signals, it is necessary to take into account the constant impact of these different types of fading, which can be caused by hydrometeors, atmospheric gas attenuation and more.

2. Literature review and problem statement

One of the effective methods of combating fading, from the point of view of the theory of automatic control, is the feedback method [2, 3] to ensure the regulation of the radio signal power emitted by the transmitters.

In addition, the known methods of organization of radio networks [4-5] and methods of regulating the radiated power of radio transmitting devices [6-11] involve changing the power of transmitters of satellite stations and ground stations, depending on the measured level of the received radio signal. It is then decided to increase or decrease the radiated power of the radio transmitters to the level required for quality communication. The quality of communication is strongly influenced by the multi-beam nature of radio propagation. Therefore, with a slight change in the location of the earth station or aircraft, the signal level may decrease significantly. There may even be a disconnection.

An important role in the process of regulating the power of radio transmitting devices is played by the sensitivity of the receivers, the power of the transmitters, the distance between the transmitter and the receiver, the number and nature of interference, the relief of the underlying surface. The quality of communication depends on the signal-to-noise ratio at the input of the receiving devices, which decreases due to the propagation of the radio signal over a distance, absorption by atmospheric gases, hydrometeors, etc.

In [12] it was shown that the data rate in wireless networks largely depends on meteorological conditions, so it is necessary to develop algorithms that would keep the data rate at a constant level, despite changing weather conditions.

3. The aim and objectives of research

Existing algorithms for regulating the power of transmitters of radio transmitting devices make it possible to increase the radiated power to the level required for a quality communication session by measuring the power level of the radio signal. However, there may be a situation where the signal level may fall sharply below the allowable level, which will cause the radio to break (for example, when exposed to heavy rain, fog, snow, smog, etc.). In this case, it will no longer be possible to exchange control or useful information between transmitting and receiving devices.

When the radio signal strength drops due to meteorological conditions (eg temperature rise, absorption in atmospheric gases, hydrometeors, fog), significant data rate losses may occur, which may not meet the requirements for satellite data systems, especially for aviation.

Thus, the main task to be solved by the proposed method is the adaptive control of the power of the transmitting devices of satellite communication systems, depending on meteorological conditions, which should allow to ensure high quality communication in different meteorological conditions.

4. The method of tandem propeller hub losses reduction

It is proposed to solve the problem by the fact that power management must be carried out depending on meteorological conditions. This can keep the quality of communication at the proper level, even in difficult weather conditions.

In the course of the research a method of power regulation of radio transmitting devices of satellite communication systems was developed. The proposed method requires current data on the state of the atmosphere. These data should include information on the deviation of climatic conditions from normal (ambient temperature: $+20^0$ +/- 5 ^{0}C; relative humidity: 60+/-15%; atmospheric pressure: from 84 kPa to 107 kPa). In particular, it is necessary to obtain information about the ambient temperature, humidity, characteristics and amount of precipitation (rain, snow, their intensity), the presence of fog (its characteristics). It is first necessary to set the initial level of radiated power of radio transmitters $P_{прд0}$ (in dB or dBm) under certain initial conditions (for example, at temperature +20 ^{0}C, relative humidity 60+/-15 %, за absence of hydro meteors). This level of radiation power is taken as the reference, in relation to which there will be a change in the power level of transmitting devices by the value ΔP, depending on the current state of the atmospheric layers. This information is processed using specialized software (SSW) in the control center of the satellite communication system. With the help of SDR, a decision is made on the need to increase or decrease the radiated power of radio transmission devices of satellite communication systems.

It is proposed that the magnitude of the change in the power level of radio transmitting devices of satellite communication systems ΔP will include power to compensate for attenuation from hydrometeors $\Delta P_{гм}$, for compensation of radio signal attenuation in atmospheric gases ΔR_{ag}, for temperature compensation $\Delta P_{тк}$, to compensate for attenuation in the fog ΔP_{fog}.

First, with the help of telemetry sensors it is necessary to establish the presence of hydrometeors, fog. If they are present, the level of their running compensation is calculated using (1).

Fig. 1 illustrates the dependence of linear attenuation by water droplets at different temperatures depending on the frequency. The attenuation is quite significant at frequencies above 5 GHz. Thus, the signals transmitted in satellite communication systems can be significantly attenuated.

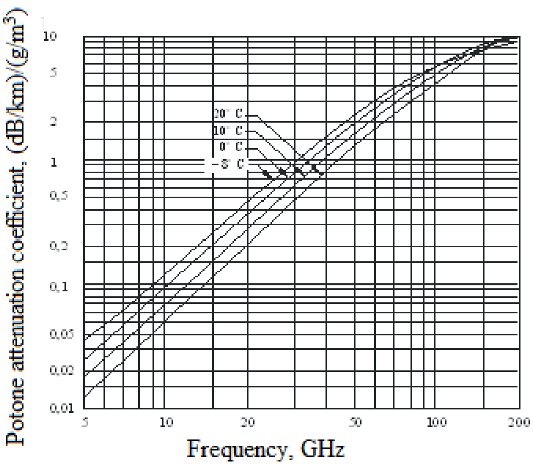


Figure 1. Dependence of linear attenuation by water droplets at different temperatures depending on frequency [16]

To estimate the power loss of the radio signal caused by the presence of hydrometeors, we use the mathematical model below.

In fig. 2 illustrates the dependence of linear attenuation in hydrometeors depending on the frequency of the radio signal for different values of precipitation intensity.

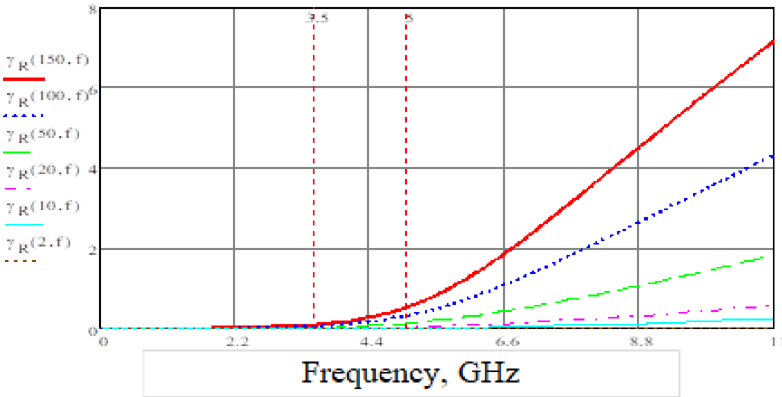


Figure 2. Dependence of linear attenuation in hydro meteors depending on the frequency of the radio signal.

Then you can determine the full level of power compensation:

- for fog:

$$\Delta P_{fog} = g_c \cdot l_{eff}, \quad (1)$$

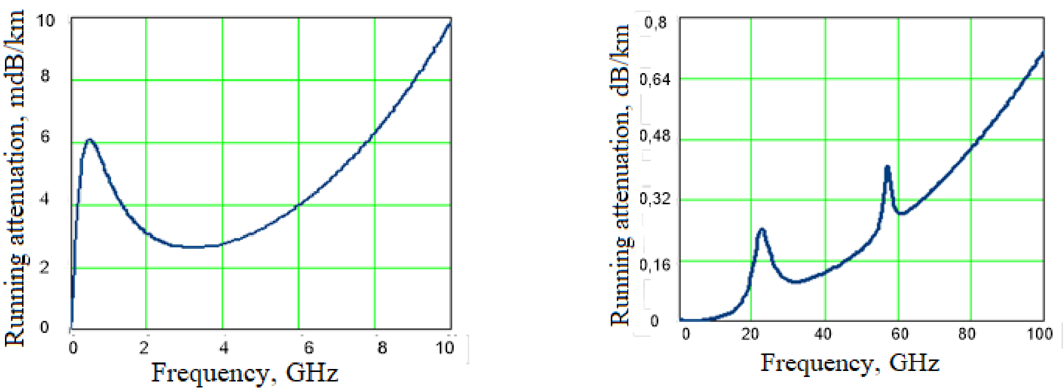
- for hydrometeors:

$$\Delta P_{gm} = \gamma_R \cdot l_{eff} \quad (2)$$

If hydrometeors or fog are absent, the level of compensation is taken equal to 0, that is $\Delta P_{fog} = 0$ and/or $\Delta P_{gm} = 0$.

Then, the value of the attenuation of radio waves caused by their molecular absorption in the gases of the atmosphere in the range of the radio line, which is equivalent, is calculated using the SDR [16].

In fig. Figure 3 illustrates the dependence of linear attenuation in atmospheric gases on the frequency of the radio signal in the range from 0 to 10 GHz (Fig. 3 (a)) and from 0 to 100 GHz (Fig. 3 (b)).



(a) (b)

Figure 3. Dependence of linear attenuation in atmospheric gases on the frequency of the radio signal in the range from 0 to 10 GHz (a) and from 0 to 100 GHz (b)

In expressions (1) and (2) $R_0 = l_{eff}$. In expressions (1) and (2) l_{eff} – this is the effective length of the signal propagation path. For satellite communication systems, the l_{eff} is defined as follows.

Snellius' law is used to calculate the length of the route section in each specific layer. To simplify, track connection appears as a ray that is refracted at the interface layers (Fig. 4).

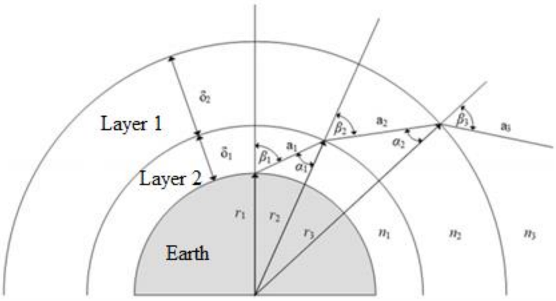


Figure 4. The route that passes through the atmosphere

The beginning of the beam lies in the first layer, in which it deviates from the normal by an angle β1 - the angle of incidence on the earth station, which is a complement to the angle of the place φ. In this layer, the beam travels its path a_1 and falls on the next layer at an angle of incidence α_1, refracts and overcomes the boundary of the section, deviating from the normal angle of exit β_2. This sequence is repeated for each layer.

Accordingly, the length of the route in the i-th layer is determined by the following expression [13]:

$$a_i = -r_i \cos\beta_i + \frac{1}{2}\sqrt{4r_i^2\cos^2\beta_i + 8r_i\delta_i + 4\delta_i^2}$$

where r_i is radius from the center of the Earth to the beginning of the layer i; δ_i is the thickness of this layer.

Angle of incidence on the layer [13]:

$$a_i = \pi - \arccos\left(\frac{-a_i^2 - 2r_i\delta_i - \delta_i^2}{2a_ir_i + 2a_i\delta_i}\right)$$

The exit angle in the next layer is expressed by Snell's law as [13]:

$$\beta_{i+2} = \arcsin\left(\frac{n_i}{n_{i+1}}\sin(\alpha_i)\right)$$

where n_i, n_{i+1} are refractive indices.

Thus, the total attenuation on the route is equal to the sum of attenuations in all layers passed by the radio signal:

$$A = \sum_i a_i y_i, dB$$

where γ_i - running attenuation of the i-th layer, calculated by the formulas above.

The effect of hydrometeors is noticeable at frequencies above 8 GHz, and in adverse environmental conditions (in the presence of metallized dust, smog, acids or alkalis in precipitation) and at much lower frequencies. At these frequencies, the attenuation in hydrometeors can be up to 10 dB [14].

Then using the SDR calculate the amount of temperature compensation by the formula:

$$\Delta P_{тк} = 10 \cdot lg(kTR) \text{ (dB)}, \quad (3)$$

where $k = 1{,}38 \cdot 10^{-23}$ J / k is became Boltzmann;
T is absolute temperature (K);
R is the required data rate in the cellular network (bps).

The magnitude of the change in the power level of the radio transmitting devices of the satellite communication systems is then determined ΔP:

$$\Delta P = \Delta P_{tc} + \Delta P_{fog} + \Delta P_{gm} + \Delta P_{ag}. \quad (4)$$

Thus in (4) terms $\Delta P_{fog}, \Delta P_{gm}, \Delta P_{ag} \geq 0$; ΔP_{tc} can be either added or negative. That is, according to the last parameter, the radiated power can both increase and decrease.

After the calculations ΔP decide to change the power of transmitters of satellite communication systems by exactly the amount ΔP. Then the satellite generates a control message, which transmits recommendations for changing the power of transmitters of earth stations or aircraft by the amount ΔP. The block diagram of the developed system of regulation of radiated power of radio transmitting devices of satellite communication networks depending on meteorological conditions is presented in fig. 5.

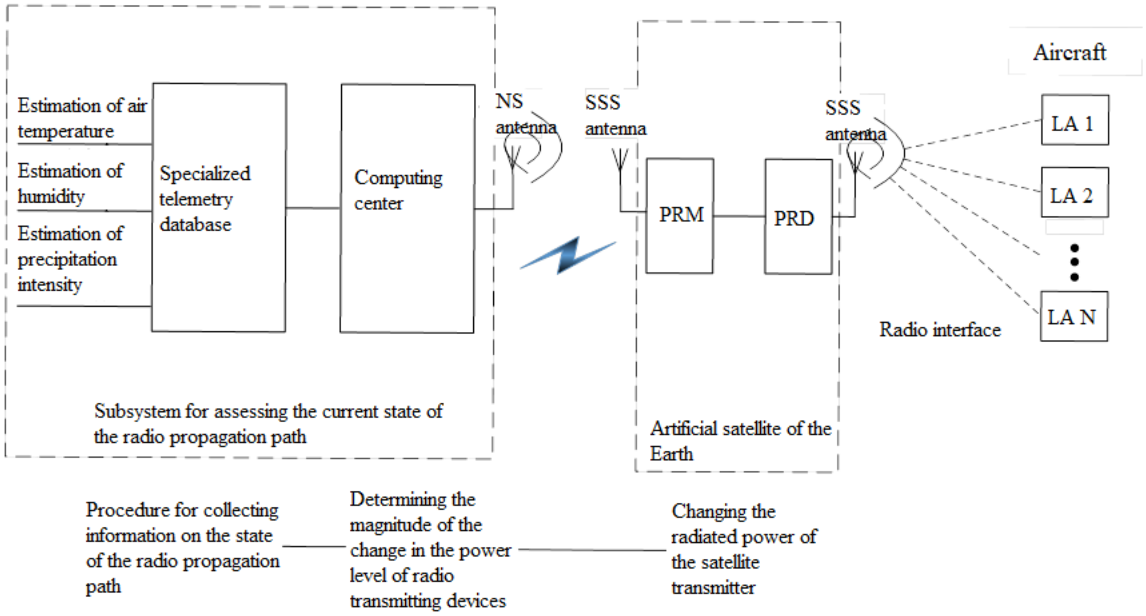


Figure 5. Block diagram of the system of regulation of radiated power of radio transmitting devices of satellite communication systems depending on meteorological conditions

Conclusions

1. The process of implementing satellite communication technologies for the CNS / ATM system in Ukraine, as well as in the world, is developing rapidly, but there are still 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.

2. The complexity of planning satellite channels is greatly influenced by the complex multi-beam nature of radio wave propagation under possible interference and fading. The developed mathematical models allow to carry out an estimation of 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.

3. To combat the negative phenomenon of radio signal attenuation due to atmospheric influences, an algorithm has been developed to regulate the radiated power of radio transmitting devices of satellite communication systems depending on the state of the radio propagation path. This algorithm allows to maintain a constant data rate in the satellite communication system, while ensuring the allowable probability of bit error and maintaining the required signal-to-noise ratio on the receiving side. This makes it possible to provide high quality communication without increasing the negative effects of electromagnetic radiation from satellite systems, as the increased power only compensates for the decrease in radio signal power under the influence of weather conditions.

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