AEROSPACE SYSTEMS FOR MONITORING AND CONTROL

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EFFECTS OF RICIAN FADING ON THE OPERATION OF AERONAUTICAL SATELLITE OFDM CHANNEL

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Abstract

Purpose: *The aim of this study is to investigate the influence of Rician fading on messages transmission via the aeronautical satellite OFDM channel with adaptive modulation and the development of a method for estimating the parameters of such a channel.* ***Methods:*** *To study the effect of Rician fading on messages transmission via aeronautical satellite OFDM channel with adaptive modulation the original model of the communication channel "Aircraft-Satellite-Ground Station" was built using software package MATLAB Simulink. The model includes "Aircraft Transmitter", "Uplink/Downlink Path", "Satellite Transponder", and "Ground Station Receiver". Each modulator block in the modulation bank performs convolutional coding and puncturing using code rates of ½, ²/3, and ¾, data interleaving, BPSK, QPSK, 16-QAM, and 64-QAM modulation.* ***Results:*** *Dependences of Estimated channel SNR on the ratio between the power of the LOS component and the diffuse component, on the downlink gain and delay in the diffuse component for different Doppler spectrum types and Doppler frequency offsets were obtained. A method for estimating the parameters of the satellite channels with fading was proposed.* ***Discussion:*** *The realistic model of aeronautical satellite OFDM link with Rician fading is developed for the first time on a basis of IEEE 802.11a standard and used for channel parameters evaluation. Proposed in this article approach can be considered as a method for estimating parameters of the channel with fading.*

Keywords: adaptive modulation; convolutional coding; Doppler frequency offset; Doppler spectrum type; free space loss; Rician fading; satellite communication OFDM channel; satellite transponder.

1. Introduction

It is expected that the number of satellite broadband subscribers worldwide will grow to about 6 million in 2020.

Fading due to multipath propagation may distort and attenuate received signals on line-of-sight (LOS) paths and thereby impair the performance of aeronautical radio systems [1, 2]. Multipath fading is the dominant propagation factor for digital radio-relay systems operating at frequencies below about 10 GHz.

Satellite communication channels are random and time-variant. The wireless multi-path channel causes in the received signal arbitrary time dispersion, attenuation, and phase shift, known as fading. Fading is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times [3].

In a mobile satellite link (mobile airborne station to a satellite and a satellite to a ground station) signal attenuation is mainly due to the free space loss, shadowing and multipath propagation. A channel model which outputs signal attenuation due to clouds and precipitation as a function of time was presented in a paper [4].

2. Analysis of the latest research and publications

A modeling method of the fade duration caused by multipath propagation on a land mobile satellite channel was proposed [5]. The model is based on the measurement of a satellite channel and applied to calculate the model parameters. The dependency of the model parameters on the attenuation threshold

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was obtained and the fade duration distribution for any threshold was calculated.

The performance analysis of QAM and QPSK modulation techniques when the system is subjected to Additive White Gaussian Noise (AWGN) and multipath Rayleigh fading were considered in a paper [6]. The research has been performed by using MATLAB for simulation and evaluation of Bit Error Rate (BER) and Signal-To-Noise Ratio (SNR) for W-CDMA system models.

A wireless communication MATLAB simulator was used for investigation Gray coding, modulation, different channel models (AWGN, flat fading and frequency selective fading channels), channel estimation, adaptive equalization, and demodulation [7].

Comparison of Rayleigh Fading, Rician Fading and AWGN Channel using Chaotic Communication based on Multiple-Input Multiple-Output (MIMO) - Orthogonal Frequency Division Multiplexing (OFDM) System was provided [8].

A user interface was designed using MATAB [9] for analysis the performance of OFDM system in terms of SNR vs. BER variation. Rayleigh Fading channel and Multipath fading channels were considered as a communication channel with BPSK, QPSK and QAM modulations.

Modern mobile satellite telecommunication technologies combine the spatial diversity and OFDM [10, 11].

OFDM technology is specifically designed to deal with interference of multipath reception. In OFDM technology serial data stream is converted to a large number of parallel streams (sub-carriers), each of which is transferred on a separate carrier [12]. Due to the orthogonal demodulation method of subcarriers the compensation of interference from adjacent frequencies takes place, despite the fact that their sidebands are overlapping [13].

Methods of predicting the effects of multipath fading on the error performance of a radio system are needed for link planning or for comparing alternative designs [1].

Effects of the Rayleigh fading on OFDM communication channel "Aircraft-Satellite-Ground Station" with the adaptive modulation was studied in our paper [14].

3. Research tasks

The aim of this study is to investigate the influence of Rician fading on messages transmission via the aeronautical satellite OFDM channel with adaptive modulation and the development of a method for estimating the parameters of such a channel.

4. "Aircraft-Satellite-Ground Station" Channel

For aeronautical satellite communication link the original model was built using the IEEE 802.11a standard [15] and the software package MATLAB Simulink.

The model (Fig. 1) consists of the "Aircraft Transmitter" (Variable-Rate Data Source, Modulator Bank, OFDM Transmitter, Transmitter Dish Antenna Gain), the "Uplink Path" (Free Space Path Loss, Phase/Frequency Offset), the "Satellite Transponder" (Receiver Dish Antenna Gain, Complex Baseband Amplifier, Phase/Frequency Offset, Transmitter Dish Antenna Gain), the "Downlink Path" (Additive White Gaussian Noise and multipath Rician fading), the "Ground Station Receiver" (Receiver Dish Antenna Gain, Receiver Noise Temperature, OFDM Receiver, Demodulator Bank), the "Packet Error Rate Calculation block", the "SNR Estimation", and the "Adaptive Modulation Control". The following operations are performed in the "Aircraft Transmitter": the generation of data with a certain bit rate that varies during the simulation; coding, interleaving, and modulation using one of the mentioned above eight modulation schemes used in the standard; OFDM signals transmission using 52 subcarriers, 4 pilot sequences, 64-point fast Fourier transform and the 16-membered cyclic prefix; using four long training sequence in the physical layer; a signal amplifying by antenna gain amplifier.

Only a linear amplifier was considered in the "Satellite Transponder" during this investigation.

In the "Ground Station Receiver" the Viterbi decoder decodes the input symbols and uses the unquantized type of decision-making. The receiver performs the reverse operations performed in the transmitter.

Packet Error Rate Calculation block shows the packet error rate as a percentage and must always be zero during investigations.

SNR Estimation block estimates the SNR based on the error vector magnitude.

Adaptive Modulation Control takes into accounts Low-SNR thresholds, Hysteresis factor, and Bit rates. Adaptive modulation improves the rate of data transmission. The implementation of adaptive modulation is according to the channel information that is present at the receiver. The type of modulation is adapted according to the Estimated SNR in a channel. Simultaneously a Bit rate is specified and then data source generates binary data according to the specified data rate in adaptive modulation control.

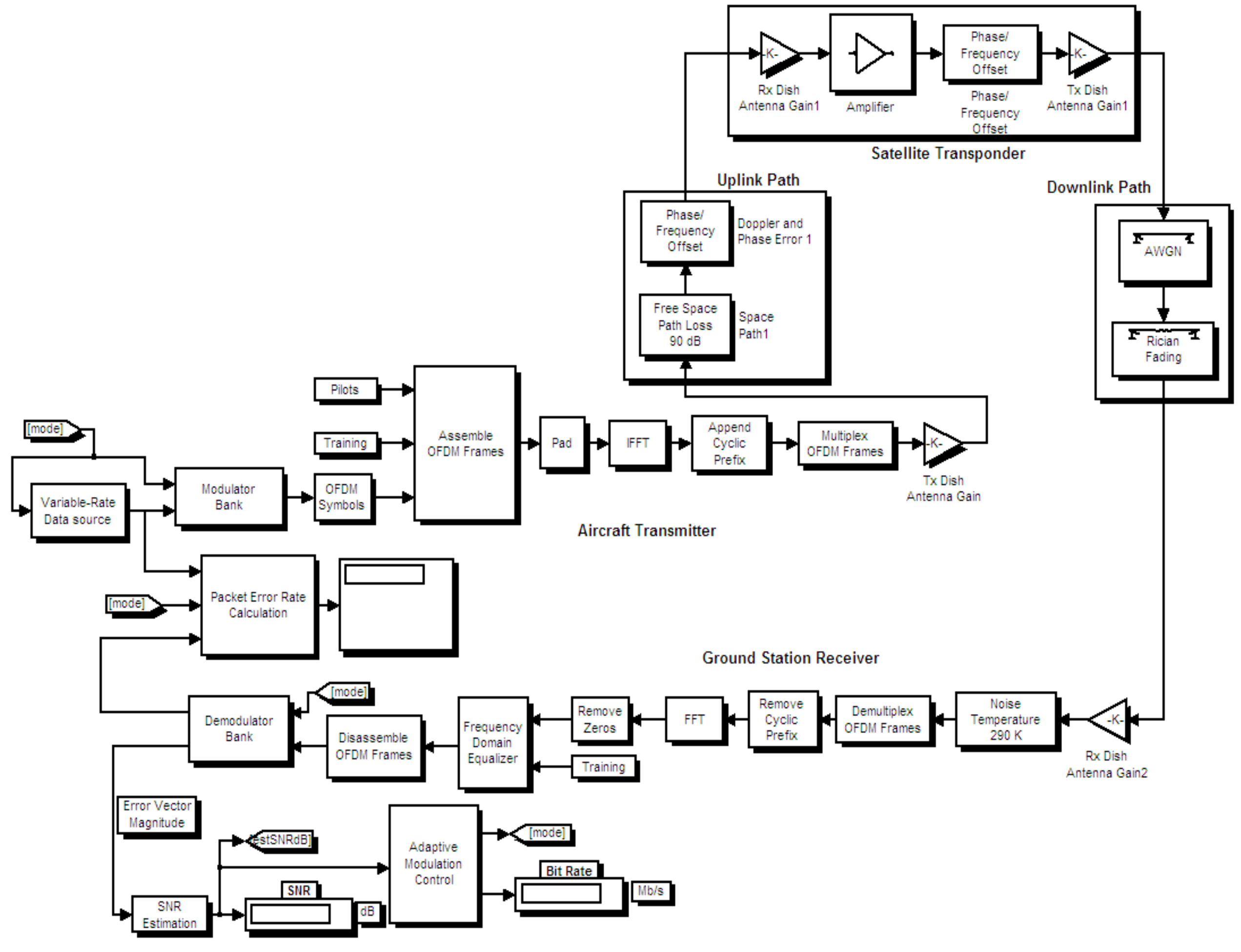

Fig. 1. Model of "Aircraft-Satellite-Ground Station" channel

The error rate calculation block calculates the bit error rate, by comparing the received data with transmitted data.

The SNR ratio thresholds (in dB) at which a transition to another type of modulation takes place are given as a vector [10 11 14 18 22 26 28]. For values of the SNR ratio less than 10 dB the modulation is used BPSK½, for values between 10 dB and 11 dB - BPSK¾, between 11 dB and 14 dB - QPSK½, between 14 dB and 18 dB - QPSK¾, between 18 dB and 22 dB - 16QAM½, between 22 dB and 26 dB - 16-QAM¾, between 26 dB and 28 dB - 64QAM$^{2}/_{3}$ and for values of the SNR ratio greater than 28 dB - 64QAM¾. In accordance with this the model has eight modes, each of which is associated with a specific modulation scheme and a convolutional code. The latter are determined by estimated values of the SNR ratio in the channel. Ideally, in the simulation a mode with the highest throughput must be used, which is maintained at a zero level of errors during the transmission of data packets. Determining appropriate mode involves repeating the simulation for several times with the change of a threshold.

Created model supports data rates 6, 9, 12, 18, 24, 36, 48, and 54 Mb/s, uses adaptive modulation and coding over a satellite communication channel with free space path losses and Rician fading, whereby the simulation varies the data rate dynamically.

In the "Uplink Path" Free Space Path Loss block simulates the loss of signal power due to the distance between the aircraft uplink transmitter and the satellite transponder receiver. The block reduces the amplitude of the input signal by an amount that is determined by the Loss (dB) parameter. Phase/Frequency Offset block applies a frequency and phase offset to the input signal.

In the "Downlink Path" Multipath Rician Fading Channel block implements a baseband simulation of mobile wireless communication when the transmitted signal can travel to the receiver along a dominant LOS or direct path and is described by the Rician distribution [3]:

$$p(r) = (r/\sigma^2)exp[-(r^2+A^2)/2\sigma^2]I_0(Ar/\sigma^2)$$
$$\text{for } (A \geq 0,\ r \geq 0) \text{ and } 0 \text{ for } (r < 0),$$

where A is the amplitude of the dominant component, σ^2 is the average power or dispersion of signal fluctuations and $I_0(.)$ is the modified Bessel function of the first kind and zero-order. The parameter K in Rician distribution is the ratio between the power of the LOS component and the diffuse component. If K-factor is a vector of the same size as Discrete path delay vector, then each discrete path is a Rician fading process with a K-factor given by the corresponding element of the vector.

Relative motion between the "Satellite Transponder" and "Ground Station Receiver" causes Doppler shifts in the signal frequency. The following types of Doppler spectrum were considered.

5. Aeronautical Satellite Channel Simulation

To simulate a channel operation the following parameters were chosen for the model: the value of signal phase-frequency shifts in the uplink and satellite transponder is equal to zero; the gain of a linear amplifier in satellite transponder was taken 10 dB; Viterbi traceback depth is 34, hysteresis factor for adaptive modulation is 3 dB, the number of OFDM symbols in the training sequence is 4, the number of OFDM symbols per transmit block are 20. The values of antenna gains were taken $G_{aircraft}$ = 12,4; $G_{satellite}$ = 31,1; G_{ground} = 62,1 (at the signal frequency of 4 GHz that corresponds to antenna diameters $d_{aircraft}$ = 0,4 m; $d_{satellite}$ = 1,0 m, d_{ground} = 2,0 m). A noise temperature of the satellite transponder transmitter amplifier and ground station receiver is taken to be 290 K.

For SNR values marked by the arrow the modulation type is changed and the data rate increases: BPSK½ (6 Mb/s), QPSK½ (12Mb/s), QPSK¾ (18 Mb/s), 16QAM½ (24 Mb/s), 16QAM¾ (36 Mb/s), 64QAM⅔ (48 Mb/s) and 64QAM¾ (54 Mb/s). The data show how big should be the SNR and what type of a modulation to be used for data transfer without errors for given uplink/downlink characteristics and a noise temperature.

Fading causes the signal to become diffuse. The K-factor parameter, which is part of the statistical description of the Rician distribution, represents the ratio between the power in the LOS component and the power in the diffuse component. The ratio is expressed linearly, not in decibels. The K-factor parameters control the gain's partition into LOS and diffuse components.

If the K-factor parameter is a vector then each discrete path is a Rician fading process with a K-factor given by the corresponding element of the vector. It is possible to attribute the LOS component a Doppler shift, through the Doppler shifts of LOS components parameter, and an initial phase, through the Initial phases of LOS components. The Doppler shifts and initial phases of LOS components parameters are of the same size as the K-factor parameter.

Relative motion between the transmitter and receiver causes Doppler shifts in the signal frequency. Data on Fig. 2-4 are given for maximum Doppler frequency 1 Hz (that means no relative motion) and on Fig. 5 – for 1000 Hz.

On Fig. 2 dependencies of Estimated SNR in channel on SNR_{AWGN} in a downlink are shown for different proportions between a power in the LOS component and a power in the diffuse component: K = [1 0], [0.75 0.25] and [0.5 0.5]. From data on Fig. 2 (for a free space path loss in Uplink 90 dB) follows that these dependencies coincide. For the lower free space path loss in Uplink (80 dB) this dependence shifts upward, and for the higher one (100 dB) shifts downward. At the same time a data transmission with a certain modulation for a bigger free space path loss in Uplink will be possible for bigger SNR_{AWGN} in a downlink. For example, for a free space path loss in Uplink 80 dB - QPSK½ modulation is observed for SNR_{AWGN} = 3 dB, for a free space path loss in Uplink 90 dB – for SNR_{AWGN} = 11 dB, and for a free space path loss in Uplink 100 dB - for SNR_{AWGN} = 21 dB. Data on Fig. 2 are given for Flat and Gaussian Doppler spectrum types. For other types of Doppler spectra the mentioned dependencies are similar.

On Fig. 3 a dependence of Estimated SNR in channel on a Gain in the diffuse component is given for a certain value of a free space path loss in Uplink (90 dB) and *K* = [0.5 0.5]. Estimated SNR does not depend on a Gain in the diffuse component and varies with SNR_{AWGN}: for SNR_{AWGN} = 10 dB the modulation QPSK½ is observed, for SNR_{AWGN} = 20 dB – the modulation 16QAM½, and for SNR_{AWGN} = 30 dB – the modulation 64QAM¾. The Doppler spectrum type has practically no effect on the considered dependence.

Because a multipath channel reflects signals at multiple places, a transmitted signal travels to the receiver along several paths, each of which may have differing lengths and associated time delays. The Discrete path delay vector specifies the time delay for each path.

On Fig. 4 a dependence of Estimated SNR in channel on the Delay in a diffuse component is given for a certain value of a free space path loss in Uplink (90 dB), *K* = [0.5 0.5], SNR_{AWGN} = 20 dB and different types of Doppler spectrum. For small Delay times (τ = 10^{-10} - 10^{-7} s) received data practically coincide for all types of Doppler spectrum being described by almost the same values of Estimated SNR and a modulation type – 16QAM½. Increasing of the Delay value in diffuse component (τ = 10^{-7} - 10^{-5} s) leads to a dramatic reduction of Estimated SNR (from ≈ 20-21 dB up to ≈ 2-5 dB), the emergence of differences between the spectra and the transition to a modulation BPSK½ already at the Delay time 10^{-6} s.

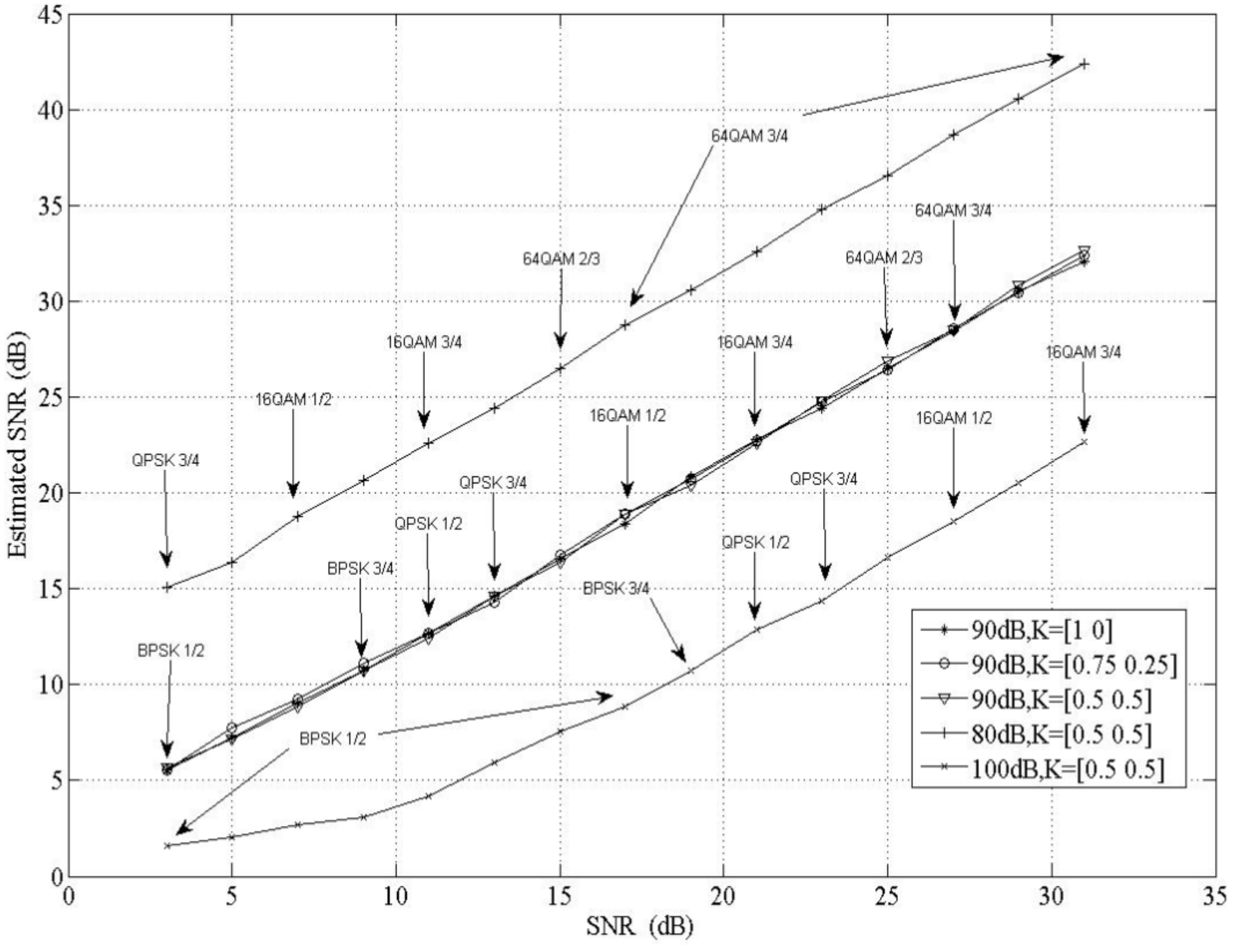

Fig. 2. Dependence of Estimated SNR on SNR in AWGN Downlink for different *K* and Free Space Path Loss for Flat and Gaussian Doppler spectrum types, MaxDoppler 1 Hz

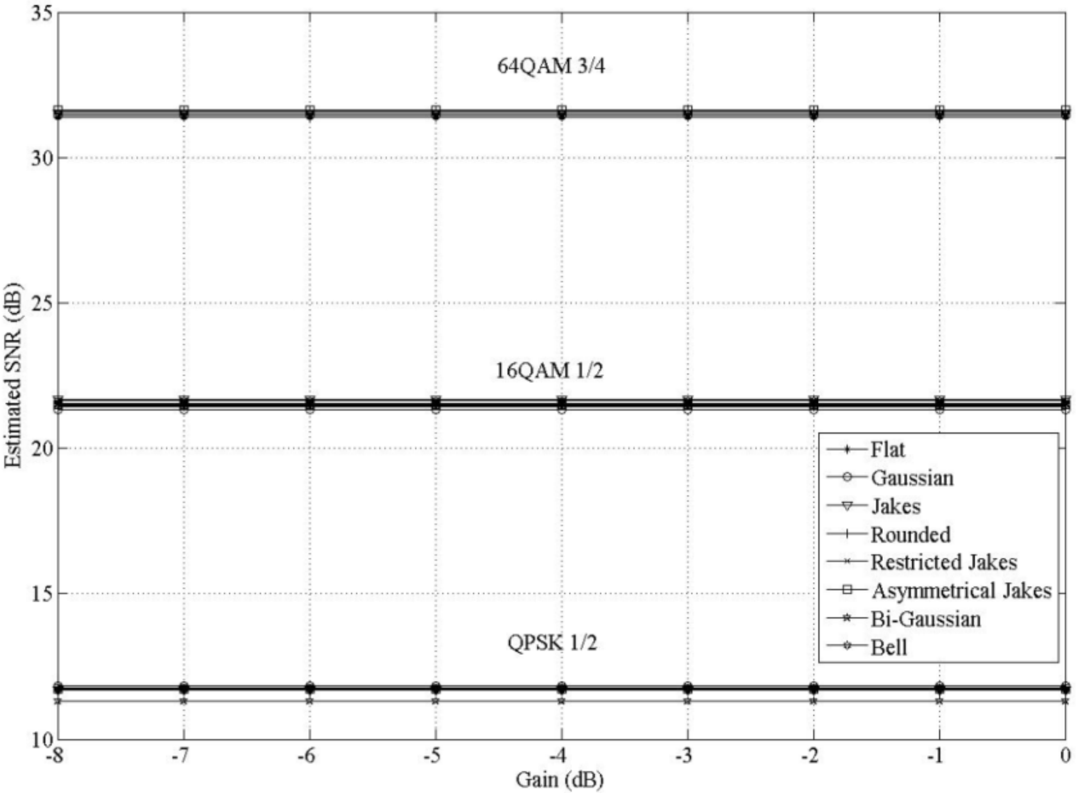

Fig. 3. Dependence of Estimated SNR on Gain in diffuse component (Free Space Path Loss in Uplink 90 dB, $K = [0.5\ 0.5]$, SNR in AWGN Downlink 10 dB (QPSK½), 20 dB (16QAM½), 30 dB (64QAM¾), MaxDoppler 1 Hz)

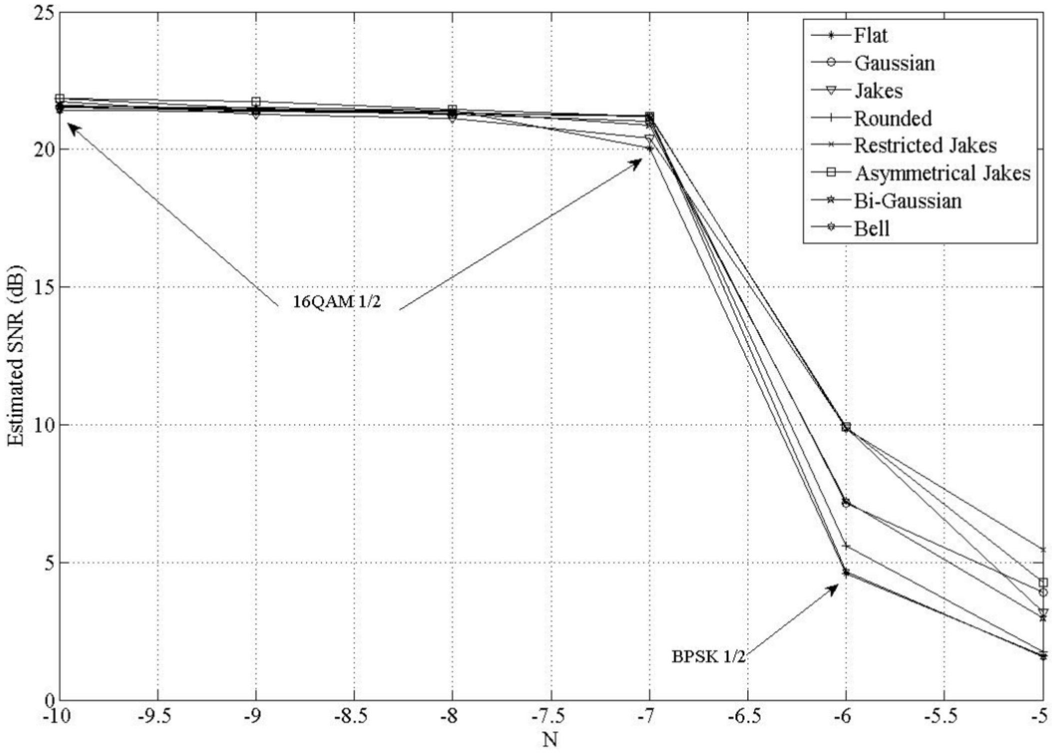

Fig. 4. Dependence of Estimated SNR on Delay in diffuse component - delay time $\tau = 10^{-N}$ s (Free Space Path Loss in Uplink 90 dB, $K = [0.5\ 0.5]$, SNR in AWGN Downlink 20 dB, MaxDoppler 1 Hz)

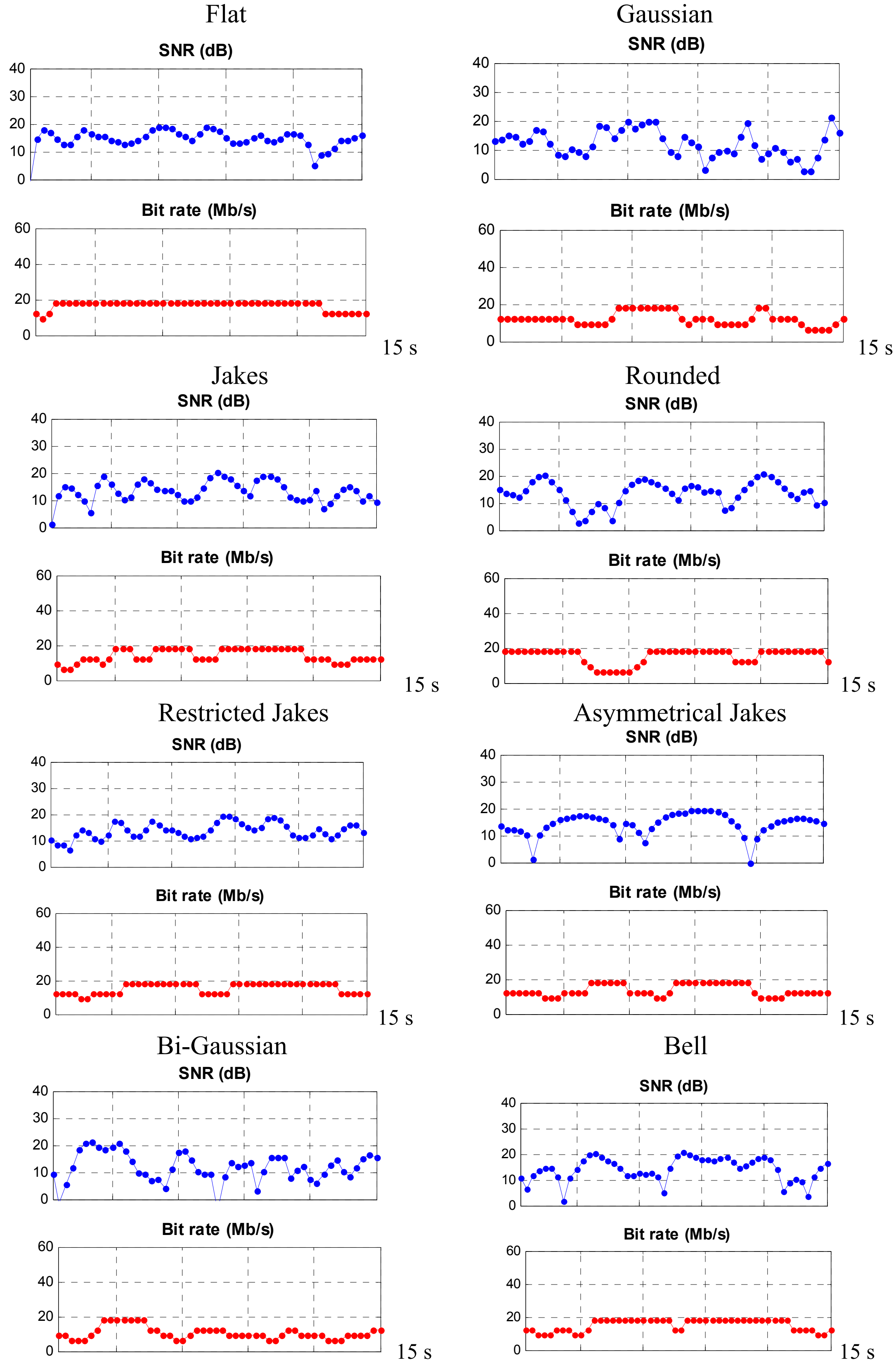

Fig. 5. Dependence of Estimated SNR and Bit rate on time for different Doppler spectrum types (Free Space Path Loss in Uplink 90 dB, $K = [0.5\ 0.5]$, $\mathrm{SNR}_{\mathrm{AWGN}}$ in AWGN Downlink 20 dB, average path gain vector (dB): [0 -4] discrete path delay vector (s) [0.0 5.0e-8], QPSK½ modulation, MaxDoppler 1000 Hz)

The strongest decrease of Estimated SNR for 10^{-5} s experiences Rounded Doppler spectrum and then in order of Estimated SNR increasing the following Doppler spectra are arranged: Bell, Bi-Gauss, Jakes, Gaussian, Asymmetrical Jakes and Restricted Jakes.

Fig. 5 shows the nature of Estimated SNR and Bit rate changes over time in the presence of the Rician Fading in channel for different types of Doppler spectra.

6. Conclusions

The realistic model of aeronautical satellite OFDM link with Rician fading is developed for the first time on a basis of IEEE 802.11a standard and used for channel parameters evaluation. Proposed in this article approach can be considered as a method for estimating parameters of the channel with fading. On the basis of data received under given conditions (a number of OFDM symbols, a noise temperature, gains of antenna dishes and the satellite transponder amplifier type) link parameters can be estimated: the level of free space loss, proportions between a power in the LOS component and in the diffusive component for which the satellite communication channel is "open"; the type of a modulation and data transfer rate, which are possible under the given conditions. The impact of a gain and a delay time in diffuse component on SNR and Bit rate can be predicted for different Doppler spectrum types. Dependences of Estimated SNR and Bit rate on time for different Doppler spectrum types and Doppler frequency shifts can be obtained.

The developed model allows predicting the operation of the channel with Rician fading and can be helpful for designing of communication systems.

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В.П. Харченко[1], А.М. Грехов[2], І.М. Алі[3], Ю.Ю. Удод[4]. Вплив завмирань Райса на роботу авіаційного супутникового OFDM каналу зв'язку
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Мета: Метою цього дослідження є вивчення впливу райсівського завмирання на передачу повідомлень через авіаційний супутниковий OFDM канал з адаптивною модуляцією і розробка методу оцінки параметрів такого каналу. **Методи дослідження:** Вплив райсівського завмирання на передачу повідомлень через авіаційний супутниковий OFDM канал з адаптивною модуляцією вивчено за допомогою моделі каналу зв'язку "Літак - Супутник - Наземна станція", побудованої з використанням програмного пакету MATLAB Simulink. Модель включає в себе "Передавач літака", "Канали Вгору/Вниз", "Супутниковий транспондер" і "Приймач наземної станції". Кожен блок модулятора в банку модуляції виконує згортальне кодування з використанням кодових швидкостей ½, ²/3, ¾, і BPSK, QPSK, 16-QAM і 64-QAM модуляції. **Результати:** Отримано залежності SNR каналу від співвідношення між потужністю каналу прямої видимості й дифузного каналу, від посилення в каналі «Вниз» і затримки в дифузному каналі для різних типів доплерівського спектра і доплерівських зсувів частоти. Запропоновано метод оцінки параметрів супутникових каналів із завмиранням. **Обговорення:** Вперше розроблено реалістичну модель авіаційного супутникового OFDM каналу зв'язку з райсівськими завмираннями на основі стандарту IEEE 802.11a, яку використано для оцінки параметрів каналу. Запропонований в даній статті підхід можна розглядати як метод оцінки параметрів каналу з завмиранням.

Ключові слова: адаптивна модуляція; втрати у вільному просторі; доплерівській зсув частоти; згортальне кодування; райсівські завмирання; супутниковий зв'язок; супутниковий транспондер; тип доплерівського спектра; OFDM канал.

В.П. Харченко[1], А.М. Грехов[2], И.М. Али[3], Ю.Ю. Удод[4]. Влияние замираний Райса на работу авиационного спутникового OFDM канала связи
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Цель: Целью данного исследования является изучение влияния райсовского замирания на передачу сообщений через авиационный спутниковый OFDM канал с адаптивной модуляцией и разработка метода оценки параметров такого канала. **Методы исследования:** Влияние райсовского замирания на передачу сообщений через авиационный спутниковый OFDM канал с адаптивной модуляцией изучено с помощью модели канала связи "Самолёт – Спутник - Наземная станция", построенной с использованием программного пакета MATLAB Simulink. Модель включает в себя "Передатчик самолёта", "Каналы Вверх/Вниз", "Спутниковый транспондер" и "Приёмник наземной станции". Каждый блок модулятора в банке модуляции выполняет сверточное кодирование с использованием кодовых скоростей ½, ²/3, ¾, и BPSK, QPSK, 16-QAM и 64-QAM модуляции. **Результаты:** Получены зависимости SNR канала от соотношения между мощностью канала прямой видимости и диффузного канала, от усиления в канале «Вниз» и задержки в диффузном канале для различных типов доплеровского спектра и доплеровских сдвигов частоты. Предложен метод оценки параметров спутниковых каналов с замиранием. **Обсуждение:** Впервые разработана реалистичная модель авиационного спутникового OFDM канала связи с райсовским замиранием на основе стандарта IEEE 802.11a и использована для оценки параметров канала. Предлагаемый в данной статье подход можно рассматривать как метод оценки параметров канала с замиранием.

Ключевые слова: адаптивная модуляция; доплеровский сдвиг частоты; потери в свободном пространстве; райсовское замирание; сверточное кодирование; спутниковая связь; спутниковый транспондер; тип доплеровского спектра; OFDM канал.

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