AEROSPACE SYSTEMS FOR MONITORING AND CONTROL

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METHOD FOR PARAMETERS ESTIMATION OF AVIATION SATELLITE COMMUNICATION CHANNEL

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Abstract. *For estimation of satellite OFDM communication channel parameters the original model of a channel "Aircraft-Satellite-Ground Station" with adaptive modulation was built using MATLAB Simulink software. Model consists of a source of information, an aircraft transmitter, an uplink/downlink path, a satellite transponder, and a ground station receiver. The dependencies of a signal to noise ratio on free space path loss for different types of modulation (BPSK, QPSK, 16QAM, 64QAM), noise temperatures, number of OFDM symbols, frequency offsets, satellite amplifier linear gain, and aircraft antenna diameter were received and analyzed. A method for parameters estimation of satellite OFDM communication channel was developed.*

Keywords: adaptive modulation; aircraft antenna diameter; convolutional coding; frequency offset; free space path loss; OFDM; satellite communication; satellite amplifier linear gain; satellite transponder; signal to noise ratio

1. Problem statement

The Global Air Navigation Plan for CNS/ATM Systems [1] recognizes the Global Navigation Satellite System (GNSS) as a key element of the Communications, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) systems. International Civil Aviation Organization (ICAO) approved an international standard for a landing system based on local correction of GNSS data to a level that would support instrument approaches [2]. The ICAO Standards and Recommended Practices (SARPS) define the characteristics of a Ground-Based Augmentation System (GBAS) service that can be provided by an airport authority or an Air Traffic Service provider. The GBAS service provides the radiated signal in space that can be used by suitably equipped airplanes as the basis of a Satellite Landing System (SLS).

Landing aircraft is one of the most important and difficult tasks of piloting. About half of all aircraft accidents occur because of the complexity and danger of this stage. This situation necessitates the use of automation.

Implementation of the automatic landing mode will not only ensure the flight regardless of the weather conditions, but also improve the level of flight safety.

Information flows analysis, ensuring the process of piloting in terminal areas, allowed moving to the new surveillance system. ICAO Committee on Future Air Navigation Systems (FANS) as an alternative adopted the concept of the so-called Automatic Dependent Surveillance (ADS). FANS is based on the use of global satellite-based technologies: communication, navigation and surveillance. A transition to a new form of navigation and air traffic - Free Flight [3] – will be possible in future.

A high accuracy of aircraft coordinates determination is required for landing. One of ways is using of the navigating information from GPS and the correcting information developed at local control-correcting station.

For transmitting of the correcting information can be used either special communication channels, or radio channels of satellite landing system with Orthogonal Frequency Division Multiplexing (OFDM).

The information transmitting by means of OFDM signals became the standard for many modern radio systems in connection with a number of advantages - high spectral efficiency, low level of an intersymbol interference, high quality of transmitting in the conditions of frequency-selective fading.

At the same time OFDM systems are sensitive to phase and frequency instability of carriers. It is especially important to provide power efficiency for an information transmitting in aviation complexes with rigid restriction of spatially-frequency parametres for onboard radio-electronic equipment.

Experience in operating navigation systems and aircraft landing at airports with different geographic position and relief conditions showed the negative impact of multipath signals from navigation structures on the quality of the systems. The sources are the reflection from the earth with the local features, vehicles, including aircraft in the air and on the ground, airport facilities and other objects. Due to this an additional error of angular positioning and operational parameters of navigation and landing depend on weather conditions, the characteristics of the underlying surface, the shape, size and location of the aerodrome facilities.

There is an actual national economic and scientific challenge to ensure the required ICAO standards of the aircraft landing in the changing conditions of navigation and landing in the presence of multipath navigation signal due to the influence of interfering reflections.

Nevertheless issues related to the OFDM satellite channel estimation still are not investigated in detail.

2. Analysis of researches and publications

OFDM as digital multi-carrier modulation technique has been adopted as physical layer scheme of broadband wireless air interface standards, such as IEEE 801.11/WiFi, IEEE 802.16/WiMAX. Simultaneously OFDM modulation is attracting more attention for delivering multimedia services over hybrid satellite/terrestrial networks to a variety of small mobile and fixed terminals with compact antennas [4, 5]. On the other hand, OFDM technique is also being applied in military communications [6].

OFDM is a method of encoding digital data on multiple carrier frequencies which was developed for wideband digital communication [7]. In an OFDM system the data is divided into multiple parallel sub streams at a reduced data rate, and each is modulated and transmitted on a separate orthogonal subcarrier. This increases symbol duration and improves system robustness.

A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. Each sub-carrier is modulated with a conventional modulation scheme at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth [8].

3. Aim of the work

Channel estimation is a critical component in wireless communications systems. Therefore the aim of this paper is: 1) to design model of aeronautical satellite OFDM communication channel "Aircraft–to–Satellite–to–Ground Station" with adaptive modulation using MATLAB Simulink software; 2) to realize parameters calculations for channels of different types; 3) to develop a method for estimating the parameters of satellite landing system communication channel.

4. Model for “Aircraft-Satellite-Ground Station” channel

Satellite communication channel was analyzed using original model designed on a basis of IEEE 802.11a standard and MATLAB Simulink demo model *commwman80211a*.

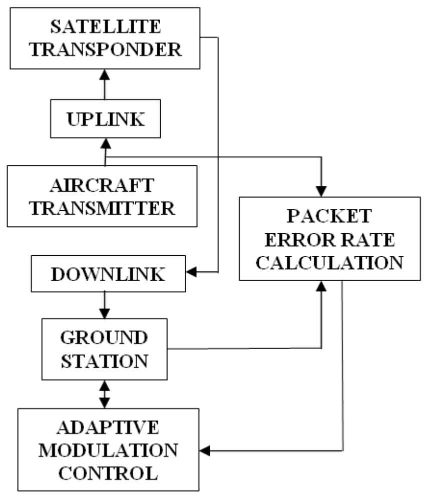

Fig. 1. “Aircraft-Satellite-Ground Station” channel

The model (Fig. 1) consists of “Uplink / Downlink” (Fig. 2), “Aircraft Transmitter” (Fig 3), “Satellite Transponder” (Fig 4), “Ground Station” (Fig. 5) and “Adaptive Modulation Control” (Fig. 6). Different types of “Uplink / Downlink” were considered: “Multipath”, “Rayleigh Fading”, “Rician Fading”, “Free Path Loss with Phase/Frequency Offset” and AWGN channels. This paper is devoted to consideration of “Free Path Loss with Phase / Frequency Offset” type of a link.

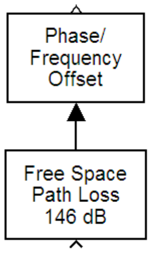

Fig. 2. “Uplink / Downlink”

Parameter settings for the model are the following: Viterbi traceback depth is 34, hysteresis factor for adaptive modulation (dB) is 3, numbers of OFDM symbols per transmit block are 20 and 1000, number of OFDM symbols in training sequence is 4, Low-SNR thresholds (dB) vector [10 11 14 18 22 26 28] where less than 10 is for BPSK ½, between 10 and 11 - for BPSK ¾, between 11 and 14 - for QPSK ½, between 14 and 18 – for QPSK ¾, between 18 and 22 - for 16-QAM ½, between 22 and 26 - for 16-QAM ¾, between 26 and 28 – for QAM 2/3 and more than 28 - for 64-QAM ¾

Low-SNR thresholds parameter is a seven-element vector that indicates how the simulation should choose a data rate based on the SNR estimate. The model has eight modes, each associated with a particular modulation scheme and convolutional code. The seven thresholds are the boundaries between eight adjacent regions that correspond to the eight modes. Ideally, the simulation should use the highest-throughput mode that achieves a desired (zero) packet error rate. Determining appropriate thresholds often involves running the simulation multiple times, varying the values of the Low-SNR thresholds parameter.

The communication system in this model performs such tasks as: generation of random data at a bit rate that varies during the simulation; coding, interleaving, and modulation using one of eight

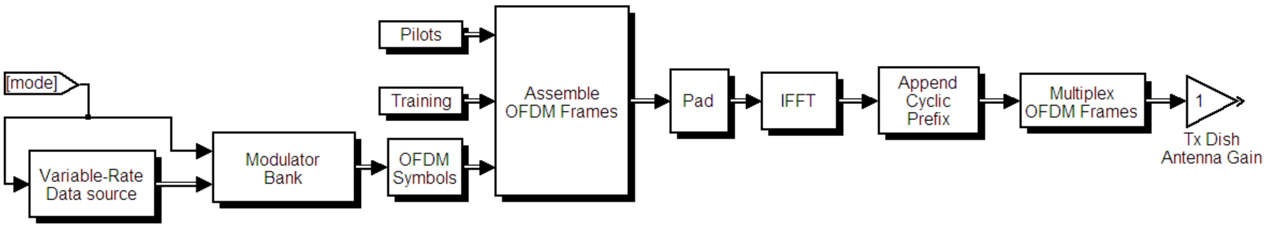

Fig. 3. “Aircraft Transmitter”

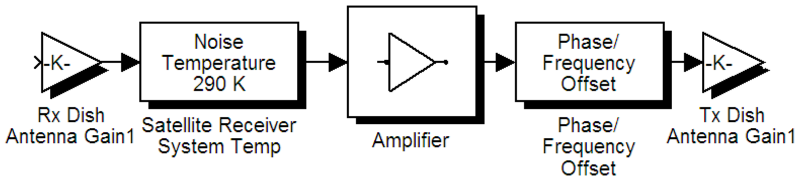

Fig. 4. “Satellite Transponder”

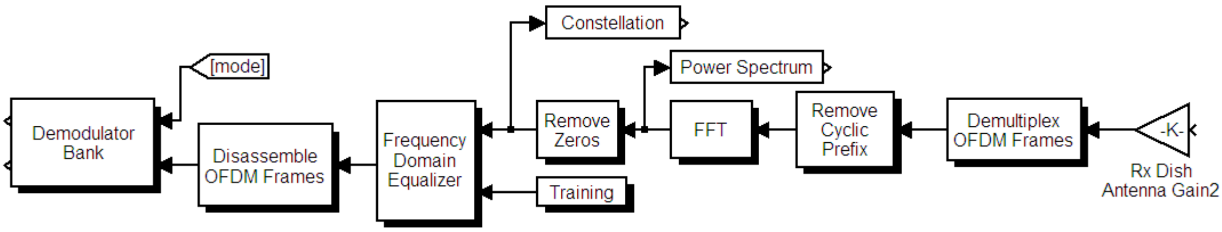

Fig. 5. “Ground Station”

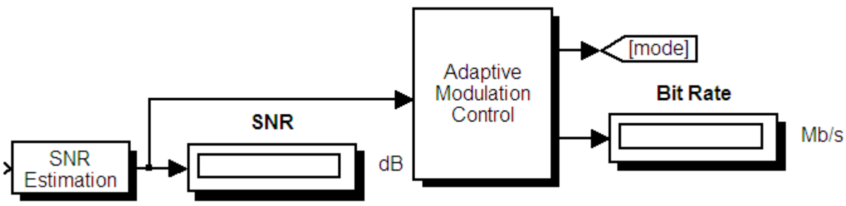

Fig. 6. “Adaptive Modulation Control”

schemes specified in the standard; OFDM transmission using 52 subcarriers, 4 pilots, 64-point FFTs (Fast Fourier Transform), and a 16-sample cyclic prefix; physical layer convergence protocol preamble modeled as four long training sequences.

Packet Error Rate Calculation block shows the packet error rate as a percentage and should always equal 0 during investigations.

5. Satellite Communication Channel Simulation

For modeling the following parameters in the model (Fig.1) were set up: phase/frequency offsets in uplink/downlink and satellite transponder are equal to zero; the gain of linear amplifier in satellite transponder was taken 1. The number of OFDM symbols per transmit block was taken 20 and 1000.

Dependencies of a SNR on free path losses for different modulation modes and transponder noise temperatures are given in Table. During modeling the value of a packet error rate was kept at zero by changing the type of modulation (using SNR estimation and adaptive rate control). In accordance with this a ratio SNR was changed. Free space path loss values were changed simultaneously in uplink and downlink channels.

A sign “ – “ in Table means that a channel is closed.

Data from Table show how big a SNR ratio should be and what type of a modulation to be used for data transmission without errors for given free space path losses and transponder noise temperature.

The number of OFDM symbols per transmit block practically does not change the dependencies whereas a noise temperature essentially impacts the results.

At noise temperature T=20 K the channel is opened for free path loss less than 136 dB and at T=290 K – less than 124 dB (see Table).

When free path loss is 124 dB: a type of modulation is QPSK 3/4 for T=20 K and BPSK ½ for T=290 K; a SNR is 15.8 dB for T=20 K and 5.3 dB for T=290 K; a bit rate is 12 Mb/s for T=20 K and 6 Mb/s for T=290 K.

Data given in Table confirm the obvious conclusion that 64QAM3/4 modulation has the highest value of SNR ratio in comparison with other types of modulation and that the lower transponder noise temperature the higher the value of SNR ratio is.

The next investigation was performed for different frequency and phase offsets in the uplink and downlink channels. All parameters in the channel remained the same. A noise temperature and number of OFDM symbols were changed.

It was obtained that channel characteristics do not depend on the value of a phase offset.

However, a frequency offset influences the dependence of a SNR on free path loss for different noise temperatures and a number of OFDM symbols (Fig. 7).

Dependences of a SNR on free path losses for 20, 200, 500 and 1000 OFDM symbols was obtained for the frequency offsets 15 Hz, 30 Hz, 50 Hz and 100 Hz. Numerical results for the frequency offset 15 Hz (a number of OFDM symbols is 20 and 200) are represented on Fig. 8.

When a number of OFDM symbols is increased to 500, the channel operation becomes highly limited and even at frequency offset of 15 Hz works only BPSK1/2 modulation at a bit rate of 6 Mb/s. A SNR value reaches 9.7 dB at both 20 K and 290 K noise temperature and does not change at any value of free path loss. The same situation in the channel occurs at 1000 OFDM symbols. However, the highest value of a SNR is 3.9 dB. Thus, it is possible to conclude that channel is sensitive to number of OFDM symbols when there is a frequency offset. As seen from Fig. 8 the dependence is linear for a small number of OFDM symbols and non-linear for a high number.

6. Method of channel parameters evaluation

It is possible to summarize the received data and to give a method for estimating the parameters of satellite link:

1. To select the Low-SNR thresholds parameter. (In considered model it is a seven-element vector that indicates how the simulation should choose a data rate based on the SNR estimate. The model has eight modes, each associated with a particular modulation scheme and convolutional code. The seven thresholds are the boundaries between eight adjacent regions that correspond to the eight modes. The simulation should use the highest-throughput mode that achieves zero packet error rates. Determining appropriate thresholds involves running the simulation multiple times, varying the values of the Low-SNR thresholds parameter).

2. If necessary, one can increase the number of modes (to create the new Low-SNR thresholds parameter) in accordance with the desired amount of modulation schemes and convolutional coding rates.

Table. Dependence of SNR on free path loss for different modulation modes

Free Path Loss (dB)		Modulation		SNR (dB)		Bit Rate (Mb/s)	
Noise temperature							
20 K	290 K	20 K	290 K	20 K	290 K	20 K	290 K
136	-	BPSK 1/2	-	5	-	6	-
135	-	BPSK 1/2	-	5.5	-	6	-
134	-	BPSK 1/2	-	6.7	-	6	-
133	-	BPSK 1/2	-	7.3	-	6	-
132	-	BPSK 1/2	-	8.3	-	6	-
131	-	BPSK 1/2	-	8.9	-	6	-
130	-	BPSK 1/2	-	9.8	-	6	-
129	-	BPSK 3/4	-	10.6	-	6	-
128	-	BPSK 3/4	-	11.7	-	6	-
127	-	BPSK 3/4	-	12.8	-	9	-
126	-	QPSK 1/2	-	13.7	-	12	-
125	-	QPSK 3/4	-	14.4	-	12	-
124	124	QPSK 3/4	BPSK 1/2	15.8	5.3	12	6
123	123	QPSK 3/4	BPSK 1/2	16.7	5.9	12	6
122	122	QPSK 3/4	BPSK 1/2	17.5	6.8	18	6
121	121	QPSK 3/4	BPSK 1/2	18.8	7.7	18	6
120	120	QPSK 3/4	BPSK 1/2	19.2	8.3	18	6
119	119	16-QAM 1/2	BPSK 1/2	20.3	9.4	24	6
118	118	16-QAM 1/2	BPSK 1/2	21.7	10.06	24	6
117	117	16-QAM 1/2	BPSK 3/4	22.5	11.07	24	6
116	116	16-QAM 1/2	BPSK 3/4	23.5	12.5	24	6
115	115	16-QAM 1/2	BPSK 3/4	24.6	13.1	24	9
114	114	16-QAM 3/4	QPSK 1/2	25.8	13.9	36	12
113	113	16-QAM 3/4	QPSK 1/2	26.7	14.9	36	12
112	112	16-QAM 3/4	QPSK 3/4	27.8	16.1	36	12
111	111	64-QAM 2/3	QPSK 3/4	28.5	16.8	48	18
110	110	64-QAM 2/3	QPSK 3/4	29.2	17.6	48	18
109	109	64-QAM 3/4	QPSK 3/4	30.5	18.6	54	18
108	108	64-QAM 3/4	QPSK 3/4	31.5	19.6	54	18
107	107	64-QAM 3/4	16-QAM 1/2	32.6	20.9	54	24
106	106	64-QAM 3/4	16-QAM 1/2	33.8	22.0	54	24
105	105	64-QAM 3/4	16-QAM 1/2	34.6	23.2	54	24
104	104	64-QAM 3/4	16-QAM 1/2	35.6	23.9	54	24
103	103	64-QAM 3/4	16-QAM 3/4	36.7	24.6	54	36
102	102	64-QAM 3/4	16-QAM 3/4	37.8	25.9	54	36
101	101	64-QAM 3/4	16-QAM 3/4	38.5	26.8	54	36
100	100	64-QAM 3/4	16-QAM 3/4	39.7	27.6	54	36
99	99	64-QAM 3/4	64-QAM 2/3	40.6	29.0	54	48
98	98	64-QAM 3/4	64-QAM 2/3	41.4	29.8	54	48
97	97	64-QAM 3/4	64-QAM 3/4	42.4	30.9	54	54
96	96	64-QAM 3/4	64-QAM 3/4	43.7	32.2	54	54

Notes. A number of OFDM symbols per transmitted block is 1000; PER=0; phase/frequency offset is 0; satellite linear amplifier gain is 1; all antennas gain is 1.

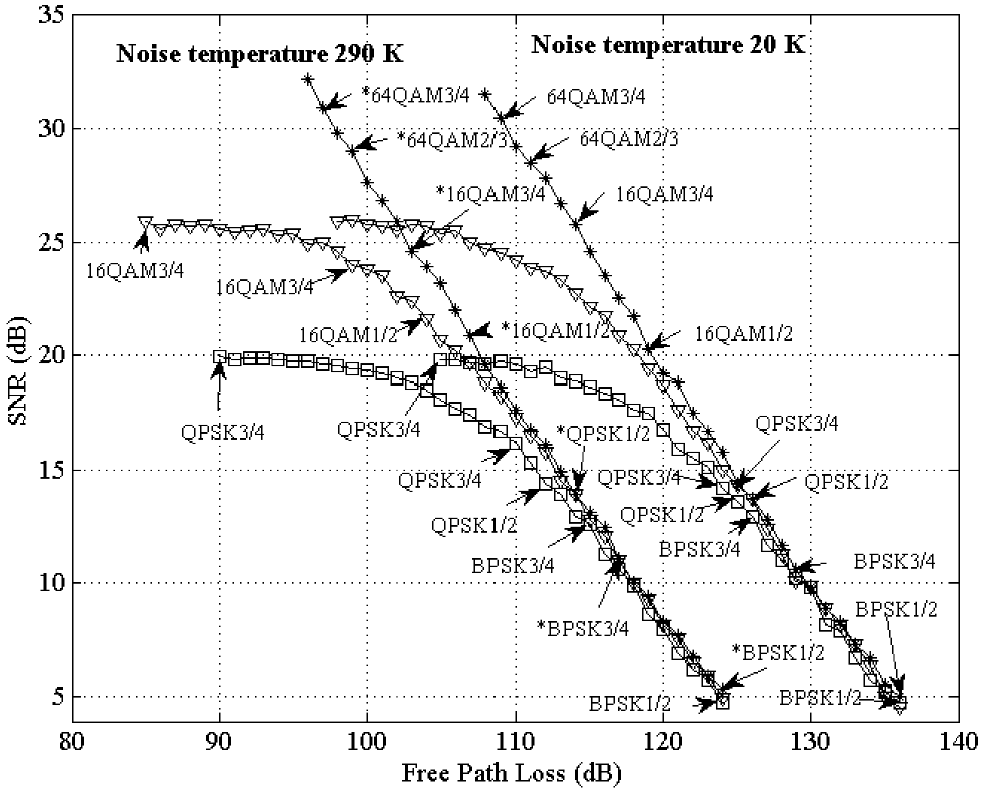

Fig. 7. Dependence of SNR on free path loss for different frequency offsets: stars – 0 Hz, triangle – 50 Hz, squares – 100 Hz

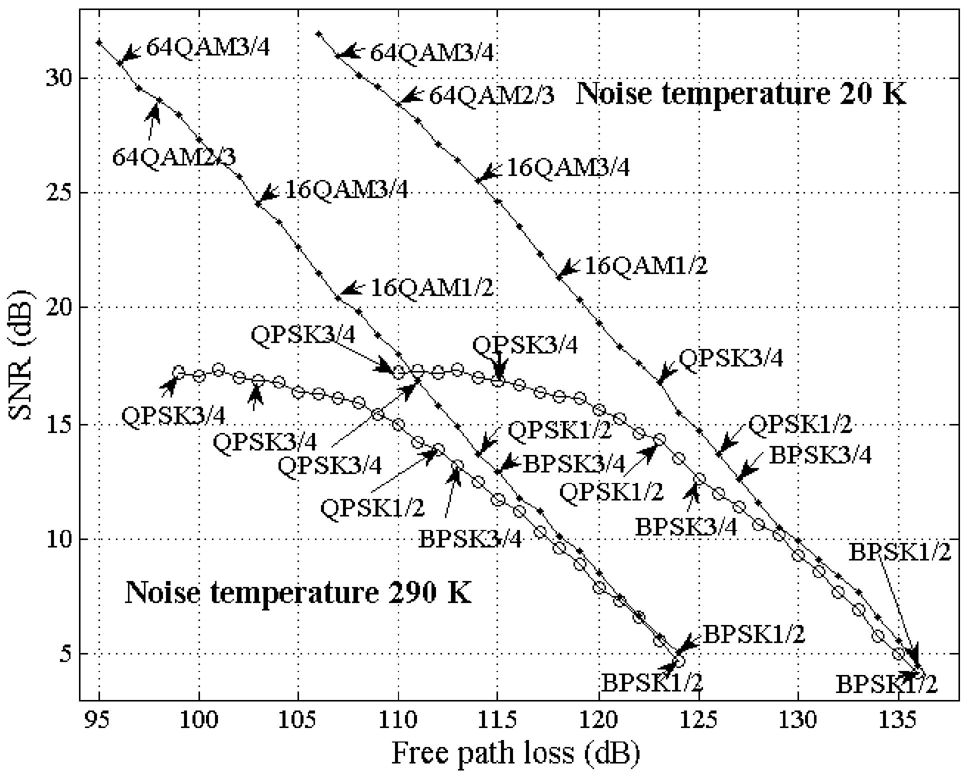

Fig. 8. Dependence of SNR on free path loss for different number of OFDM symbols: points – 20, circles – 200; frequency offset is 15 Hz;

antennas gain=1, linear amplifier gain=1, phase offset=0

3. In this case it is necessary to create the appropriate modulation Bank (for the new Low-SNR thresholds parameter).

4. To select the type of the communication channel (Multipath, Rayleigh Fading, Rician Fading, Free Path Loss with Phase/Frequency Offset, AWGN).

5. For the selected communication channel to take the appropriate model from the created model kit.

6. On the basis of relations received is this paper (under the given conditions: a number of OFDM symbols, noise temperatures, gains of antenna dishes and the satellite transponder amplifier, a phase-frequency shift) to estimate the channel parameters:

– The level of free space loss, for which the satellite communication channel is "open";

– The type of a modulation, which is possible under the given conditions;

– Data transfer rate, which is possible under the given conditions.

7. For the channel with different conditions it is necessary to make further calculations using the created model kit.

7. Conclusions

On a basis of IEEE 802.11a standard the realistic model with adaptive modulation for satellite communication channel parameters evaluation is developed for the first time. Different types of uplink/downlink can be taken.

Dependencies were received between a SNR ratio, the type of a modulation (BPSK, QPSK, 16QAM, 64QAM), a bit rate, free space path losses and transponder noise temperatures (Table).

A frequency offset essentially influences the dependence of a SNR on free path loss for different noise temperatures and a number of OFDM symbols (Fig. 7).

It was shown that channel is sensitive to number of OFDM symbols at presence of a frequency offset. The dependence of a SNR ratio on the free path loss for a different number of OFDM symbols (Fig. 8) is linear for a small number of OFDM symbols and non-linear for a high number.

A method for parameter estimation of satellite landing system communication channel was developed.

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В.П. Харченко[1], А.М. Грехов[2], І.М. Алі[3]. Метод оцінювання параметрів авіаційного супутникового каналу зв’язку
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Для оцінювання параметрів супутникового комунікаційного OFDM каналу з адаптивною модуляцією побудовано оригінальну модель каналу зв'язку "Літак-Супутник-Наземна Станція" з використанням програмного комплексу MATLAB Simulink. Модель складається із джерела інформації, передавача літака, каналу нагору/униз, супутникового транспондера, приймача наземної станції. Отримано залежності співвідношення сигнал-шум від втрат у вільному просторі для різних типів модуляції (BPSK, QPSK, 16QAM, 64QAM), різних температур шуму, кількості символів OFDM, зсуву частоти, лінійного коефіцієнта підсилення супутникового транспондера, діаметра антени літака. Розроблено метод оцінювання параметрів супутникового комунікаційного OFDM каналу.
Ключові слова: адаптивна модуляція; втрати у вільному просторі; діаметр антени літака; згортальне кодування; зсув частоти; коефіцієнт підсилення транспондера; співвідношення сигнал-шум; супутниковий зв’язок; супутниковий транспондер; шумова температура; OFDM

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Для оценивания параметров спутникового коммуникационного OFDM канала с адаптивной модуляцией построена оригинальная модель канала связи "Самолет-Спутник-Наземная Станция" с использованием программного комплекса MATLAB Simulink. Модель состоит из источника информации, передатчика самолета, канала вверх/вниз, спутникового транспондера, приемника наземной станции. Получены зависимости соотношения сигнал-шум от потерь в свободном пространстве для разных типов модуляции (BPSK, QPSK, 16QAM, 64QAM), разных шумовых температур, количества символов OFDM, сдвига частоты, линейного коэффициента усиления спутникового транспондера, диаметра антенны самолета. Разработан метод оценивания параметров спутникового коммуникационного OFDM канала.
Ключевые слова: адаптивная модуляция; диаметр антенны самолета; коэффициент усиления транспондера; потери в свободном пространстве; свёрточное кодирование; сдвиг частоты; соотношение сигнал-шум; спутниковая связь; спутниковый транспондер; шумовая температура; OFDM

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