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Volodymyr Kharchenko[1]
Yurii Barabanov[2]
Andrii Grekhov[3]
Mykola Bogunenko[4]
Julia Rudnyk[5]

ERROR-CONTROL CODING OF ADS-B MESSAGES FOR IRIDIUM SATELLITES

National Aviation University
Kosmonavta Komarova avenue 1, 03680, Kyiv, Ukraine
E-mails: [1]kharch@nau.edu.ua; [2]brbnv@i.ua; [3]grekhovam@ukr.net; [4]l-39@ukr.net; [5]rudnykjj@ukr.net

Abstract. *For modelling of ADS-B messages transmitting on the base of low-orbit satellite constellation Iridium the model of a communication channel "Aircraft - Satellite - Ground Station" was built using MATLAB Simulink. This model allowed to investigate dependences of the Bit Error Rate on a type of signal coding/decoding, ratio E_b/N_0 and satellite repeater gain.*

Keywords: Bit Error Rate; convolutional coding; model of a communication channel "aircraft - satellite - ground station"; satellite communication channel.

1. Introduction

On 20 June 2012 satellite operator Iridium has decided that they will be putting Automatic Dependent Surveillance - Broadcast (ADS-B) receivers on its next-generation satellite constellation, aimed at bringing global, real-time aircraft surveillance for air navigation service providers [Aviation…2012]. This new satellite system will enable continuous space-based monitoring and control of aircraft, using space-qualified 1090 MHz Extended Squitter (ES) ADS-B receivers built into each of the 66 satellites in Iridium Next, Iridium's second-generation satellite constellation. Iridium Next satellites are scheduled to launch from 2015 to 2017, and will provide this capability as the new satellites are commissioned, with full service expected by 2017.

ADS-B is a surveillance technology for tracking aircraft as part of the Next Generation Air Transportation System (NextGen) [Minimum… 2002]. ADS-B makes flying significantly safer for the aviation community. When using this system both pilots and controllers will see the same radar picture. ADS-B consists of two different services "ADS-B Out" and "ADS-B In". With ADS-B, information is sent to aircraft using ADS-B In, which displays all aircraft in the area, even those not equipped with ADS-B technology. The position report is updated once per second.

In aviation telecommunications satellite systems are widely used [Diatlov 1997; Kantor, Povolotskiy 1994; Bobrovskiy 1992; Konkov 1994]. Advantages of satellite communication in aviation are connected with possibility of operation with many airplanes at long distances and with independence of communication expenses on distances to airplanes.

Operation of satellite communication link is very sensitive to its parameters and even small alterations of these parameters can cause changing of data rate and ground coverage of satellite system.

For this reason it is important to develop models of real satellite communication channels and investigate methods of critical situations correction.

2. The analysis of researches and publications

The Iridium system includes 66 LEO satellites at an altitude of 785 km and equally divided into 6 orbital planes [Kharchenko et al. 2012]. The orbits are circular with an inclination angle of 86.4° degrees [Manual…2007]. Each satellite communicates with the AES. Each satellite uses three phased-array antennas for the user links, each of which contains an array of transmit/receive modules. These arrays are designed to provide user-link service by communicating within the 1616-1626.5 MHz band. The gateway connects the Iridium satellite network to ground communication networks, such as the terrestrial Public Switched Telephone Networks (PSTNs) and Public Switched Data Networks (PSDNs), and communicates via ground-based antennas with the gateway feeder link antennas on the satellite.

The gateway can also serve as a gateway to the ATN for forwarding ATN messages from the aircraft to the required Air Traffic Command (ATC) or Aircraft Operational Communication (AOC) unit or vice versa.

Channels are implemented in the Iridium Satellite Network using a hybrid Time Division Multiple Access/Frequency Division Multiple Access (TDMA/FDMA) architecture based on Time Division Duplex (TDD) using a 90 millisecond frame.

Iridium system employs Quadrature Phase Shift Key (QPSK) modulation and Forward Error Correction Coding (FECC) in the form of convolutional encoding with Viterbi decoding [Viterbi 1971]. Iridium uses a rate 3/4, constraint length 7, (r=3/4; K=7) convolutional code on both transmission and reception. The supportable transmission rates for voice (data) are 4.8 kbps (2.4 kbps).

The purpose of this paper is:

1) to design the model of communication channel "Aircraft - Satellite - Ground Station" with Iridium system parameters using MATLAB Simulink software [Diakonov 2005];

2) on the base of this model investigate a channel integrity and receive dependences of the Bit Error Rate (BER) on a type of signal coding/decoding, ratio E_b/N_0, data rate and satellite repeater gain.

3. Model for "Aircraft-to-Satellite-to-Ground Earth Station" Link

Our model comprises Source of Data (Bernoulli Binary Generator), Aircraft Transmitter (modulator with or without Convolutional encoder), Uplink Path (AWGN channel), Satellite Repeater (Receiver Dish Antenna Gain, Complex Baseband Amplifier with Noise, Transmitter Dish Antenna Gain), Downlink Path (AWGN channel), Ground Station Receiver (demodulator with or without Viterbi Decoder), Error Rate Calculation block and Display (Fig. 1).

Complex Baseband Amplifier block in satellite transponder generates a complex baseband model of an amplifier with thermal noise. It simulates linear amplifier and allows to specify noise (noise temperature – specifies the noise in Kelvin; noise factor – specifies the noise by the following equation:

Noise factor = 1 + Noise temperature/290).

In this paper during a simulation QPSK modulation scheme was considered only. For QPSK modulation BER was calculated without and with convolutional coding as function of a ratio E_b/N_0. The value of a ratio E_b/N_0 was changed symmetrically in uplink AWGN and downlink AWGN channels. All calculations were done when receiver/transmitter dish antenna gain was equal to unit.

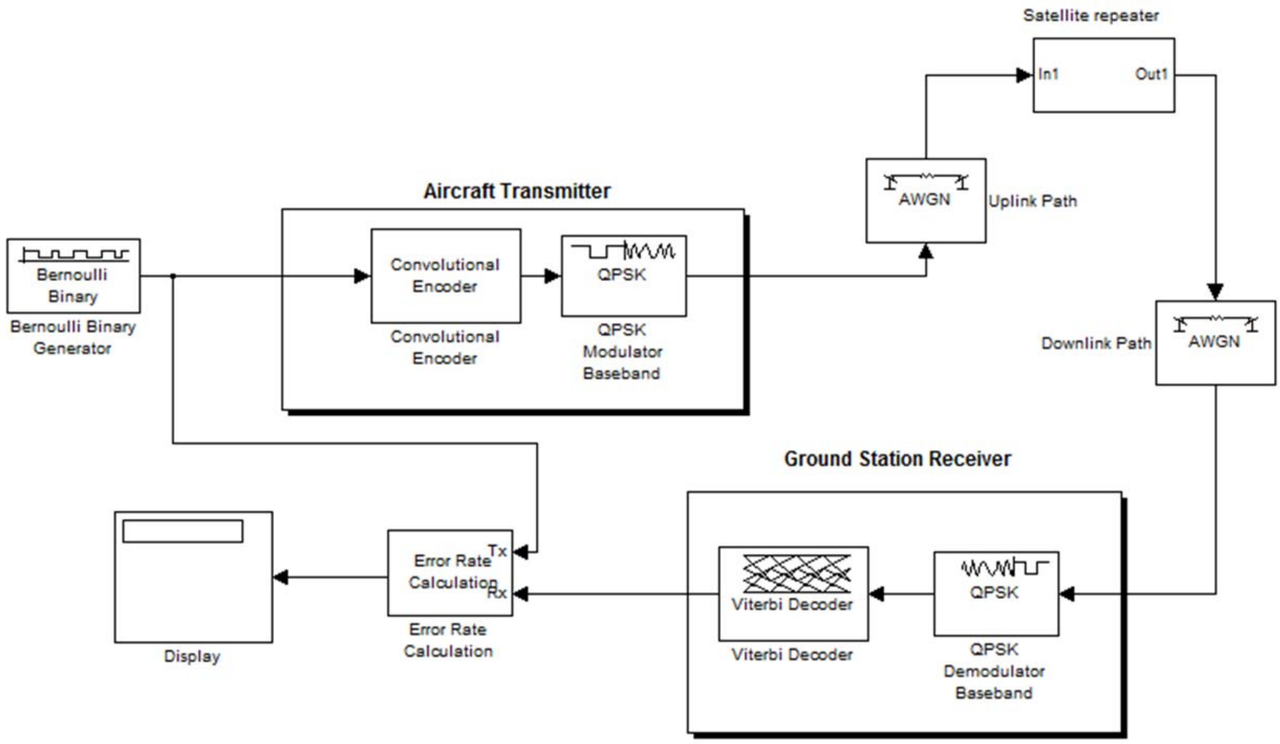

Fig. 1. "Aircraft-to-Satellite-to-Ground Earth Station" Link

Noise factor in complex baseband amplifier was taken as 2 (290 K – typical noise level). When investigating effect of coding for different modulation types we took satellite linear amplifier gain equal to unit.

These models also allow investigation of BER dependence on satellite transponder amplifier gain without and with coding and such dependencies were obtained for QPSK modulation.

4. Aeronautical satellite channel simulation

For modeling were used Iridium system parameters: QPSK modulation, FECC in the form of convolutional encoding with Viterbi decoding, a rate 3/4, constraint length 7 convolutional code on both transmission and reception.

The source (Bernoulli Binary Generator) generates random binary numbers. It was set to frame-based outputs, with a probability of zero 0.5, initial seed 61, sample time 1 and samples per frame 1.

Convolutional encoder encodes binary data. Viterbi decoder uses the Viterbi algorithm to decode convolutionally encoded input data. Convolutional encoder and Viterbi decoder operated with Trellis structure: poly2trellis (7, [171 133]) and with Continuous Operation mode. Poly2trellis function is used to create a trellis using the constraint length, code generator (octal) and feedback connection (octal). The poly2trellis function accepts a polynomial description of a convolutional encoder and returns the corresponding trellis structure description. The output of poly2trellis is a mask parameter for the Viterbi Decoder.

Function poly2trellis (ConstraintLength, Code Generator) performs the conversion for a rate k/n feed forward encoder. ConstraintLength is a 1-by-k vector (7) that specifies the delay for the encoder's k input bit streams. CodeGenerator is a k-by-n matrix [171 133] of octal numbers that specifies the n output connections for each of the encoder's k input bit streams.

5. Results

Results of simulations are shown in Figs 2, 3. First, it is interesting to compare a value of BER for different types of coding.

From Fig. 3 follows that for low values E_b/N_0 (up to 10 dB) cyclic coding is more effective than convolutional coding. But for E_b/N_0 bigger than 11 dB convolutional coding is more effective.

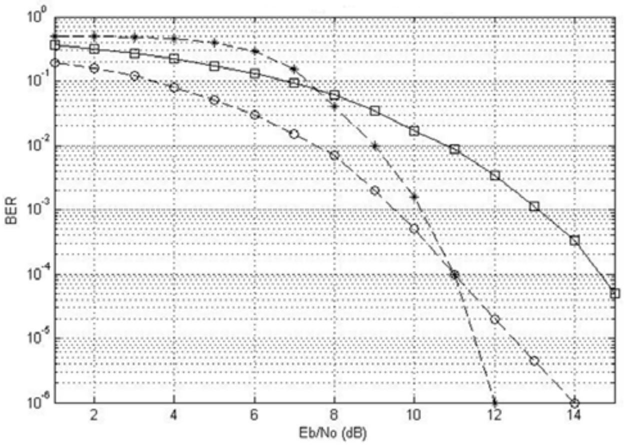

Fig. 2. Effect of coding:
solid line (squares) – QPSK without coding; dashed line (circles) - QPSK with Hamming (7, 4), *t*=1 coding;
dashed line (asterisks) – QPSK Convolutional coding (rate 3/4)

An investigation of BER dependence on satellite transponder amplifier gain without and with coding was provided for two meanings of a ratio E_b/N_0 (8 dB and 10 dB) in uplink and downlink when receiver/transmitter dish antenna gain was equal to unit, noise factor in complex baseband amplifier was taken as 2 (Fig. 3). For QPSK decreasing of BER is bigger for higher ratio E_b/N_0 (compare upper plot for $E_b/N_0 = 8$ dB and lower plot for $E_b/N_0 = 10$ dB correspondingly in Fig. 3).

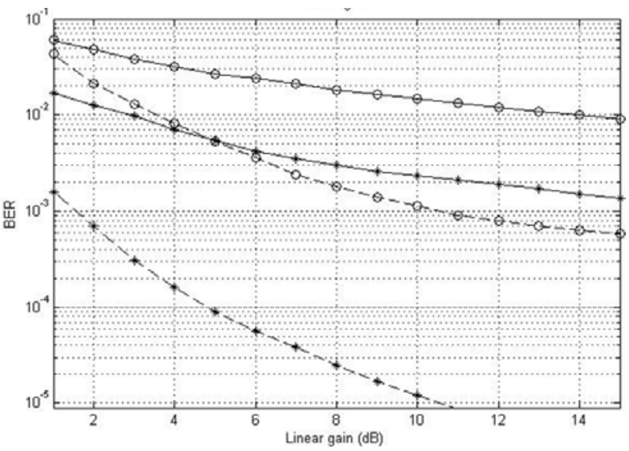

Fig. 3. Impact of Satellite Transponder Amplifier Gain on QPSK:
solid line (circles) – QPSK without coding for $E_b/N_0 = 8$ dB;
dashed line (circles) - QPSK with Convolutional coding (rate 3/4) for $E_b/N_0 = 8$ dB;
solid line (asterisks) – QPSK without coding for $E_b/N_0 = 10$ dB;
dashed line (asterisks) – QPSK Convolutional coding (rate 3/4) for $E_b/N_0 = 10$ dB

We have investigated coding with different coding rates and have received the same BER plots for 1/2 and 3/4 rates.

It was important to analyze transmission of information with different data rates. Modeling alteration of data rate using different sampling time in Bernoulli Binary Generator has shown non-sensitivity of BER to these manipulations.

6. Conclusions

1. For modelling of ADS-B messages transmitting on the base of low-orbit satellite constellation Iridium the model of a communication channel "Aircraft - Satellite - Ground Station" was built using MATLAB Simulink.

2. This model allows investigating dependences of BER on a type of signal coding and satellite repeater gain.

3. Proposed model can be used as basic model for investigation of communication between two airplanes and ground stations using several satellites.

4. Developed model can also be used for finding optimal methods of error-correcting coding and channel integrity.

References

Aviation Today. 2012. Available from Internet: <http://www.aviationtoday.com/the-checklist/Iridium-Adds-ADS-B-to-its-Iridium-NEXT-Constellation_76558.html>.

Bobrovskiy, D.G. 1992. *Low-orbital Satellite Communication Systems*. Networks. N 4: 73–79 (in Russian).

Diakonov, V.P. 2005. *MATLAB 6.0/6.1/6.5/6.5+SP1 + Simulink 4/5.* Processing of Signals and Images. Complete User's Guide. Moscow, Solon-Press. 592 p. (in Russian).

Diatlov, A.P. 1997. *Satellite Systems for Communication with Moving Objects.* Manual. Part 1. Taganrog. 95 p. (in Russian).

Kantor, L.Y.; Povolotskii, I.S. 1994. *Systems of Personal Mobile Communication Using Low-orbital Satellites*. Bulletin of Communications. N 11: 61–65 (in Russian).

Kharchenko, V.P.; Barabanov, Yu.M.; Grekhov, A.M. 2012. *Modeling of Satellite Channel for Transmission of ADS-B Messages*. Proceedings of the National Aviation University. N 3: 9–14 (in Ukrainian).

Konkov, A.M. 1994. *Prospects for Development of Low-orbital Satellite Communication Systems*. Bulletin of Communications. N 1: 34–38.

Manual For ICAO Aeronautical Mobile Satellite (Route) Service Part 2-Iridium Draft V4.0, 2007. 77 p.

Minimum Aviation System Performance Standards for Automatic Dependent Surveillance-Broadcast (ADS-B). RTCA, Inc. June 25, 2002. DO-242A.

Viterbi, A. 1971. *Convolutional Codes and Their Performance in Communications Systems*. IEEE Trans. Commun. Technol. N 5: 751–772.

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В.П. Харченко[1], Ю.М. Барабанов[2], А.М. Грехов[3], М.М. Богуненко[4], Ю.І. Рудник[5]. Завадостійке кодування ADS-B повідомлень супутників Iridium
Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
E-mails: [1]kharch@nau.edu.ua; [2]brbnv@i.ua; [3]grekhovam@ukr.net; [4]l-39@ukr.net; [5]rudnykjj@ukr.net
Для моделювання передачі ADS-B повідомлень за допомогою низькоорбітального супутникового комплексу Iridium у середовищі MATLAB Simulink побудовано модель каналу зв'язку «літак–супутник–наземна станція», яка дозволила дослідити залежності коефіцієнта двійкових помилок від типу кодування/декодування сигналу, співвідношення E_b/N_0 та коефіцієнта підсилення супутникового повторювача.
Ключові слова: згортальне кодування; коефіцієнт двійкових помилок; модель каналу зв'язку «літак–супутник–наземна станція»; супутниковий канал зв'язку; MATLAB Simulink.

В.П. Харченко[1], Ю.М. Барабанов[2], А.М. Грехов[3], Н.Н. Богуненко[4], Ю.И. Рудник[5]. Помехоустойчивое кодирование ADS-B сообщений спутников Iridium
Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mails: [1]kharch@nau.edu.ua; [2]brbnv@i.ua; [3]grekhovam@ukr.net; [4]l-39@ukr.net; [5]rudnykjj@ukr.net
Для моделирования передачи ADS-B сообщений с помощью низкоорбитального спутникового комплекса Iridium в среде MATLAB Simulink построена модель канала связи «самолет–спутник–наземная станция», позволяющая исследовать зависимости коэффициента двоичных ошибок от типа кодирования/декодирования сигнала, соотношения E_b/N_0 и коэффициента усиления спутникового повторителя.
Ключевые слова: коэффициент двоичных ошибок; модель канала связи «самолет–спутник–наземная станция»; сверточное кодирование; спутниковый канал связи; MATLAB Simulink.

Kharchenko Volodymyr (1943). Doctor of Engineering. Professor. Holder of a State Award in Science and Engineering of Ukraine. Winner of a State Prize of Ukraine in Science and Engineering.
Vice-Rector for Scientific-Research Work, National Aviation University, Kyiv, Ukraine.
Head of the Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Civil Aviation Engineers Institute with a Degree in Radio Engineering, Kyiv, Ukraine (1967).
Research area: management of complex socio-technical systems, air navigation systems and automatic decision-making systems aimed at avoidance conflict situations, space information technology design, air navigation services in Ukraine provided by CNS/ATM systems.
Publications: 402.
E-mail: knarch@nau.edu.ua

Barabanov Yurii (1951). Candidate of Engineering (1996). Associate Professor.
Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Education: Dipl.-Military Radio Engineering Degree from High Military Engineering Aviation Institute, Kyiv, Ukraine (1973).
Research area: computer modeling of antennas, wireless and satellite communication networks, telecommunications, ADS-B systems.
Publications: 51.
E-mail: brbnv@i.ua

Grekhov Andrii (1951). Doctor of Physics and Mathematics (1990). Professor (1991). Expert of EUROCONTROL for ADS-B systems.
Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Education: Physical Department of the Kyiv State Taras Shevchenko University, Ukraine (1973), M.Sc. Degree with Honors confirming qualification of Physicist Theorist.
Research area: air satellite communications and information channels, computer modeling of information flows transmission in airborne collision avoidance systems, ADS-B systems, onboard recorder and communication channels, surveillance processes and modern signal processing, expansion of terrestrial surveillance systems for ADS-B using satellite system IRIDIUM, noise resistant coding and forward error correction, aviation security assessment based on simulation.
Publications: 151.
E-mail: grekhovam@ukr.net

Bogunenko Mykola (1957). Associate Professor.
Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Education: Kharkov High Military School of Pilots, Kharkov, Ukraine (1978), Air-Force Academy, Ukraine (1991).
Research area: navigation and management, problems develop of air navigation systems, aviation safety provision, develop of air traffic control intelligence systems, flight safe services, vortex wake detection systems, application of geoinformation systems for aviation.
Publications: 14.
E-mail: l-39@ukr.net

Rudnyk Julia (1990). Master.
National Aviation University, Kyiv, Ukraine.
Publications: 4.
E-mail: rudnykjj@ukr.net