TECHNICALUNIVERSITY OF GABROVO
Faculty of Electrical Engineering and Electronics
Department of Communications Equipment and Technologies

M.Eng. SEYHAN SADAK MYUMYUNALI

RESEARCH AND IMPROVEMENT OF THE QUALITY OF SERVICE IN SATELLITE COMMUNICATION CHANNELS

AUTHOR'S SUMMARY

of Dissertation
for obtaining of educational and scientific degree "Doctor"

Field of higher education: 5. Technical Sciences
Professional area: 5.3. Communication and Computer Technology
Doctoral Program: Communication Networks and Systems

Scientific supervisor:
Prof. Stanimir Mihaylov Sadinov, PhD

Reviewers:
1. Prof. Raycho Todorov Ilarionov, DSc
2. Assoc. Prof. Egnar Ibrahimova Ozdikililer, PhD

Gabrovo, 2022

The dissertation work was discussed and scheduled for official defense at a meeting of the Extended Departmental Council of the Department of "Communication Equipment and Technologies" at the Faculty of Electrical Engineering and Electronics of the Technical University of Gabrovo, held on 24.11.2022.

The dissertation thesis contains 129 pages. The scientific content is presented in an introduction, five chapters and a conclusion, includes 72 figures and 24 tables. 137 references and 12 Internet addresses are cited. The numbering of figures, tables and formulas in the author's summary is consistent with that in the dissertation.

The research on the dissertation thesis was carried out in the Department of "Communication Equipment and Technologies" at the Faculty of Electrical Engineering and Electronics of the Technical University of Gabrovo and on the territory of the city of Gabrovo.

The official defense of the dissertation thesis will take place on February 24, 2023 at 2 p.m. in room 2215, Academic Building №2 ("Bajdar") of the Technical University of Gabrovo.

Defense materials are available for those interested in office 3209, Academic Building №3 of the Technical University of Gabrovo.

The reviews and opinions of the members of the scientific jury and the author's abstract are published on the university's website: www.tugab.bg.

e-mail: seyhan1982@abv.bg
Title: Research and Improvement of the Quality of Service in Satellite Communication Channels

I. GENERAL CHARACTERISTICS OF THE DISSERTATION WORK

Relevance of the problem:

The development of satellite communications is related to the search and experimentation of new orbits and the improvement of channel coding methods, the use of new modulation schemes and the expansion of the frequency spectrum, and this leads to interesting results related to the improvement of the efficiency and quality of connection. Choosing a channel code with a higher efficiency would allow to reduce the rate of the code used and to increase the multiplicity of the modulation used, while maintaining the error probability. This, in turn, leads to an increase in channel throughput. In order to obtain maximum noise immunity, it is necessary to optimize the parameters of the modulation constellation after optimizing the channel code. The optimization of the modulation constellations allows to achieve an optimal compromise between the noise immunity of the radio channel, the energy efficiency and the resistance to nonlinear distortions.

The chosen topic and the problems related to it make it possible to combine heterogeneous statistical analytical and software methods for data analysis and processing, and the means of information and communication technologies are used to ensure the transfer of satellite data and measurement setups with monitoring of the parameters of the satellite channel. The presented topic leads to the creation of methodologies from procedures related to correct approaches in monitoring and control in communication systems for satellite digital broadcasting, by determining optimal ranges of changes of specific technical parameters and criteria related to the effective operation and setting of satellite communication channels

Research methods:

To achieve the goal and the tasks set in the research, analytical, simulation and practical methods are applied. The Matlab/Simulink and Free Space Propagation Simulator programming environments were used as a tool for the simulation studies. The chosen research methodology is adequate.

Novelties:

Simulation models for satellite communications have been created, research has been carried out and contributions related to efficient use of frequency spectrum, type of modulation and channel coding have been defined in order to obtain a higher quality of service on satellite communication channels. Test setups have been implemented and experiments have been made to evaluate the packet error in a communication channel for connection with an artificial satellite of the "cubesat" type, and graphical dependences have been presented, providing information for the search for optimal solutions in the selection of the operating frequency range, altitude and orbit parameters. the transmission power, parameters of the receiving-transmitting antenna, as well as to evaluate the influence of the complex combination of these parameters.

Purpose and tasks of the research:

The purpose of the dissertation work is to present and investigate the signal processing processes - generation, coding, modulation, transmission and reception of DVB-S/S2 signals - by synthesizing simulation models and conducting practical experimental results.

In order to realize the formulated purpose, it is necessary to solve the following *general tasks*:

1. Synthesize a simulation model of a DVB - S/S2 system in the Simulink graphical environment of Matlab, which corresponds to the sequence of signal processing in a system and

through which complete information about the bit content of the signal is obtained after each of the operations in the process of its processing.

2. To conduct research and evaluation of noise immunity, energy efficiency and resistance to non-linear distortions of signals and determine their optimal values according to set criteria depending on the applied processing, modulation form and modulation parameters and channel coding.
3. To implement simulation and experimental modeling, analysis and evaluation of the satellite-to-Earth link communication channel for low-Earth orbit satellites with the combined use of different operating frequency bands, transceiver settings and channel parameters.
4. Да се представят експериментални изследвания на покритието и качеството на обслужване в системите за спътникова цифрова телевизия, като се предложат методи и мерки за неговото подобряване на база параметрите и характеристиките на спътниковите сигнали и осигуреното радиопокритие.

Subject and object of research of the dissertation work:

The subject of research are the processes related to the processing, transmission and reception of satellite communication signals in satellite transmitters and receivers - modulation, channel coding, multiplexing, polarization characteristics of the signal, synchronization, configuration, adjustment and coordination of the transceiver equipment. As criteria for determining the quality of service, various evaluation parameters and quality indicators such as equivalent isotropic radiated power (EIRP), field strength, spectral and vector characteristics of the signal and the signal-to-noise ratio were used in criteria of maximum permissible values of the modulation erro rate (MER), binary (BER) and packet (PER) error rates, etc.

The object of research in the dissertation work is the wireless transmission environment with its features and influence, as well as the processes of signal processing and transmission in satellite communication channels, in particular in satellite television systems according to the DVB-S/S2 standard, in satellite transmission systems of data and in communications with satellite systems operating in low Earth orbit.

Approbation of the dissertation work:

The main stages of the development of the dissertation work are presented in six publications of international conferences and scientific publications, fully covering the minimum requirements regarding the considered criterion. Three of the papers were presented at the International Scientific Conference "Unitech" and three at a national conference and "TechCo", one of them being independent, and the other five being prepared in co-authorship with the scientific supervisor and author team. Publications have been published in peer-reviewed proceedings from Unitech International Scientific Conference and TechCo National Conference in the academic period 2020-2022.

II. BRIEF CONTENTS OF THE DISSERTATION WORK

CHAPTER I. STATUS, PROBLEMS AND PERSPECTIVES IN THE CONSTRUCTION AND OPERATION OF SATELLITE COMMUNICATION CHANNELS AND SERVICES

1.1. Principles of construction of satellite communication systems

Communication satellites revolve around the Earth in orbits whose planes pass through the center of the globe. Depending on the inclination angle α between the plane of the orbit and the plane that passes through the equator, there are equatorial ($\alpha = 0°$), polar ($\alpha = 90°$) and inclined or intermediate ($0° < \alpha < 90°$) orbits of the satellites (Fig.1.3).

In order for a satellite to periodically appear over the same area during a certain time, it must rotate a whole number of times in a day. If the satellite is located 265 km above the equator, the number of rotations is 16, at an altitude of 1,670 km – 12, and at an altitude of 6,420 km – 6.

A satellite located at an altitude of 35,887 km in the plane of the equator is said to be in a so-called geostationary orbit. Such a satellite completes one revolution around the Earth in exactly one Earth day. If the direction of its motion coincides with the direction of rotation of the Earth, then it will appear stationary to an earthly observer and will always be in the same field of view.

The first to calculate the location of a communication satellite so that it would always be over the same geographic point was the American physicist and science fiction writer Arthur Clarke in 1945. In his honor, the geostationary orbit is called "Clark's Belt" . [126-133]

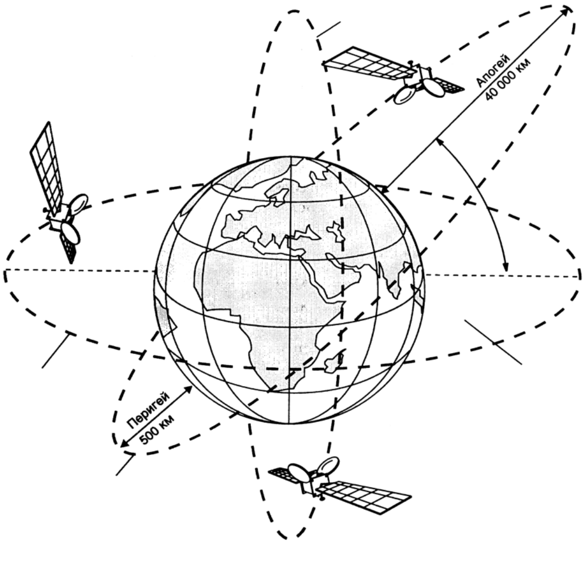


Fig. 1.3. Types of satellite orbits

Currently, all commercial communications satellites are in geostationary orbit. At one position, at one longitude, several satellites can be located, at a distance of 100 km from each other. For example, seven satellites of the Astra series are placed in the same position at 19^0 east longitude.

The most important advantages of communication satellites in geostationary orbit are:

- *Continuous 24/7 radio connection;*
- *Simplified organization of connections on a global scale;*
- *High signal stability in a given radio channel;*
- *Lack of tracking devices in ground station antenna systems.*

A disadvantage of using the geostationary orbit is the oversaturation with satellites in certain sections and the impossibility of serving the polar regions.

1.2. Application of satellite TV repeaters

The satellite receives low-power signals from the Earth and, after amplifying them, retransmits them back. The close proximity of the receiving and transmitting antenna would make the system unstable if the satellite were to operate as a repeater or regenerator. Therefore, the retransmission (retransmission) is carried out at different frequencies - a chain of frequency converters called transponders is placed between the receivers and the transmitters mounted on the satellite. The transmission frequency to the satellite (on the "uplink" channel) is usually higher than the transmission frequency to Earth (on the "downlink" channel). In this case, the frequency converters are step-down and are often called "step-down converters". The necessary microwave power between 3 and 400 W per transmitter is directed to the Earth through parabolic mirror antennas. Small powers are used for a sharply focused beam in certain small areas, and large powers are used for global continental coverage [126,133].

In combination with cable networks, satellite repeaters are currently the main means of providing multi-program high-quality television broadcasting.

The satellite television broadcasting system includes the following subsystems:

- *Предавателен телевизионен център*
- *Активен спътник ретранслатор*
- *Приемна апаратура*

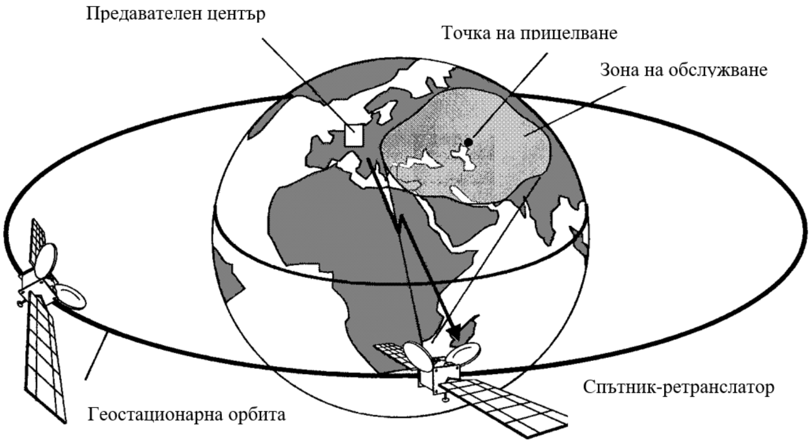


Fig. 1.5. Satellite retransmission of television signals

The part of the earth's surface that must be covered by television broadcasting at a given signal level is called the "service area". This area usually has a complex geometric shape.

In satellite television broadcasting, the level of the broadcast signal is assumed to be characterized by the product of the power (in watts – W) that is supplied to the antenna and its amplification factor (in decibels – dB) relative to an isotropic emitter with a power of 1W. An isotropic emitter is one that has uniform radiation in all directions.

The above product is called equivalent isotropic radiated power (EIRP) and is measured in dBW. In engineering practice, this parameter is determined by the expression:

$$EIRP = G_T + 10lg\,(\alpha_T P_T), \qquad (1.1)$$

where G_T is the gain of the transmitting antenna; α_T is the power transmission coefficient of the waveguide path of the on-board equipment from the output of the transmitter to the radiator of the antenna.

Depending on the value of EIRP, they are divided into four groups:

1. Low power with EIRP = 45 – 50 *dBW*
2. Medium power with EIRP = 50 - 55 *dBW*
3. Optimum in power with EIRP = 55 - 60 *dBW*

4. High power with EIRP = 60 – 65 *dBW*

The total energy losses from the satellite to the Earth (in decibels) are calculated using the formula

$$L = L_0 + L_\Sigma, \qquad (1.2)$$

where L_Σ is the additional attenuation of the signal (absorption by the atmosphere, refraction, depolarization, location of the receiving antenna, etc.), L_0 are the free-space losses due to signal attenuation with distance from the source (in decibels). For the frequency ranges used in satellite radio and television broadcasting and at the maximum distance between the receiver and the transmitter $L_0 \approx 206\ dB$.

Since Bulgaria is located in the so-called second climate zone and the angle of the site is about 40°, the additional losses are 1.5 dB. If the emitting satellite operates in the 12 GHz band, the total path loss between the satellite and Earth will be about 207 dB.

Most often, as a characteristic of the satellite line, it is represented by the power flux density at the reception point PFD (Power Flux Density), which represents the signal power per unit area and is determined in dBW/m^2 by the formula:

$$PFD = EIRP - L\ 20lgF + 21,5 \quad , \qquad (1.3)$$

where *EIRP* is in *dBW* , *L* – in *dB*, *F* - frequency in *GHz*. For example, if $EIRP = 50 - 55\ dBW$; $L = 207\ dB$ and $F = 12\ GHz$, than $PFD = -(114 \div 109)\ dBW/m^2$.

1.3. Status and relative share of satellite communications in the Republic of Bulgaria

In 2021, the volume of the "Services for transmission and/or distribution of radio and television programs" market segment amounted to BGN 453.187 million and marked an increase of 6% compared to 2020.

Summary information on the number of companies that provided services for transmission and/or distribution of radio and television programs, on the number of their subscribers/users, as well as on the amount of revenue generated by them, together with the structure of the segment, is presented in [159].

According to the data presented by the telecommunications operators, in 2021 growth was marked by the revenues from three services included in the segment - IPTV (by 18.7%), satellite television (by 3.3%) and services for the distribution of radio and television programs wholesale (by 2.3%), for the considered one-year period. The revenues of the remaining services in the segment are decreasing compared to 2020. A decrease is observed in the amount of revenues from cable TV - by 2.5% compared to 2020.

In 2021, the largest share in the total volume of the segment (92%) continues to be occupied by revenues from the provision of retail services for the distribution of radio and television programs (Fig. 1.7): cable television, satellite (satellite) television and IPTV. For another year, revenues from satellite TV occupy the highest share in the total volume of the segment, and in relative terms this share decreases by 1 percentage point in a one-year period to 38.1%, followed by the share of revenues from IPTV, which in 2021 d. continues its upward development. Only the share of revenues from the provision of IP television recorded growth compared to the previous year by 3.4 percentage points, reaching 31.4% of the total volume of the segment and approaching the share of revenues from satellite television.

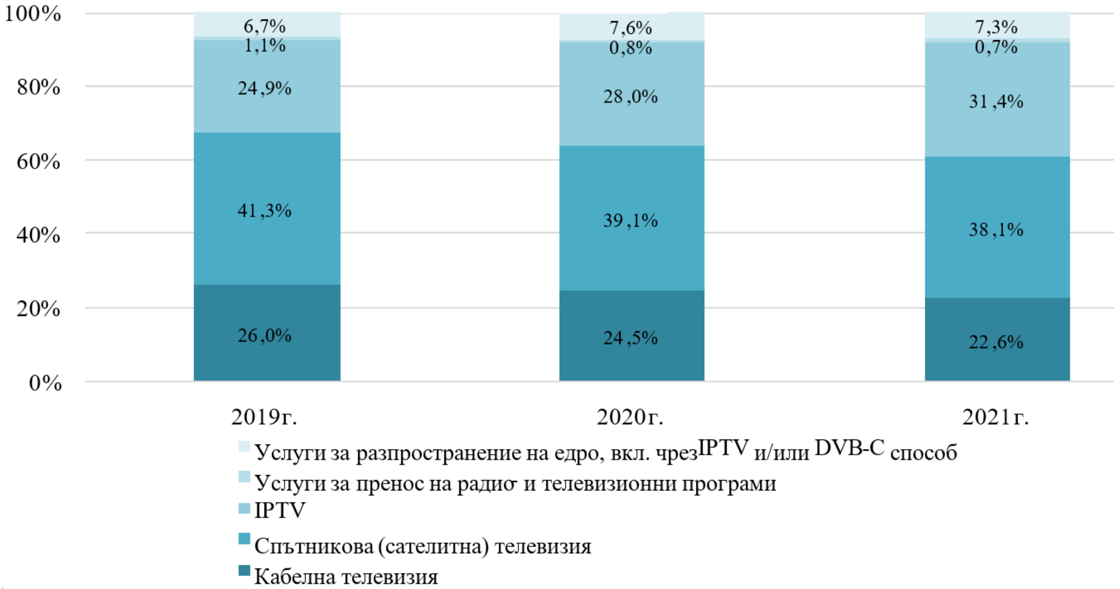


Fig. 1.7. Revenue structure by types of services of the market segment "Services for transmission and/or distribution of radio and television programs" for the period 2019 - 2021.

1.4. Implementation of standards for satellite distribution of digital television signals

1.4.2. DVB-S2 standard

The DVB-S standard does not have flexibility - on the one hand, in certain conditions it allows to achieve reception with up to one error per hour, which is higher than necessary, and on the other hand, in heavy rain, the protection is insufficient for the Ku range and often the reception is interrupted. This has necessitated the development of a new standard. The new standard is also provoked by the development of technologies and is the result of serious research and computer simulations. The standard is known as DVB-S.2 and the variant EN 302 307 v1.1.2 was published in 2006 [30].

When preparing the DVB-S.2 standard, the following requirements were set:

- to increase the efficient use of the transport capabilities of the satellite channels;
- that there should be a differential approach when choosing the transport parameters of the channel during the simultaneous transmission of different services;
- to be compatible with the DVB-S standard.

As a result, a universal standard DVB-S2 has been developed, allowing to build broadcast networks for both standard TV and high-definition TV, networks for providing interactive services, for professional applications, for data transmission and for creating IP highways[34].

1.5. Problems of satellite television broadcasting and methods of solving them

To ensure the necessary quality of receiving digital TV programs, it is necessary that the bit error rate (BER - Bit Error Rate) at the output of the channel decoder is in the range of 10^{-11}. This corresponds to the so-called quasi error free reception (QEF – Quasi Error Free). Quasi-error-free reception is achieved when the Carrier to Noise Ratio (CNR) at the input of the satellite receiver is greater than a set value. Problems in meeting this requirement are caused by the huge signal attenuation (over 200 dB) and the high level of noise in the satellite radio link.

In satellite and terrestrial systems, the $BER \leq 10^{-11}$ requirement is met by applying two-level (external and internal) coding and additional bit shifting. The channel codes that have prevailed in DVB systems of the first generation are the Reed-Solomon and the convolutional code, and in the second generation systems – the BCH and LDPC codes. These codes are described in detail in the existing standards for satellite TV broadcasting [26, 30, 31, 34].

To increase the efficiency of the Reed-Solomon code, the codeword length can be increased while maintaining the code rate, or the code rate can be decreased while maintaining the codeword length. Such studies were done in [102]. However, the reduction of the code rate leads to a reduction of the transmitted information in the packet, which degrades the throughput of the link channel. Therefore, it is necessary to make a compromise when choosing the code parameters (packet length and code rate) between noise immunity, throughput and complexity of the equipment used.

When choosing the optimal convolutional code, it is important to consider two main factors. The first is the length of memorization, and hence the generator polynomials of the outputs, and the second is the computational complexity of the decoder. In [95] and [96], the optimal generator polynomials of convolutional codes with memory length up to 9 and code rate 1/2 and 1/3 are given. The optimal generator polynomials of convolutional codes with rates 1/2, 1/3 and 1/4 and storage length up to 14 are presented in [64], and for codes with rates 1/2, 1/3 and 2/3 and length of remembering up to 13, 9 and 8 – in [42], [119] and [130]. The main disadvantage of convolutional codes is its complex decoding. Even when using a Viterbi decoder, increasing the memory length increases the computational complexity of the decoder significantly. This leads to a limitation of the memory length of the convolutional code, and hence its efficiency.

The BCH code is a generalized version of the Reed-Solomon code, and the basic dependences of the code's efficiency on its parameters are analogous. The difference between the Reed-Solomon codes used and the BCH code is that the latter is binary and has a significantly longer codeword length.

The main advantage of the second generation DVB systems in terms of noise immunity is due to the LDPC codes. Although proposed long ago (1963) in Gallagher's dissertation [44], their use only began in the late 1990s. The codes proposed by Gallagher were "regular" (with the same number of units in each row and the same number of units in each column of the check matrix), and then the "irregular" codes were proposed, which found greater application due to more its good characteristics (higher efficiency, flexibility, etc.) The main problem of LDPC codes is the difficult calculation of the generator matrix based on the check matrix. In [106], [23] and [24] "irregular" LDPC codes with a specific check matrix structure are described, where the calculation of the generator matrix is relatively simple.

Research in the field of LDPC codes is mainly directed in the following two directions: improving their efficiency and reducing the complexity of the coding and decoding equipment. An iterative decoding algorithm is proposed in [40], which reduces the complexity of this process, and in [75] block diagrams implementing the encoding and decoding processes are presented. In [117], an algorithm for computer television receivers is proposed, where for LDPC decoding, in addition to the central processor, a video accelerator supporting the CUDA technology is used, providing several times the acceleration of the decoding process.

When choosing a modulation, the aim is to achieve the largest possible channel capacity while preserving the noise immunity of the radio channel and minimal non-linear distortions of the signals in it. It is known that the channel capacity increases with an increase in the multiplicity of manipulation, but this leads to a greater probability of error in the received video information. Therefore, in satellite DVB systems, phase keying (PSK) with a multiple of more than eight is not used. At the same frequency of manipulation, quadrature amplitude manipulation (QAM) provides greater noise immunity of the channel, but this modulation is not suitable for transmitting the signals on the non-linear satellite TV channel. Therefore, in second-generation satellite DVB systems, together with QPSK and 8PSK methods, amplitude-phase manipulation (APSK) is used, which is not inferior to QAM in terms of noise immunity, but is more resistant to nonlinear distortions and provides greater energy efficiency of the transmitter. In [47] it is proved that when the link channel is linear its noise immunity is almost the same using APSK and QAM method, and in [90] and [92] the advantages of APSK modulation compared to QAM in a non-linear channel are shown for connection.

The DVB-S standard provides a QPSK method for transmitting TV signals via a satellite radio channel, while the DVB-S2 standard uses four types of modulation (QPSK, 8PSK, 16 APSK and 32 APSK), and QPSK and 8PSK. This is explained by the fact that they have a constant amplitude and are more resistant to nonlinear distortions, which allows the final power amplifier in the satellite repeater to operate in a mode close to the saturation point. 16APSK and 32APSK modulations are intended mainly for professional applications, but they can also be used for TV broadcasting, since due to their greater bandwidth efficiency they allow to increase the capacity of the satellite radio channel. These pre-correction methods at the transmitting station in order to reduce the effects of the nonlinearity of the final power amplifier in the satellite repeater.

APSK modulations are specially optimized for use in a non-linear power amplifier by arranging the signal points in circles instead of squares as in QAM. Although these modulations are more resistant to nonlinear distortions than QAM, their energy efficiency is less than that of PSK, because the symbol points in APSK constellations are located on more than one concentric circle.

Various algorithms have been developed to optimize the parameters of the APSK constellation, the most popular of which are the maximization of the minimum Euclidean distance [49] and the maximization of mutual information [78]. In the DVB-S2 standard, 16APSK and 32 APSK constellations are used, which are optimized according to the second criterion, and their parameters are given in [48]. Expressions for determining the symbol and bit error in 64APSK constellations can be found in [1], and an optimized 64APSK constellation is proposed in [39].

CHAPTER II. SYNTHESIS OF MODELS FOR SIMULATION RESEARCH OF DIGITAL SYSTEM ACCORDING TO DVB-S2 STANDARD

DVB-S2 is the second generation digital video broadcasting standard. The system is a modern solution for channel coding, and the coding scheme is based on a combination of LDPC (low density parity check) and BCH codes. LDPC codes can achieve extremely low error rates near channel capacity by using a low-complexity iterative decoding algorithm. External BCH codes are used to correct random errors made by the LDPC decoder[132].

Channel codes for DVB-S2 provide a significant increase in capacity over DVB-S under the same transmission conditions and allow error-free operation (packet error rate below 10^{-7}) at about 0.7 dB to 1 dB of the Shannon limit, in depending on the transmission mode[139].

2.1. DVB-S2 model structure and basic signal processing operations

The DVB-S2 model (Fig. 2.1) is an advanced version of the channel coding scheme used in the second generation of the digital video broadcasting standard (DVB-S2). The coding scheme is based on a sequence of links of LDPC and BCH codes. Modeling of the BCH coder, the LDPC coder, the interleaver, the modulator, as well as their analogues in the receiver, according to the DVB-S2 standard, are presented.

2.2. Results of the simulation studies of the model of the DVB-S2 system

When starting the simulation, the constellation of the received modulated signal is visualized [A5]. The number of erroneously received bits of the LDPC signal (Linear Error Correction Code) and the number of erroneously received packets are displayed by the error counters and updated continuously over time.

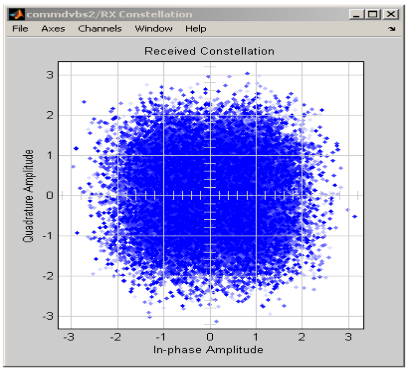


Fig. 2.8. Received QPSK signal constellation at SNR=10 dB

Fig. 2.8 also shows the efficiency of the LDPC codes at the parameters used: QPSK, rate ½, Es/No = 1dB and 50 iterations during decoding. And at lower SNR values, the LDPC decoder rarely makes an error. The scattered constellation clearly shows how noisy the channel is.

If the value of Es/No is reduced, for example to 0.5 dB, the bit error rate of the LDPC will be much higher. This is consistent with steep performance curves of LDPC codes.

In Fig. 2.9 and Fig. 2.10 graphical dependences of Error1 (the number of errors resulting from LDPC encoding/decoding) and Error2 (the number of errors resulting from BCH encoding/decoding) depending on the signal-to-noise ratio at different values of the transmitted signal power P are shown. From Fig. 2.9. it is found that as the SNR increases, the dependences for both powers (3W and 1W) are analogous and exponentially decreasing with a difference in the required signal-to-noise ratio of 4.8 dB. The dependencies for Error2 are initially linear.

At very small powers - P=0.5W, the values of the Error1 and Error2 parameters are zero, and Error1 for R=1.5W at SNR between 2 and 3 dB is linearly decreasing.

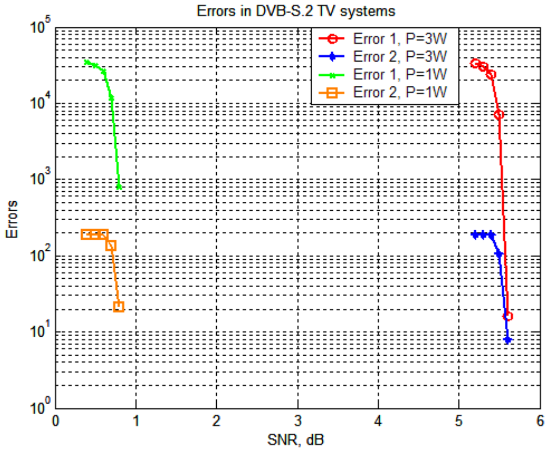


Fig. 2.9. Graphical dependencies of Error1 and Error2 as a function of P1 and P2

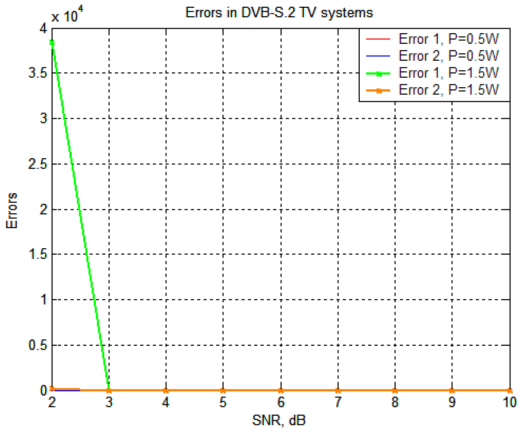


Fig. 2.10. Graphical dependencies of Error1 and Error2 as a function of P1 and P2

From comparing the graphical dependences shown in Figs. 2.9 and 2.10, the different nature of the reduction of the error values Error1 and Error2 at different powers of the transmitted signal is established, and at lower powers the dependence of Error1 is linearly decreasing. At smaller values, regardless of the small values of the signal-to-noise ratio, the efficiency of both types of coding is very high, resulting in zero errors.

2.3. Modeling and study of coding processes and their effectiveness in digital signal transmission according to the DVB-S/S2 standard

2.3.1. Description and parameters of the simulation model

For the purpose of simulation study and analysis of DVB-S/S2 digital signal transmission, I will use a simulation model [A2] developed for MATLAB 8.3 [139]. The ETSI EN302 307 (DVB-S2) standard [30] uses a special coding scheme to increase the channel capacity. The concatenation of LDPC and BCH codes is the basis for this coding scheme. LDPC codes proposed by Gallagher in 1960 can achieve a very low error value close to the channel capacity by using a low-complexity iterative decoding algorithm [54, 74]. The external BCH codes are used to correct sporadic errors made by the LDPC decoder.

Channel coding for DVB-S2 provides significantly increased capacity compared to DVB-S, under the same transmission conditions. Depending on the transmission mode, DVB-S2 provides quasi-error-free operation (QEF) (packet error rate below 10^{-7}) at about 0.7 dB to 1 dB of the Shannon limit. This example simulates a BCH encoder, an LDPC encoder, a bit shifter, a modulator, as well as the reverse processing in the receiver, according to the DVB-S2 standard. The example outputs the error coefficient in the demodulator, LDPC decoder, and BCH decoder outputs, determines the distribution of the number of iterations performed by the LDPC decoder, and displays the resulting constellation diagrams.

<u>Simulation result in QPSK 1/4 mode:</u>

By changing the SNR ratio and considering the BER value after the modulator ($\mathrm{BER}_{\mathrm{MOD}}$) and the BER value after the LDPC-decoder ($\mathrm{BER}_{\mathrm{LDPC}}$), the following results are obtained:

Table 2.5. Tabular results for $\mathrm{BER}_{\mathrm{MOD}}$ and $\mathrm{BER}_{\mathrm{LDPC}}$ in function of SNR in QPSK 1/4 mode

SNR, dB	-4	-3	-2,75	-2,5	-2,25	-1	1	4
$\mathrm{BER}_{\mathrm{MOD}}$	$2{,}64.10^{-1}$	$2{,}4.10^{-1}$	$2{,}33.10^{-1}$	$2{,}26.10^{-1}$	$2{,}21.10^{-1}$	$1{,}86.10^{-1}$	$1{,}31.10^{-1}$	$5{,}64.10^{-2}$
$\mathrm{BER}_{\mathrm{LDPC}}$	$1{,}86.10^{-1}$	$1{,}32.10^{-2}$	$4{,}91.10^{-4}$	0	0	0	0	0

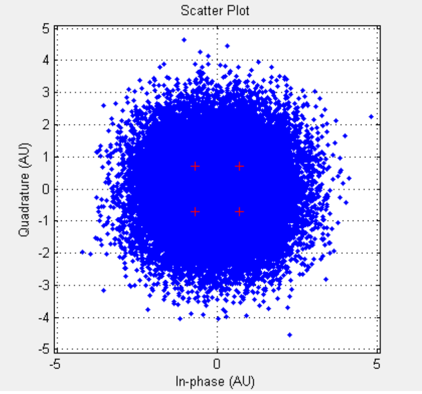


Fig. 2.14. Constellation diagram of the received signal in QPSK 1/4 mode

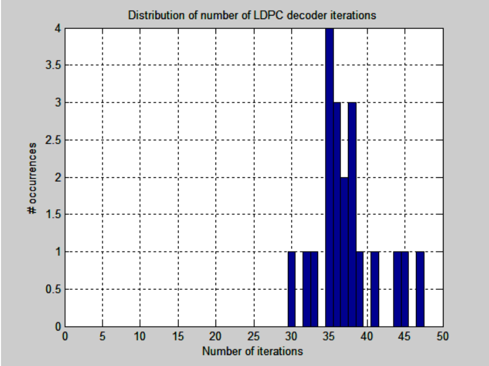


Fig. 2.15. Distribution of the number of iterations performed by the LDPC decoder at QPSK 1/4

Conclusion 4 of the study:

From Table 2.5 and the obtained graphical results, it can be determined that in QPSK 1/4 mode the minimum value of SNR for which there will be no errors after the LDPC decoder turns out to be SNR = –2.5dB at $BER_{MOD} = 2,26.10^{-1}$.

Simulation result in 8-PSK 9/10 mode:

Changing the SNR ratio and considering the BER value after the modulator (BER_{MOD}) and the BER value after the LDPC-decoder (BER_{LDPC}) gives the following results:

Table 2.7. Tabular results for BER_{MOD} and BER_{LDPC} in function of SNR in 8-PSK 9/10 mode

SNR, dB	-4	1	4	8	10	10,85	12	14	16
BER_{MOD}	$3,31.10^{-1}$	$2,15.10^{-1}$	$1,41.10^{-1}$	$5,87.10^{-2}$	$2,91.10^{-2}$	$1,95.10^{-2}$	$1,03.10^{-2}$	$2.26.10^{-3}$	$2,14.10^{-4}$
BER_{LDPC}	$3,36.10^{-1}$	$2,20.10^{-1}$	$1,44.10^{-1}$	$5,98.10^{-2}$	$2,39.10^{-2}$	0	0	0	0

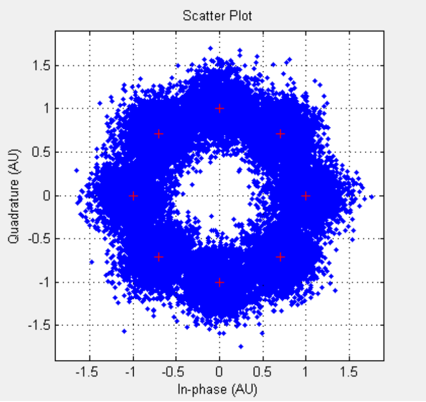


Fig. 2.18. Constellation diagram of the received signal in 8-PSK 9/10 mode

Conclusion 5 of the study:

From Table 2.7 and the obtained graphical results, it can be determined that in the 8-PSK 9/10 mode, the minimum SNR value for which there will be no errors after the LDPC decoder turns out to be SNR = 10,85dB at $BER_{MOD} = 1,95.10^{-2}$.

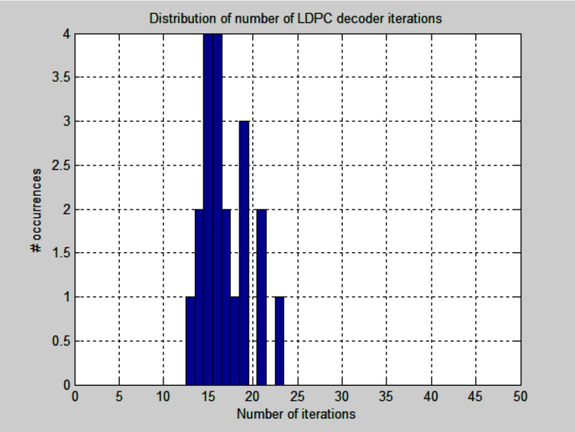


Fig. 2.19. Distribution of the number of iterations performed by the LDPC decoder at 8-PSK 9/10 mode

2.3.3. Comparative analysis of simulation results

Based on the summarized results in Tables 2.5, 2.6 and 2.7, Fig. 2.20 shows the dependence of BER as a function of the signal-to-noise ratio SNR obtained after the demodulator, and in Fig. 2.21 – BER as a function of SNR after the LDPC decoder.

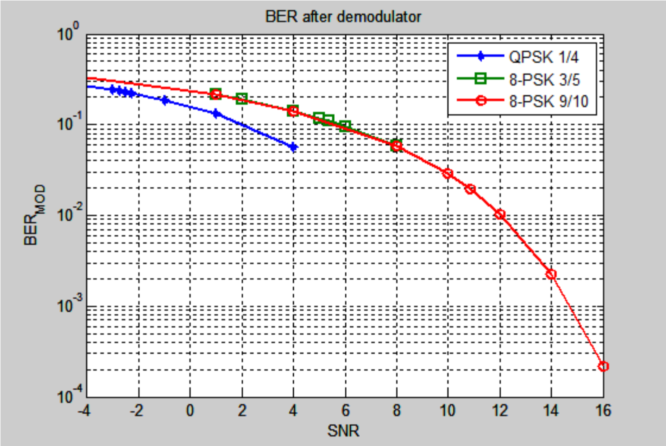


Fig. 2.20. BER dependence as a function of SNR for QPSK 1/4, 8-PKS 3/5 and 8-PSK 9/10 modes after the demodulator

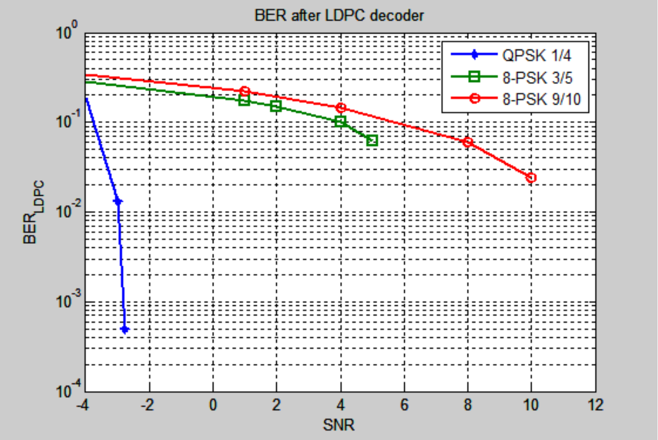


Fig. 2.21. BER dependence as a function of SNR for QPSK 1/4, 8-PKS 3/5 and 8-PSK 9/10 modes after the LDPC decoder

2.4. Conclusions to the second chapter

One of the main disadvantages of the DVB-S system is the use of QPSK modulation, which is low-efficiency and does not allow full use of the transponder frequency spectrum. The distribution of high-definition programs, as well as the construction of interactive satellite networks with addressable services, requires the availability of higher transport resources. This necessitates the transition to DVB-S2. In order to fulfill the compatibility requirement in DVB-S2, two modes have been introduced - the first allows downward compatibility, but has a lower efficiency (for now, there is no information on using this mode in practice). The second mode gives and uses all the capabilities of DVB-S2, but cannot be received with DVB-S set-top boxes.

Presented and described in detail models for simulation research of digital television systems according to DVB-S2 and DVB-T standards. Results are attached in analytical and graphical form of the dependencies of the number of errors Error1 and Error2 as well as the received signal constellations for different values of the signal/noise ratio SNR at a constant power of the transmitted signal. Decreasing the SNR value is found to increase the influence of noise on the received signal and scatter the vector constellation.

In the DVB-S2 system, the BER value strongly depends on the SNR and decreases rapidly as it increases, i.e. environment has a strong influence on the number of errors accepted. In the DVB-T system, the BER value starts to decrease after SNR=16 dB and cannot reach the small values in the DVB-S2 system. This requires the external and internal encoding/decoding used in the DVB-S2 system to be significantly more efficient.

In the DVB-S2 system, the BER value strongly depends on the SNR and decreases rapidly as it increases, i.e. environment has a strong influence on the number of errors accepted. In the DVB-T system, the BER value starts to decrease after SNR=16 dB and cannot reach the small values in the

DVB-S2 system. This requires the external and internal encoding/decoding used in the DVB-S2 system to be significantly more efficient.

A detailed description of a simulation model for DVB-S/S2 digital signal transmission is presented, followed by an investigation and comparative analysis of the modeling results for different modulation modes and FEC.

CHAPTER III. EXPERIMENTAL STUDY OF SIGNAL PARAMETERS AND CHARACTERISTICS IN SATELLITE DIGITAL TELEVISION SYSTEMS

3.1. Scheme of the experimental setup

For the purposes of experimental research and analysis of digital signal transmission according to the DVB-S/S2 standard, the experimental set-up is presented with the block diagram of Fig. 3.1.

Fig. 3.1. Block diagram for conducting the experimental studies

The experimental setup is located in the lab. 1133B of the Accademy Building 1 ("Integral") of the Technical University - Gabrovo. [A2]

The satellite antenna used is a "parabola" type with a diameter of 120 cm, with reflector material - aluminum, focus 45 cm, reflector thickness 1 mm, electrostatically powder-painted light gray color; F/D = 0.375, gain 11.350 GHz - 40.9 dB, gain 12.125 GHz - 41.5 dB, gain 12.626 GHz - 41.8 dB; with polar suspension suitable for linear motors.

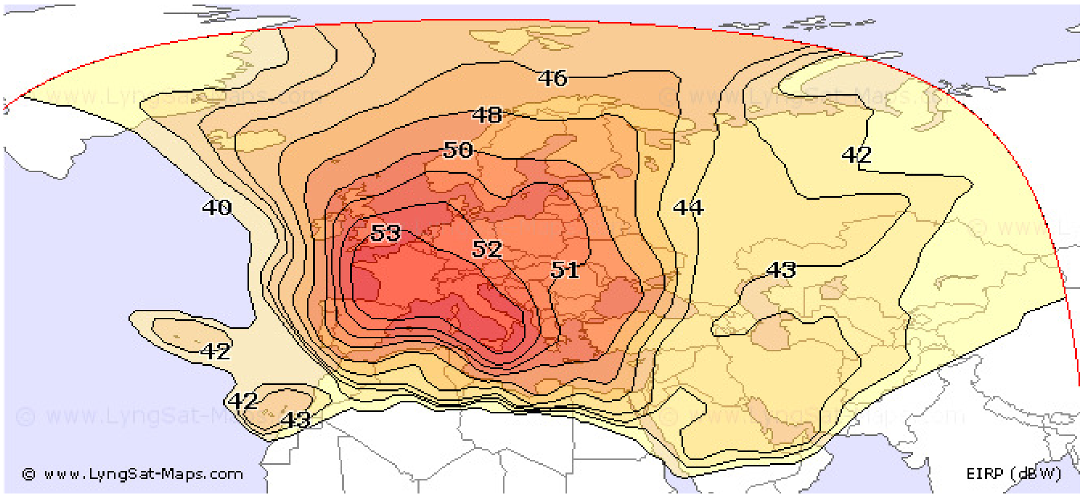
The converter mounted on the satellite dish is EUROSTAR, model ESKD-T2B; input frequency 10.70 to 12.75 GHz, output frequency (LO) 950 to 1950 MHz, output frequency (HI) 1100 to 2150 MHz, noise figure 0.5dB.

The IT-083 is a dedicated analyzer for measurements and signal analysis in satellite digital television systems, developed by the Russian company PLANAR [139], with accompanying software ItToolsSatellite08C for PC operation.

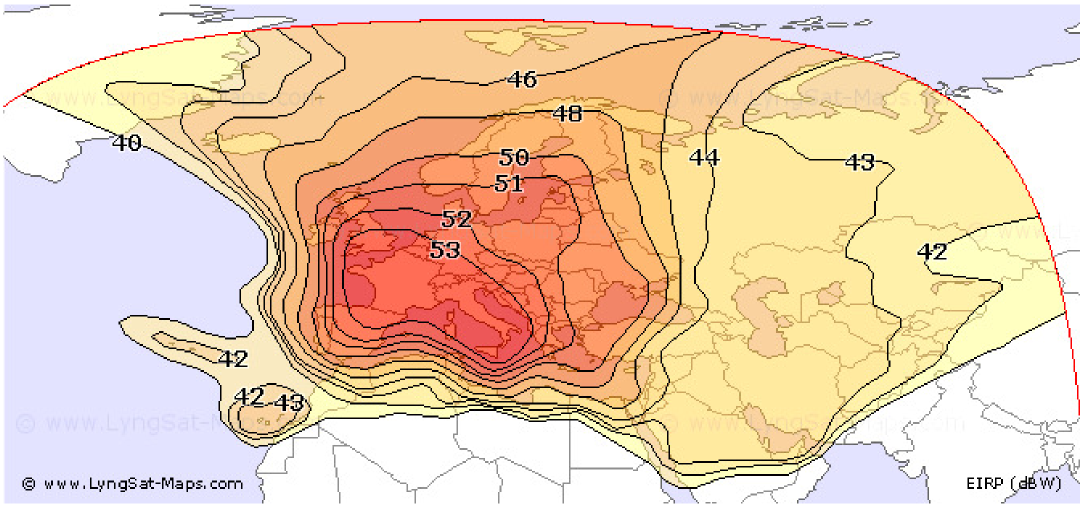
3.2. Setting up the receiving satellite dish

In the line of sight from the lab. 1133B hits the Eutelsat Hot Bird 13.0°E satellite, whose coverage area for Europe is shown in Fig. 3.2 [140].

The satellite provides EIRP = 44dBW for satellite dish size 95 – 120 cm.



a) Eutelsat Hot Bird 13B

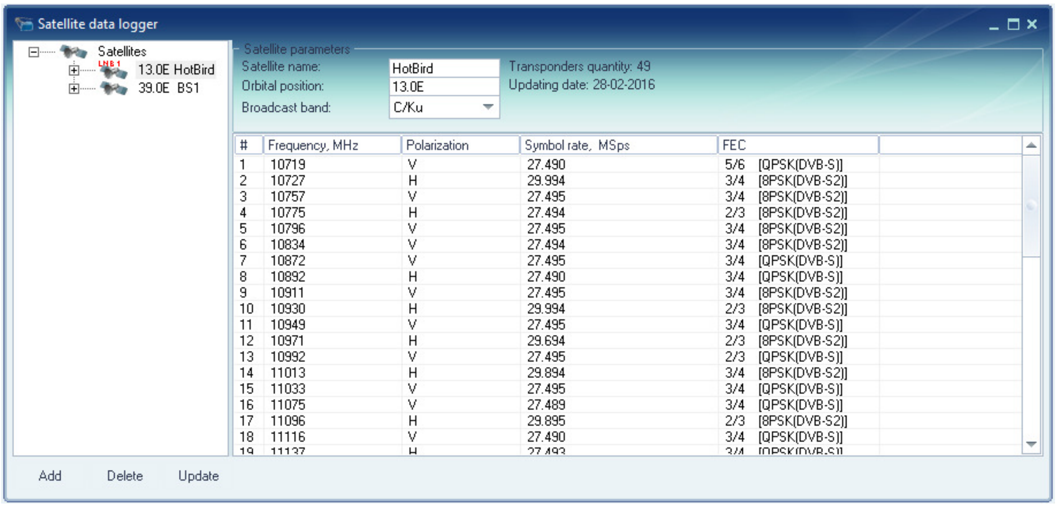


b) Eutelsat Hot Bird 13C

Fig. 3.2. Eutelsat Hot Bird satellite coverage area 13.0^{o}E

3.3. Conducting experimental research

The first step before starting the measurements is to enter the required satellite and scan the transponders to it. After connecting the IT-083 to the satellite dish converter, it automatically scans and selects the active transponders and stores them in the so-called Satellite Data Logger - Fig. 3.4.



Satellite name: HotBird
Orbital position: 13.0E
Broadcast band: C/Ku
Transponders quantity: 49
Updating date: 28-02-2016

#	Frequency, MHz	Polarization	Symbol rate, MSps	FEC
1	10719	V	27.490	5/6 [QPSK(DVB-S)]
2	10727	H	29.994	3/4 [8PSK(DVB-S2)]
3	10757	V	27.495	3/4 [8PSK(DVB-S2)]
4	10775	H	27.494	2/3 [8PSK(DVB-S2)]
5	10796	V	27.495	3/4 [8PSK(DVB-S2)]
6	10834	V	27.494	3/4 [8PSK(DVB-S2)]
7	10872	V	27.495	3/4 [QPSK(DVB-S)]
8	10892	H	27.490	3/4 [QPSK(DVB-S)]
9	10911	V	27.495	3/4 [8PSK(DVB-S2)]
10	10930	H	29.994	2/3 [8PSK(DVB-S2)]
11	10949	V	27.495	3/4 [QPSK(DVB-S)]
12	10971	H	29.694	2/3 [8PSK(DVB-S2)]
13	10992	V	27.495	2/3 [QPSK(DVB-S)]
14	11013	H	29.894	3/4 [8PSK(DVB-S2)]
15	11033	V	27.495	3/4 [QPSK(DVB-S)]
16	11075	V	27.489	3/4 [QPSK(DVB-S)]
17	11096	H	29.895	2/3 [8PSK(DVB-S2)]
18	11116	V	27.490	3/4 [QPSK(DVB-S)]
19	11137	H	27.493	3/4 [QPSK(DVB-S)]

Fig. 3.4. Scan and view transponders to Hot Bird 13.0^{o}E with IT-083

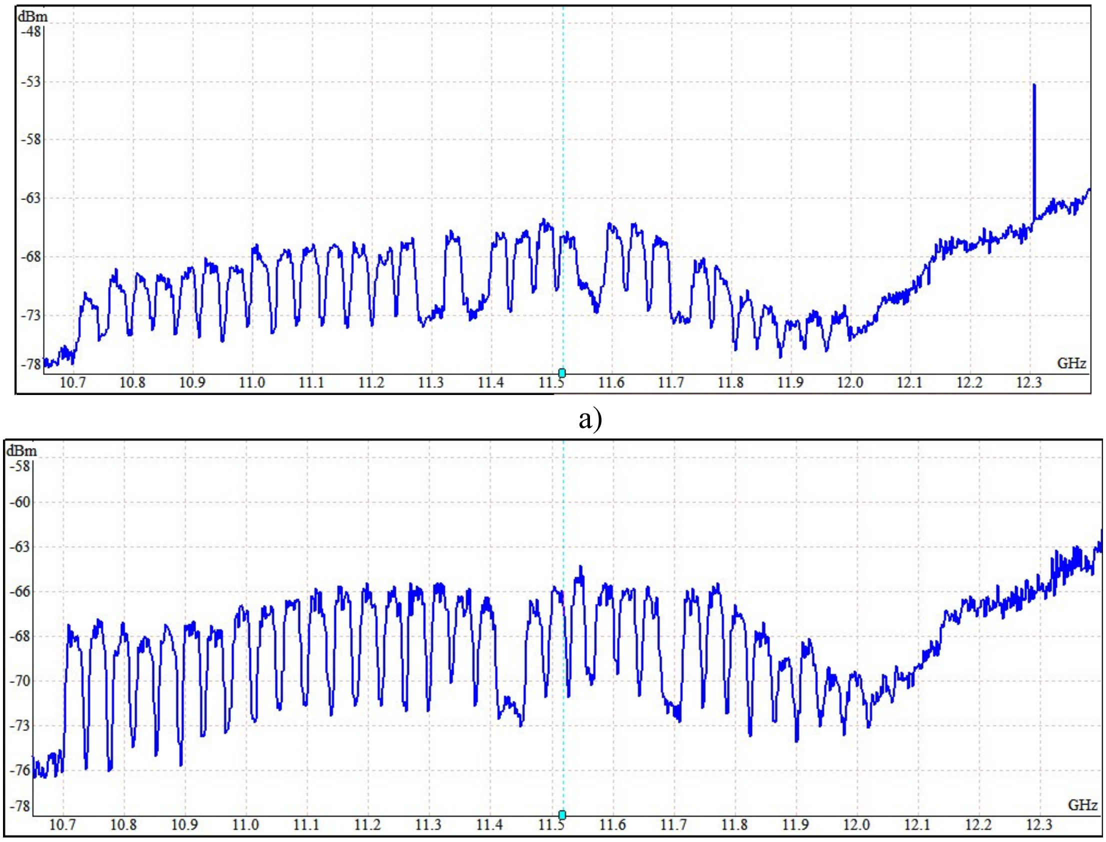
The list of satellite data for a given satellite includes:

- Serial number of the transponder;
- Frequency in MHz of the transponder;
- Polarization;
- Symbol rate in MS/s;
- FEC (error correction) and modulation format.

After the device has scanned the full frequency range, it automatically generates a list of detected transponders, on the basis of which further measurements can be made.

To measure the full frequency spectrum, we select the Spectrum option of the IT-083 analyzer or use the Spectrum Analyzer function from the Device menu of the application software in case the analyzer is connected to a personal computer.

In Fig. 3.5 the frequency spectrum from 10.7 GHz to 12.4 GHz of the signal at the output of the converter of the satellite dish when received from a satellite Hot Bird 13,0^{o}E is presented.



a)

b)

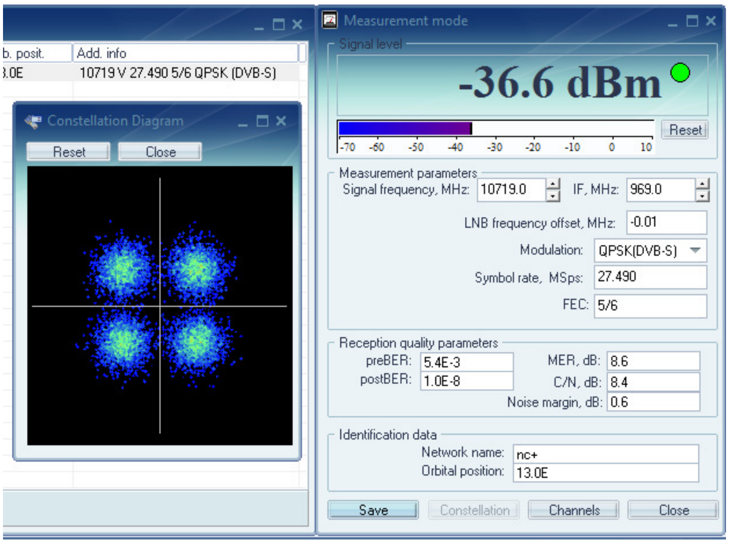
Fig. 3.5. Frequency spectrum of measurements of the output of the converter signal at a) horizontal and b) vertical polarization for Hot Bird 13,0^{o}E

The IT-083 allows the frequency spectrum to be plotted on the X-axis either by the serial number of the transponders, or by the intermediate frequency (from 950 to 2150 MHz) of the transponders, or as shown in Fig. 3.5 – by the frequency of the transponders.

Since the full list of Hot Bird 13.0^{o}E transponders is very large, detailed measurements for only a few will be listed below.

<u>Measurement result of a transponder with a frequency of 10719 MHz:</u>

In Fig. 3.6 shows the results of measuring the transponder signal with a frequency of 10719 MHz/V (vertical polarization).



b. posit. Add. info
.0E 10719 V 27.490 5/6 QPSK (DVB-S)

Signal level
-36.6 dBm

Measurement parameters
Signal frequency, MHz: 10719.0
IF, MHz: 969.0
LNB frequency offset, MHz: -0.01
Modulation: QPSK(DVB-S)
Symbol rate, MSps: 27.490
FEC: 5/6

Reception quality parameters
preBER: 5.4E-3
postBER: 1.0E-8
MER, dB: 8.6
C/N, dB: 8.4
Noise margin, dB: 0.6

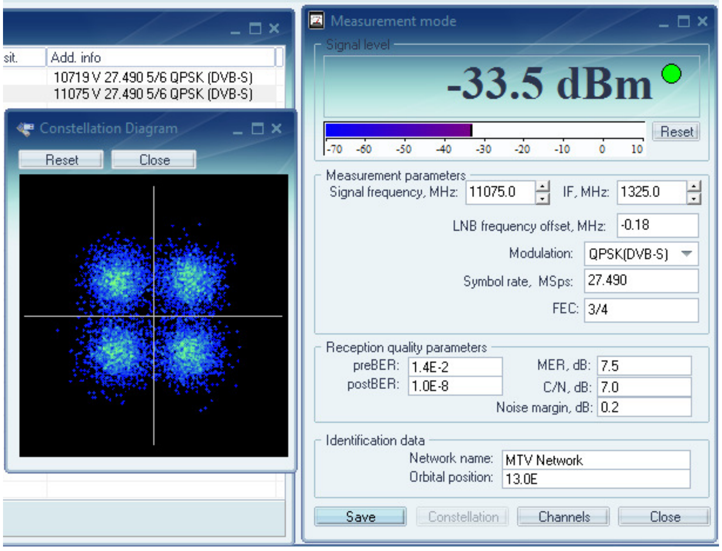
Identification data
Network name: nc+
Orbital position: 13.0E

Fig. 3.6. Vector diagram control and measurement of the signal level of a transponder with a frequency of 10719 MHz

From the right side of Fig. 3.6 it is reported that the transponder frequency corresponds to the 969 MHz intermediate frequency. The modulation format is QPSK with a symbol rate of 27490 MSps and an error correction depth of FEC 5/6. The measured power level is –36.6 dBm with the value of the error coefficient after the demodulator being preBER = $5.4.10^{-3}$ and after the error correction postBER = 1.10^{-8} for the ratio of the signal carrier to the noise level C/N = 8.4 dB and modulation error value MER = 8.6 dB. In the left part of Fig. 3.6 the vector diagram of the signal is presented.

<u>Measurement result of a transponder with a frequency of 11075 MHz:</u>

In Fig. 3.7 shows the results of measuring the transponder signal with a frequency of 11075 MHz/V (vertical polarization).



sit. Add. info
10719 V 27.490 5/6 QPSK (DVB-S)
11075 V 27.490 5/6 QPSK (DVB-S)

Signal level
-33.5 dBm

Measurement parameters
Signal frequency, MHz: 11075.0
IF, MHz: 1325.0
LNB frequency offset, MHz: -0.18
Modulation: QPSK(DVB-S)
Symbol rate, MSps: 27.490
FEC: 3/4

Reception quality parameters
preBER: 1.4E-2
postBER: 1.0E-8
MER, dB: 7.5
C/N, dB: 7.0
Noise margin, dB: 0.2

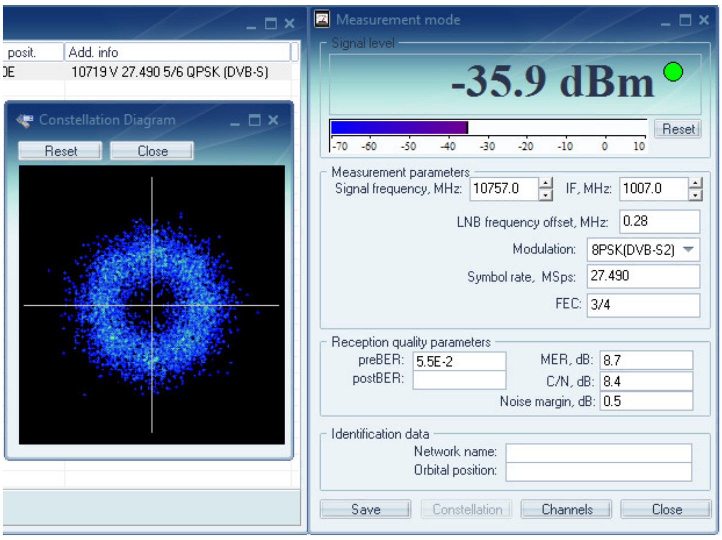
Identification data
Network name: MTV Network
Orbital position: 13.0E

Fig. 3.7. Vector diagram control and measurement of the signal level of a transponder with a frequency of 11075 MHz

From the right side of Fig. 3.7 it is reported that the frequency of the transponder corresponds to the 1325 MHz intermediate frequency. The modulation format is QPSK with a symbol rate of 27490 MSps and an error correction depth of FEC 3/4. The measured power level is –33.5 dBm with the value of the error coefficient after the demodulator being preBER = $1.4.10^{-2}$ and after the error correction postBER = 1.10^{-8} for the ratio of the signal carrier to the noise level C/N = 7.0 dB and modulation error value MER = 7.5 dB. In the left part of Fig. 3.7 the vector diagram of the signal is presented.

Measurement result of a transponder with a frequency of 10757 MHz:

In Fig. 3.10 shows the results of measuring the transponder signal with a frequency of 10757 MHz/V (vertical polarization).



posit.	Add. info
)E	10719 V 27.490 5/6 QPSK (DVB-S)

Measurement mode

Signal level: -35.9 dBm

Measurement parameters
Signal frequency, MHz: 10757.0
IF, MHz: 1007.0
LNB frequency offset, MHz: 0.28
Modulation: 8PSK(DVB-S2)
Symbol rate, MSps: 27.490
FEC: 3/4

Reception quality parameters
preBER: 5.5E-2
postBER:
MER, dB: 8.7
C/N, dB: 8.4
Noise margin, dB: 0.5

Identification data
Network name:
Orbital position:

Fig. 3.10. Vector diagram control and measurement of the signal level of a transponder with a frequency of 10757 MHz

From the right side of Fig. 3.10 it is reported that the transponder frequency corresponds to the 1007 MHz intermediate frequency. The modulation format is 8-PSK (DVB-S2) with a symbol rate of 27490 MSps and an error correction depth of FEC 3/4. The measured power level is –35.9 dBm and the value of the error coefficient after the demodulator is preBER = 5.5.10^{-2} and the amount of errors in the received signal is too large to be able to recover the signal after the error correction. The signal carrier to noise ratio is C/N = 8.4 dB and the modulation error value MER = 8.7 dB. In the left part of Fig. 3.10 the vector diagram of the signal is presented.

3.4. Comparative analysis of experimental results and research conclusions

A scheme of the experimental set-up for measuring the parameters and signals when receiving a digital signal according to the DVB-S/S2 standard was synthesized in educational laboratory 1133B on the territory of the Department of CET at the TU-Gabrovo. A preliminary calculation of the azimuth and elevation angles required to correctly point the receiving satellite dish at a selected Eutelsat Hot Bird 13.0°E satellite was performed. After scanning the available transponders, a measurement of the signal parameters of 5 transponders was carried out, and the obtained results were examined and analyzed in detail.

The obtained results presented in Fig. 3.6 to Fig. 3.11, can be summarized in the following tabular form.

Table 3.2. Comparative analysis of experimental results

f, MHz	Modulation	FEC	Polarization	preBER	postBER	CNR, dB	MER, dB	IF, MHz
10719	QPSK	5/6	V	5,4.10^{-3}	1.10^{-8}	8,4	8,6	969
11075	QPSK	3/4	V	1,4.10^{-2}	1.10^{-8}	7,5	7,0	1325
11137	QPSK	3/4	H	2,1.10^{-2}	4,4.10^{-5}	7,0	6,1	1387
11804	QPSK	2/3	V	1,3.10^{-2}	1.10^{-8}	7,6	7,1	2054
10757	8-PSK	3/4	V	5,5.10^{-2}	-	8,4	8,7	1007

From the experimental studies of the signal parameters and the quality of the received satellite TV program, it can be summarized that for the QPSK (DVB-S) modulation format transponders studied, the quality of the TV picture is excellent, regardless of the fact that for the transponder with a frequency of 11137 MHz a lower postBER value is obtained.

The studied transponders with 8-PSK modulation format do not allow the reception of a quality TV image, as the best results for preBER and CNR are reported for the indicated transponder with a frequency of 10757 MHz.

CHAPTER IV. INVESTIGATION OF “SATELLITE - EARTH” COMMUNICATION CHANNEL PARAMETERS

4.1. Features of the “satellite – earth” communication channel

Satellite systems have limited radiated power on board the satellite. Radio signals used in communication are subject to attenuation caused by a number of specific factors. For these reasons, it is necessary to use the most effective noise-resistant modulation and coding methods.

Of particular importance for the Satellite-Earth communication channel is the energy budget. As the name suggests, the power budget is a measure of how much power is available compared to how much power is needed taking into account the influence of a given noise - it is one of the most important measures to determine and in many cases determines what antennas should be are used, frequencies, power and modulation scheme [A1].

4.1.3. “Satellite – Earth” transmission channel bandwidth

One of the most important quantities that qualifies channel noise is the signal-to-noise ratio (or the ratio of the signal carrier to the noise for the digital modulations we are considering). Depending on the situation, we will denote this dimensionless value as S/N or C/N respectively. This quantity is important for the following theorem: Given a channel of bandwidth B subjected to Gaussian white noise with signal-to-noise ratio S/N, the highest possible information transmission rate with a tolerably low error rate is given by:

$$C = B\log_2\left(1+\frac{S}{N}\right) \tag{4.19}$$

This is known as the Shannon–Hartley theorem and is a special case of the noisy channel coding theorem associated with an analog channel subject to Gaussian noise. C is the capacity of the channel. We will use the theorem to estimate the link channel errors and define several important quantities for it [92]. Shannon's theorem can be converted to:

$$\frac{E_b}{N_0} = \left(\frac{S}{N}\right)\frac{B}{R} \tag{4.20}$$

The Fig. 4.1 gives some dependences between BER and Eb/N0 for different modulations. The relationship between the two is given by the error function (erfc) with a coefficient, depending on the modulation scheme:

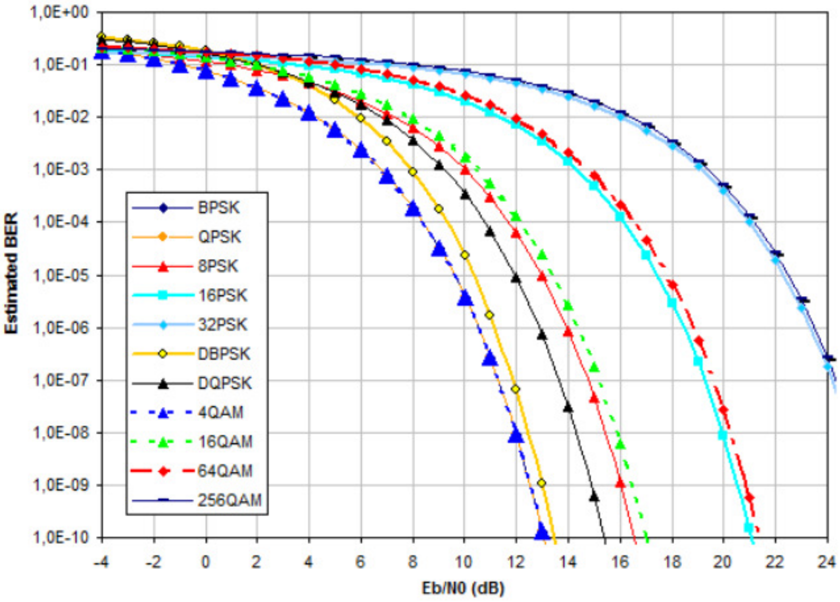


Fig. 4.1. BER = $f(E_b/N_0)$ for different modulation formats

4.2. Investigation of a communication channel for connection with an artificial satellite of the "CubeSat" type

4.2.1. Synthesizing of the experimental setup scheme

The research and analysis of a communication channel for connection with an artificial nano-satellite of the CubeSat type is realized by using a training platform [A1] consisting of:

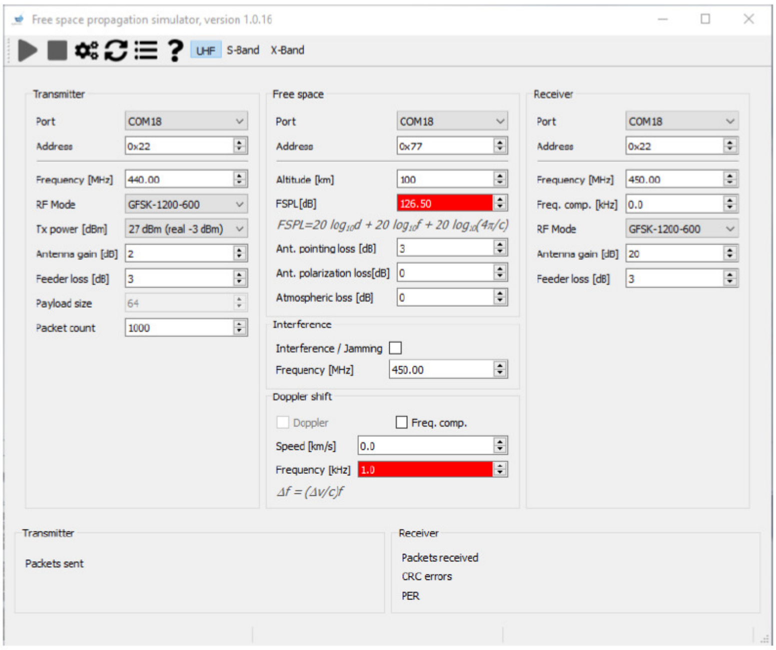
- hardware transceiver modules,
- module "Free Space Module" imitator of a satellite communication channel,
- InnoSpaceComm software tool.

The connection of the hardware transceiver modules with the "Free Space Module" simulator of a satellite communication channel is shown in Fig. 4.3.

Fig. 4.3. Wiring diagram of the EnduroSat satellite communication system for training

The EnduroSat Educational Communication System is part of the InnoSpaceComm project and provides an opportunity to gain hands-on experience with a satellite communication system. It operates in the UHF, S and X frequency bands and simulates real-world communication scenarios. The system consists of two identical UHF transceivers and one Free Space Propagation Simulator (FSPS), which simulates the changes in the radio signal as it traverses the space between Earth and the target satellite. The system is managed via a graphical user interface (GUI) program that controls all three hardware via standard mini-USB connections (virtual COM ports) and is easily accessible for Windows 10.

To start the graphical user interface, double-click on the created icon on the desktop - Free Space Propagation Simulator. Starting the application loads the main window. It is filled with various options regarding the characteristics of the transmitter, the "free space" and the receiver, which are divided into three columns (see Fig. 4.9).



Transmitter

Port	COM18
Address	0x22
Frequency [MHz]	440.00
RF Mode	GFSK-1200-600
Tx power [dBm]	27 dBm (real -3 dBm)
Antenna gain [dB]	2
Feeder loss [dB]	3
Payload size	64
Packet count	1000

Free space

Port	COM18
Address	0x77
Altitude [km]	100
FSPL[dB]	126.50

$FSPL=20\ log_{10}d + 20\ log_{10}f + 20\ log_{10}(4\pi/c)$

Ant. pointing loss [dB]	3
Ant. polarization loss[dB]	0
Atmospheric loss [dB]	0

Interference

Interference / Jamming	☐
Frequency [MHz]	450.00

Doppler shift

☐ Doppler ☐ Freq. comp.

Speed [km/s]	0.0
Frequency [kHz]	1.0

$\Delta f = (\Delta v/c)f$

Receiver

Port	COM18
Address	0x22
Frequency [MHz]	450.00
Freq. comp. [kHz]	0.0
RF Mode	GFSK-1200-600
Antenna gain [dB]	20
Feeder loss [dB]	3

Transmitter

Packets sent

Receiver

Packets received
CRC errors
PER

Fig. 4.9. FSPS GUI software main window with the three settings fields (Transmitter, Free space and Receiver)

Once the hardware modules are connected to the computer, they will appear on different COM ports. The baud rate is not an adjustable parameter and needs to be set to 115200 baud. To facilitate differentiation between modules, each has a unique identifier (Address) that contains a value in hexadecimal format. The default address is:

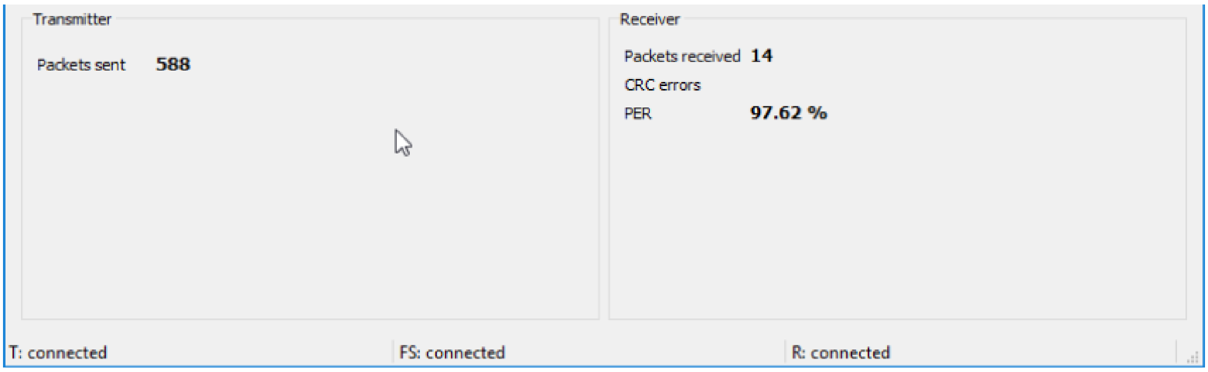
– 0x22 - usually this is the UHF transmission;
– 0x23 - usually this is the receiving UHF;
– 0x77 - this is the FSPS module.

It is also valid to use UHF with address 0x23 as the transmitting module and UHF with address 0x22 as the receiving module. The important thing is that the UHF module physically connected to the TX input of the FSPS module should be used as the transmitter and the one connected to the RX input of the FSPS module should be used as the receiver.

If the combination of COM port and Address is incorrect, the program will report that the combination is incorrect. The message will appear in the footer of the main program window and will be colored red.

Usually, connecting the modules one at a time is a good way to connect the device to the COM port. Once this is done, all that remains is to calculate the value of the free path loss (FSPL). If a correct value for FSPL is entered, then the box in the middle column labeled FSPL [60] (see Fig. 4.9) will lose its red color and the simulation can be started.

If the COM ports and modules are properly matched, then packets will be transmitted and packets can be received (see Fig. 4.10). This depends on the values entered in the various configuration fields.



Packets sent 588

Packets received 14

CRC errors

PER 97.62 %

T: connected

FS: connected

R: connected

Fig. 4.10. Real-time statistics of the simulation performance (packets sent and received and packet error rate PER)

4.3. Simulation study of a CubeSat - Earth transmission communication channel

4.3.1. Research on transmission in the UHF frequency range

For the purposes of the first study, when transmitting in the UHF frequency range, the following parameters were selected:

- Operating frequency 430 MHz;
- Modulation and transmission rate: GFSK 19200-19200 and GFSK 19200-4800;
- Transmitter power: 31 dBm and 28 dBm;
- Transmitter antenna gain: 2dB;
- Losses in the feeder in the transmitter: 3dB;
- Altitude of orbit: 100 to 600 km;
- Antenna pointing losses: 3dB
- Polarization loss: 3dB
- Losses in the atmosphere: 1dB
- Receiver antenna gain: 20dB;
- Losses in the feeder in the receiver: 3dB.

Table 4.7. Transmission in the UHF frequency range at different satellite heights, GFSK modulation parameters and transmitter power

Altitude of orbit, km	400	450	500	550	600
FSPL, dB	137,16	138,18	139,09	139,92	140,98
PER at GFSK 19200-19200, TX = 31dBm	0	3	15	42	90
PER at GFSK 19200-19200, TX = 28dBm	7	41	91	100	100
PER at GFSK 19200-4800, TX = 31dBm	0	3	13	43	78
PER at GFSK 19200-4800, TX = 28dBm	8	19	73	90	100

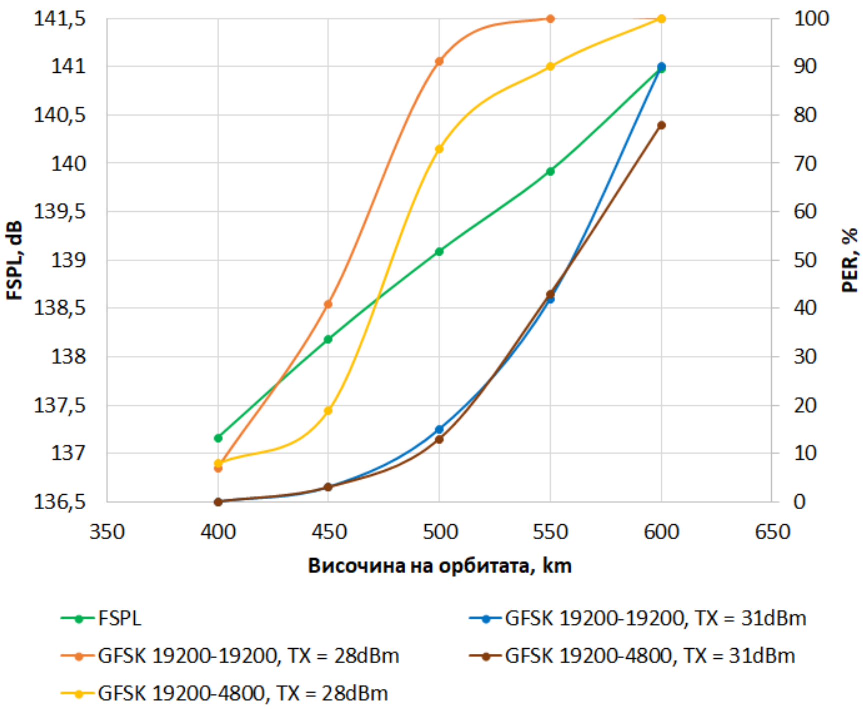


Fig. 4.12. PER and FSPL as a function of orbit altitude at various GFSK modulation parameters and transmitter power

In this study, the evaluation of the communication channel is performed based on the obtained packet error coefficient PER in % for different altitudes of the Cubsat orbit, as well as for different parameters of the GFSK modulation and transmitter power. The results of the study are presented in Table 3.7 and Fig. 3.10.

4.3.2. Study on transmission in the S frequency range

For the purposes of the second study, the following parameters were selected for transmission in the S frequency range:

– Operating frequency: 2000 to 2500 MHz;
– Modulation and transmission rate: GFSK 19200-19200;
– Transmitter power: 31 dBm and 28 dBm;
– Transmitter antenna gain: 5dB;
– Losses in the feeder in the transmitter: 3dB;
– Altitude of orbit: 400 km;
– Antenna pointing losses: 3dB
– Polarization loss: 3dB
– Losses in the atmosphere: 1dB
– Receiver antenna gain: 30dB;
– Losses in the feeder in the receiver: 3dB.

This study evaluates the communication channel based on the received packet error coefficient PER in % for different operating frequencies in the S frequency range at a fixed height of the Cubsat orbit, as well as fixed parameters of the GFSK modulation, but at different transmitter power. The results of the study are presented in Table 4.8 and Fig. 4.13.

Table 4.8. Transmission in the S frequency range at a fixed altitude of the satellite orbit and the GFSK modulation at different transmitter power

Operating frequency, MHz	2000	2100	2200	2300	2400	2500
FSPL, dB	150,5	150,9	151,3	151,7	152,1	152,4
PER at GFSK 19200-19200, TX = 31dBm	19	15	23	45	49	39
PER at GFSK 19200-19200, TX = 28dBm	66	73	71	94	93	98

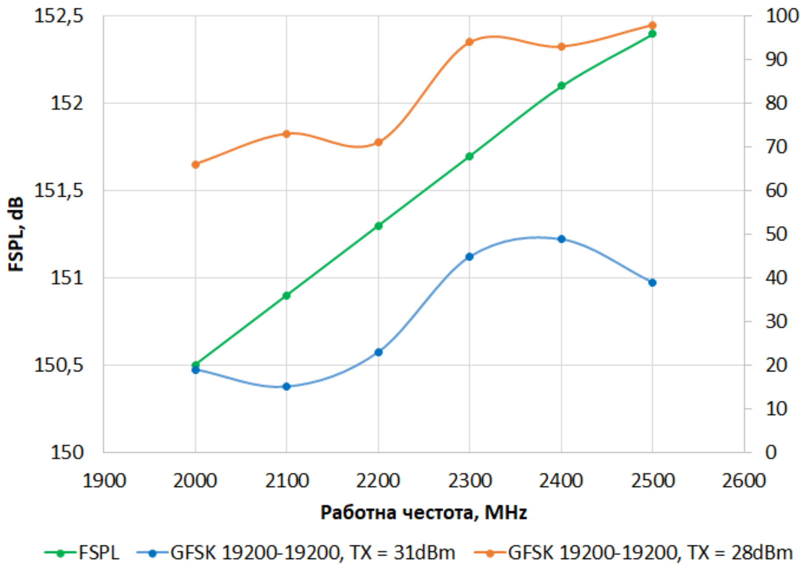


Fig. 4.13. PER and FSPL as a function of operating frequency in the S band at different transmitter power

4.3.3. X frequency range transmission test

For the purposes of this third study, the following parameters were selected for transmission in the X frequency range:

- Operating frequency: 8400 MHz;
- Modulation and transmission rate: GFSK 19200-19200;
- Transmitter power: 31 dBm;
  Transmitter antenna gain: 5dB;
- Losses in the feeder in the transmitter: 3dB;
- Altitude of orbit: 200 km;
- Antenna pointing losses: 3dB
  Polarization loss: 3dB
- Losses in the atmosphere: 1dB
- Receiver antenna gain: 40dB;
- Losses in the feeder in the receiver: 3dB.
- Doppler shift estimation speed: –8 km/s to +10 km/s (approaching and receding satellite).

Table 4.9. Transmission in the X frequency range at a fixed altitude of the satellite orbit and the GFSK modulation at different Doppler speed and different transmitter power

Doppler velocity, km/s	-8	-6	-4	-2	0	1
Doppler frequency, dB	-224	-168	-112	-56	0	28
PER at GFSK 19200-19200, TX = 31dBm	5	8	8	6	9	16
PER at GFSK 19200-19200, TX = 28dBm	5	12	7	8	9	5

Doppler velocity, km/s	2	3	4	6	8	10
Doppler frequency, dB	56	84	112	168	224	280
PER at GFSK 19200-19200, TX = 31dBm	13	9	8	35	6	8
PER at GFSK 19200-19200, TX = 28dBm	11	10	10	14	11	10

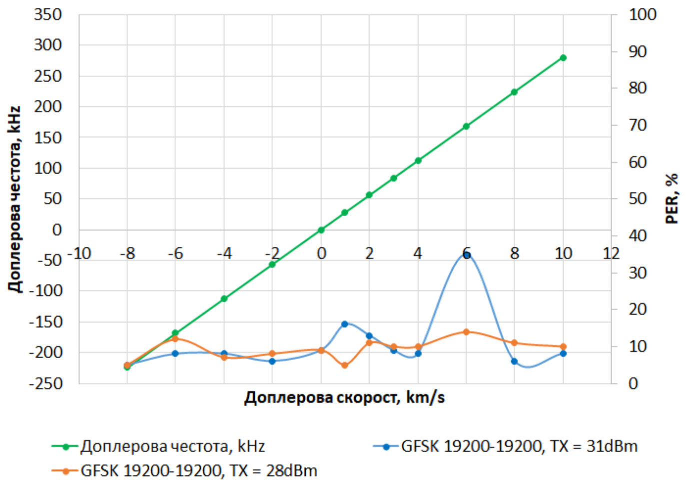


Fig. 4.14. PER and Doppler frequency as a function of X-band Doppler velocity at different transmitter power

In this study, an evaluation of the communication channel is performed based on the received packet error coefficient PER in % for different values of the Doppler speed and frequency in the X frequency range at a fixed height of the CubeSat orbit, as well as fixed parameters of the GFSK modulation, but at different transmitter power. The results of the study are presented in Table 4.9 and Fig. 4.14.

For the purposes of this final fourth study, the following parameters were selected for transmission in the X frequency range:

- Operating frequency: 8400 MHz;
- Modulation and transmission rate: GFSK 19200-19200 and GFSK 19200-4800;
- Transmitter power: 28 dBm;
- Transmitter antenna gain: from 5dB to 15dB;
- Losses in the feeder in the transmitter: 3dB;
- Altitude of orbit: 200 km;
- Antenna pointing losses: 3dB
- Polarization loss: 3dB
- Losses in the atmosphere: 1dB

- Receiver antenna gain: 40dB;
- Losses in the feeder in the receiver: 3dB.

Table 4.10. X-band transmission with variable transmitter antenna gain and GFSK modulation parameters

Antenna gain of the transmitter, dB	5	6	7	8	9	10
PER at GFSK 19200-19200	9	10	10	15	32	9
PER at GFSK 19200-4800	39	38	42	41	44	38

Antenna gain of the transmitter, dB	11	12	13	14	15
PER at GFSK 19200-19200	8	4	13	15	8
PER at GFSK 19200-4800	36	37	35	21	28

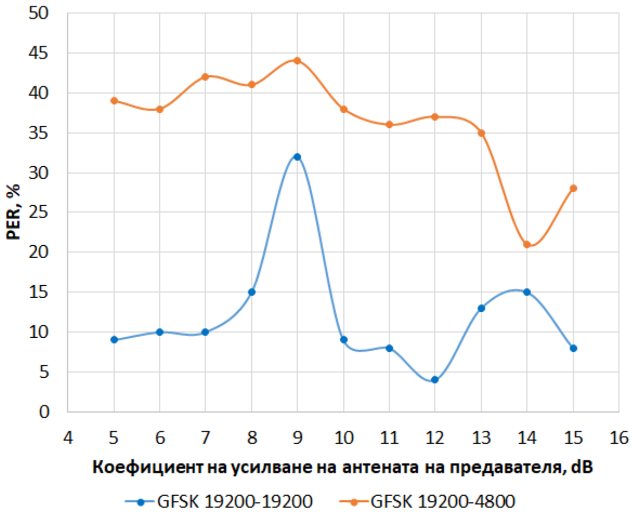


Fig. 4.15. PER as a function of X-band transmitter antenna gain at various GFSK modulation parameters

In this latest study, an evaluation of the communication channel is performed based on the resulting packet error ratio PER in % for different values of the transmitter antenna gain in the X frequency band at a fixed altitude of the CubeSat orbit, but with different GFSK modulation parameters . The results of the study are presented in Table 4.10 and Fig. 4.15.

4.4. Conclusions to Chapter Four

On the basis of the considered platform, four studies have been carried out, which show the complex influence of all parameters on the quality of the communication channel: orbit height, transmitter power, choice of modulation format, transmission coefficients, etc.

As a result of the conducted research, the following more important conclusions can be summarized:

– Cube-satellites are much faster and easier to build. They take up less space and are significantly lighter than traditional satellites. They also cost much less to launch, meaning they can be part of a greater number of missions and launched in swarms;

– Cube-satellites provide an opportunity for quick and easy imaging of the Earth's surface, inexpensive conducting of biological experiments, automated data collection, early warning of events, etc. applications that significantly accelerate scientific and applied tasks related to space technologies;

– The platform is extremely suitable for training students and doctoral students in space communication technologies;

– Despite being resource-constrained, they allow solving specific tasks that would require much more time.

CHAPTER V. INVESTIGATION OF THE PERFORMANCE OF A SATELLITE COMMUNICATION DATA TRANSMISSION SYSTEM UNDER EFFECTIVE MODULATION METHODS

5.1. Performance analysis of a satellite data communication system

In future communication networks, the need to provide more capacity will continuously grow to satisfy the growing traffic demanded by users as well as new quality of service (QoS) applications [A3, 93, 100]. Network operators face serious challenges in providing Internet services to users in rural or other hard-to-serve areas, while guaranteeing QoS [93]. A possible solution to this challenge is the use of a satellite communication network. Broadband satellite networks play a major role in overall communication due to their wide coverage and reliable connections [100]. They are a cost-effective solution for providing communication services in very hard-to-serve areas. In recent years, thanks to advanced technologies in on-board processing, dynamic resource allocation, highly directional beam technology and the use of microwave and UHF radio frequency systems with high throughput (HTS - High Throughput Satellite), satellites in geostationary orbit (GEO - Geostationary Orbit) with network connections can successfully be used for an Internet access backbone. Next-generation HTS systems are targeting total terabit-per-second capacity. These systems are expected to meet the growing demand for Internet of Things (IoT) Internet services such as remote control, telemetry and sensor data monitoring. In addition, they will be able to support multimedia transmission, control of unmanned aircraft systems and TDMA emergency data services.

In order to provide Internet services with QoS support over satellite networks, it is necessary to evaluate the network level performance of the satellite network. It is crucial to evaluate the practical performance of the network. This report considers a MF-TDMA (Multi-Frequency Time Division Multiple Access) satellite network with a mesh topology [100]. The design of a complete satellite network to provide Internet services with QoS support is also considered. Two types of services are considered in the analysis: delay-tolerant and delay-sensitive services. Application layer performance metrics are defined and network performance is evaluated for different environments, service types, and number of users in order to derive the main factors to be considered in QoS policy.

5.1.1. Satellite network architecture

To evaluate a satellite network guaranteeing QoS, it is necessary to analyze the channel and network layers [21,93,100].

When analyzing network performance, the following assumptions regarding the network architecture model should be noted:

1. The satellite network is based on DVB-RCS and includes a GEO satellite, a hub terminal with a Network Control Center (NCC) and Network Management Center (NMC) and user terminals (UTs), as shown in Fig. 5.1.

2. In the channel layer, the resource allocation scheme is Demand Assigned Multiple Access (DAMA) with MF-TDMA technology [21,93,100].

3. The satellite uplink data channel (UDC - Uplink Data Channel) is switched to the downlink data channel (DDC - Downlink Data Channel). In this way, a mesh connection to the satellite terminals is provided (Fig. 5.1).

4. For network management, there is a Forward Control Channel (FCC), a Return Control Channel (RCC) and a Log-on Channel (LOC). FCC is used to broadcast control messages from the

hub terminal with NCC and NMS to the UT. RCC and LOC are used to transmit control messages from the UT to the hub terminal. For MF-TDMA synchronization in all UTs and hub terminals, a Ranging Channel (RC) is used to correct time and frequency synchronization.

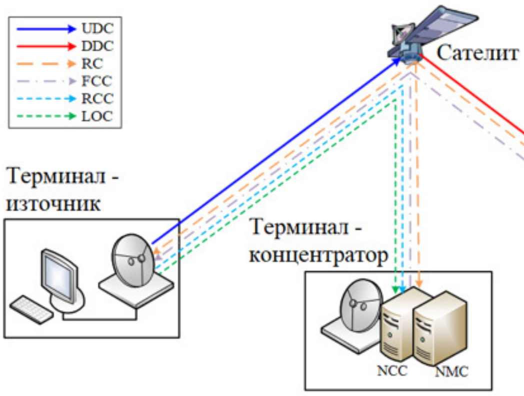


Fig. 5.1. *Model of the satellite communication system for data transmission*

5.1.3. Network layer architecture

The network layer architecture is shown in Fig. 5.2.

The satellite network can be divided into separate sub-autonomous systems (AS - Autonomous System) by each service provider or each beam. If all UTs share routing information with each other, a large resource will be consumed to share it [8]. Thus, an OSPF (Open Shortest Path First) routing scheme is used in the same AS, and BGP (Border Gateway Protocol) is used between individual AS - Fig. 5.2 [53].

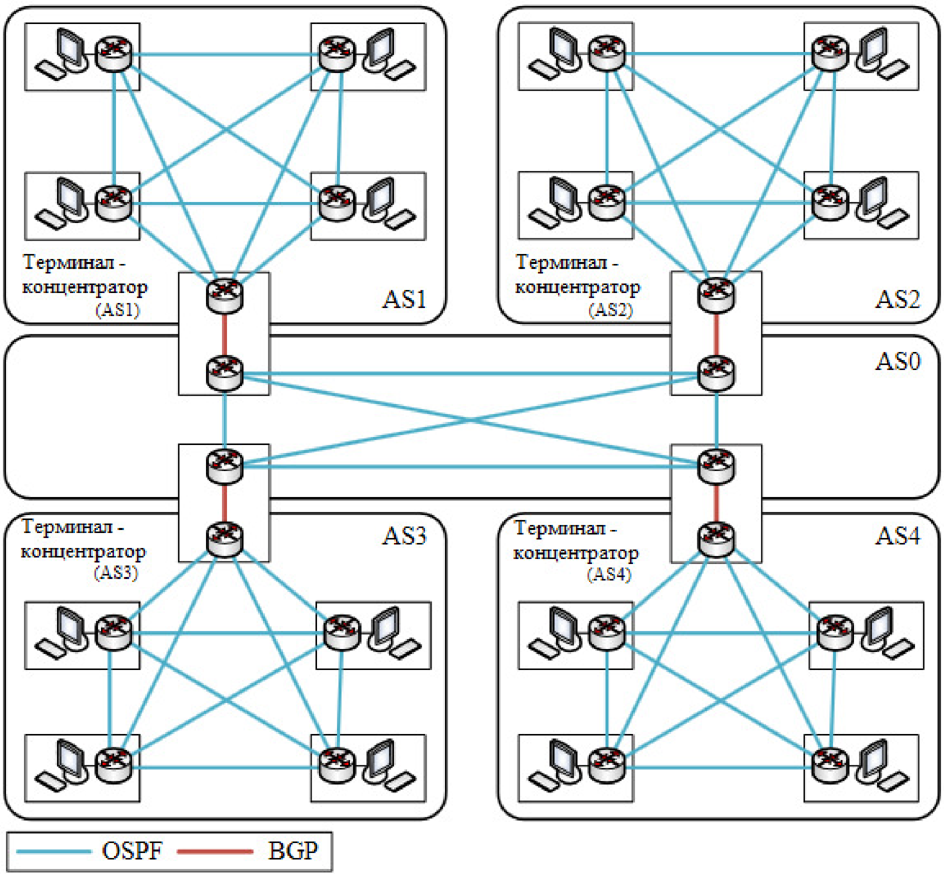


Fig. 5.2. *Модел на мрежовия слой на сателитната комуникационна система*

5.1.4. QoS support

In order to provide Internet services with QoS support, the QoS class must be defined for them. The priority and characterization of the services must then be reflected in the scheduling and allocation of resources at the channel and network layers. For example, the resource for delay-sensitive services such as VoIP and video streaming services should be allocated by CRA and RBDC with delay minimization [6,7]. NMS manages QoS class and QoS policy like service priority, maximum data rate, etc. This information is forwarded to NCC and UT. In NCC and UT, this information is used in the DAMA controller, DAMA agent and schedulers [5,21,93]. The data transmission speed in UT is limited to prevent traffic congestion and depends on the type of terminal. The maximum data rate will also depend on the maximum equivalent isotropically radiated power (EIRP).

5.1.5. Performance analysis results

The performance analysis and evaluation uses a MATLAB-based simulation model with input parameters presented in Table 1. The total bandwidth and control channel are 10 MHz and 3 MHz, respectively. Thus, the bandwidth available to transmit the service traffic can be calculated as:

$$B_A = (B_T - B_C).(1 - R_G).\mathrm{R_P}, \tag{5.1}$$

where B_T and B_C are respectively the total bandwidth and the bandwidth to be allocated to transmit the control information, R_G is the guardband ratio. R_P is the MF-TDMA packetization factor. Thus, the available bandwidth is 6.044 MHz. For example, if the spectral efficiency is assumed to be 1 bps/Hz, the maximum transmission capacity is 6.044 Mbps in the simulation.

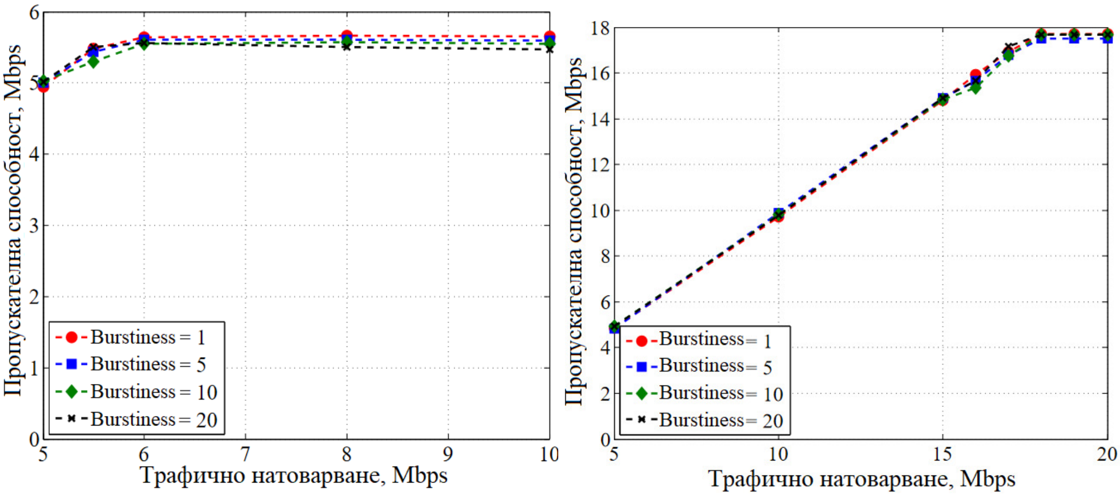
Table 5.1 *Simulation parameters*

Parameter	**Value**
Total bandwidth	10 MHz
Security Bandwidth	10%
Control channel	3 MHz
MF-TDMA packing factor	0,95
Frame length	0,5 s
Delay in resource allocation	4 frames
Distribution time delay in sat. channel	125 ms
Maximum data rate	45 Mbps
Number of User Terminals (UTs)	50 – 150
Spectral efficiency	1, 3 bps/Hz
Number of service flows	50 – 150
Average bit rate of each stream	33 – 440 kbps
Average data size (at the application layer)	2 – 500 KB
Average arrival time	0,5 – 10 s

5.1.5.1. Performance evaluation for delay-tolerant services

Scenario 1 investigates the performance for delay-tolerant services depending on the traffic load A burstiness factor of 1 to 20 is used in resource allocation depending on the traffic type classifier adopted for the different services. VBDC was used in resource allocation. The delay limit is 3–10 s, taking into account the resource allocation delay. Fig. 5.3 shows the throughput as a function of the traffic load for the spectral efficiency of 1 and 3 bps/Hz.

In Fig. 5.3 packet broadcast factor does not greatly affect performance. When the traffic load is greater than the maximum transmission capacity, the throughput values for the spectral efficiency of 1 and 3 bps/Hz approach 5.5 Mbps, 12 Mbps, and 18 Mbps, respectively.

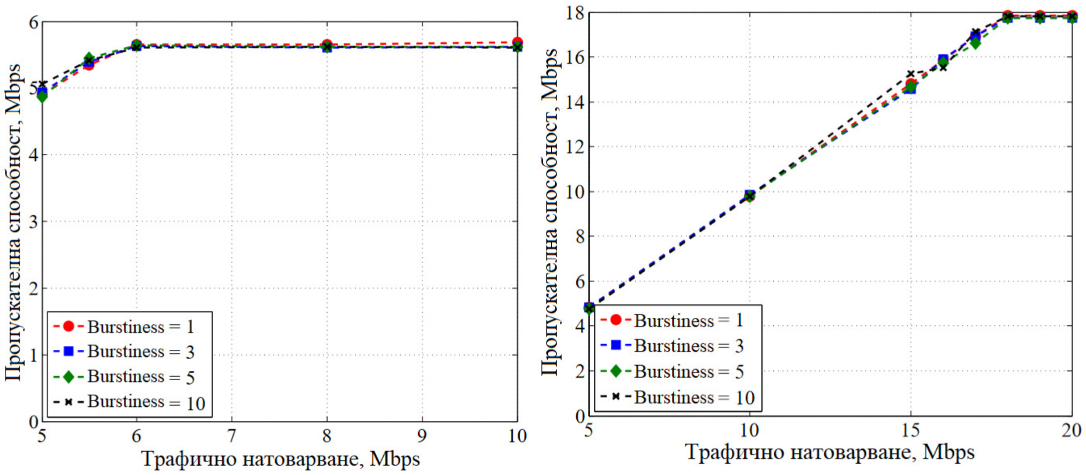


a) at 1 bps/Hz *b) at 3 bps/Hz*

Fig. 5.3. *Network throughput as a function of traffic load at VBDC for delay-tolerant services*

5.1.5.2. Performance evaluation for delay-sensitive services

Scenario 2 determines the performance of the delay-sensitive service depending on the traffic load.



a) at 1 bps/Hz *b) at 3 bps/Hz*

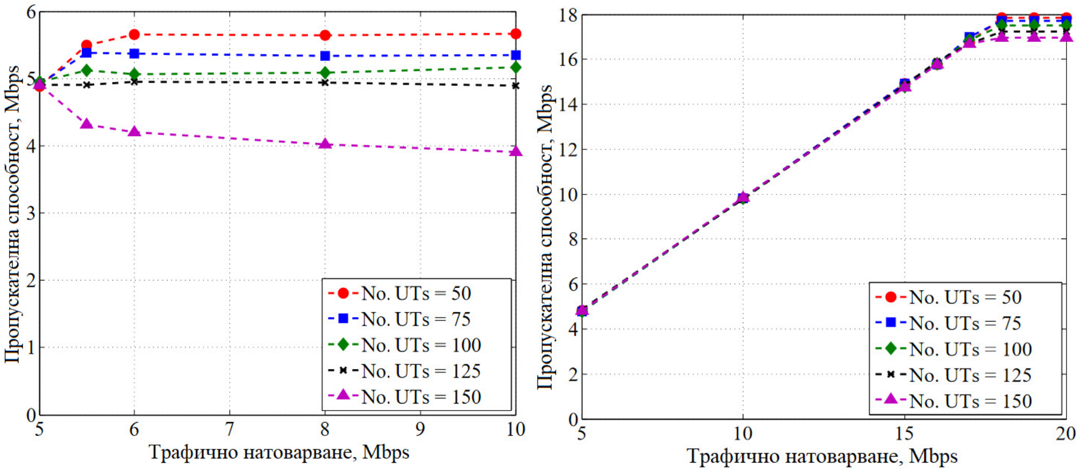
Fig. 5.4. *Network throughput as a function of traffic load at VBDC for delay-tolerant services*

In resource allocation, RBDC is implemented to eliminate the delay in resource allocation. A tight delay limit of 1–4 s is set for comparison with scenario 1 and VBDC. Since RBDC is usually applied to allocate resources to applications such as VoIP and streaming video services, the packing ratio is 1–10, which is less than that in scenario 1.

Fig. 5.4 shows the throughput as a function of the traffic load for the spectral efficiency of 1 and 3 bps/Hz. When the traffic load is greater than max. transmission capacity, the throughput values converge to the results of scenario 1.

5.1.5.3. Performance evaluation depending on the number of users

In scenario 3, the QoS performance is analyzed according to the traffic load and the number of UTs in the satellite network. VBDC is implemented in resource allocation. In this scenario, the total traffic load is constant and the data rate for each UT is the total traffic load divided by the number of UTs. Thus, the amount of data to be transmitted in each ST decreases as the number of UTs increases.



a) at 1 bps/Hz *b) at 3 bps/Hz*

Fig. 5.5. *Network throughput depending on traffic load at VBDC and different number of user terminals (UTs)*

Fig. 5.5 shows the dependence of the throughput as a function of the traffic load for the spectral efficiency of 1 and 3 bps/Hz. It can be seen that the maximum performance slightly decreased as the number of UTs increased. For the spectral efficiency of 3 bps/Hz, the maximum throughput for 50 UTs, 75 UTs, 100 UTs, 125 UTs, and 150 UTs is about 18 Mbps, 17.87 Mbps, 17.68 Mbps, 17.41 Mbps, and 17.13 Mbps per user, respectively. When transmitting small data, the probability that the MF-TDMA time slot has not been completely filled increases, resulting in a slight decrease in maximum performance.

5.2. Investigation and analysis of polarization modulation efficiency in satellite communication systems

With the development of satellite communications, the number of satellites increased dramatically and a higher frequency was adopted to meet interference mitigation [A4, 2]. As the carrier frequency increases, the synchronization complexity increases and the synchronization time becomes longer. It is difficult to establish exact carrier frequency synchronization during demodulation in the case of, for example, high frequency narrowband or high dynamic satellite communication. Modern application applies differential phase modulation (DPSK) and incoherent demodulation to meet the non-exact carrier synchronization conditions for communication needs.

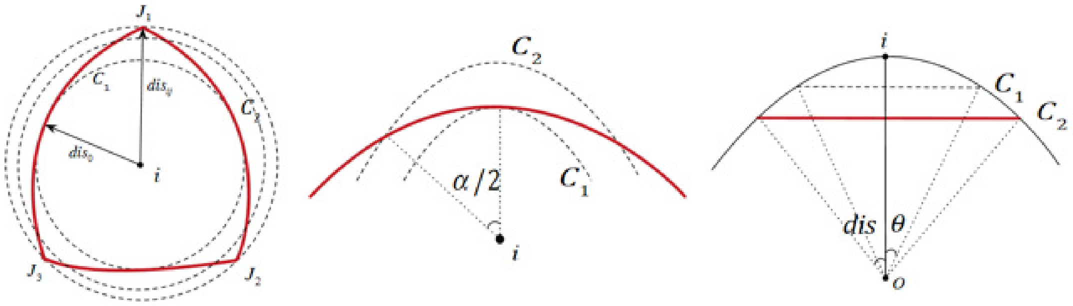
The use of polarization characteristics is given great importance and is widely used in radar, optical fiber and satellite communication [6]. For example, in conventional satellite communication, the use of the dual polarization frequency (DPFR - Dual Polarization Frequency Reuse) doubles the frequency capacity factor. In optical fiber communication, the different polarization states of light are used to carry information that is PolSK modulated (Polarization Shift Keying). With the development of polarization theory, the application of polarization states to carry information is motivated, which determines the so-called polarization modulation (PM – Polarization Modulation). For example, PAM (Polarization Amplitude Modulation) modulation is proposed in [121], which combines polarization modulation with traditional modulation to improve the energy efficiency of the system. In [77], a continuous polarization modulation method is proposed to improve the spectral efficiency.

In the field of satellite communications, the study of polarization properties is far from sufficient. Satellite antenna systems are becoming highly directional, highly flexible and have very good polarization identification capabilities. With the development of high-performance digital signal processing processors, the built-in processing capacity becomes progressively larger, which provides the basis for applying polarization modulation on a satellite. An introduction to polarization modulations for satellite communications, transceiver design and application analysis for satellite communications is presented. The Symbol Error Rate (SER) of the symbol using PM is determined by performing the Monte Carlo simulation.

There is a big difference between satellite and terrestrial wireless communications. The main characteristics of the satellite link channel are AWGN channel, long time delay, power and bandwidth limitations.

5.2.5. *PM performance of AWGN channel*

In the AWGN channel, the noise leads to a shift of the polarization state in the Poincaré sphere. The Poincaré sphere is therefore divided into several decision regions for the constellation points. The decision region at a particular point in the 8PM system is shown in Fig. 5.12.



a) b) c)

Fig. 5.12. *One solution area for an 8PM constellation point: a) front view, b) front view zoom, c) sphere cross-section*

In Fig. 5.12 dis_{ij} is half of the neighboring constellation points and denotes the i-th constellation point and its decision zone relative to the j-th endpoint, and $\alpha(dis, \theta) = 2\arccos(\tan dis/\tan\theta)$.

The received signal signal-to-noise ratio (RSNR) is defined as RSNR = P/σ^2, where P is the received power and σ^2 is the noise power. Then the joint distribution of the received signal in the Poincaré sphere is expressed as [2]:

$$f(\theta_i, \varphi_i) = \frac{\sin\theta_i}{4\pi} e^{-\frac{RSNP}{2}(1-\cos\theta_i)}\left[1 + \frac{RSNP}{2}(1+\cos\theta_i)\right] \tag{5.5}$$

where $\theta_i = \pi/2 - 2\varepsilon_i$, $\varphi_i = \pi/2 - 2\tau_i$The symbol error ratio (SER) of an M-fold PM can be defined as $SER = \frac{1}{M}\sum_{i=1}^{M} P_e^i$ in AWGN channel, where $P^i{}_e$ is the SER function of each point of the constellation and expresses as (5.4).

5.2.6. *Simulation results of PM signals*

The theoretical SER curves for 2PM, 16PM, 20PM and 16PM modulation are presented in Fig. 5.13.

Монте Карло симулацията на 4PM модулация се извършва при условия на AWGN канал, дължина на последователността 1000000 и 2-битово картиране за символ. RSNR варира от 10 dB до 20 dB в AWGN канал и приемникът използва MLD. Резултатите от това изследване са показани на Fig. 5.14.

The simulation results are consistent with the theoretical ones for a 4PM system within a certain error range. The error comes mainly from the approximation of the first-order Bessel function in [3].

The resulting Stokes vectors *gRi* (*i* = 1,2,3) are calculated from the amplitude and relative phase of the two signals in the PM communication system, and it is not necessary to recover the exact frequencies because the signals pass through a filter after frequency conversion. This means that polarization modulation is suitable for scenarios without carrier recovery, such as high-frequency narrowband or high-dynamics satellite communication systems, where DPSK incoherent demodulation was previously applied.

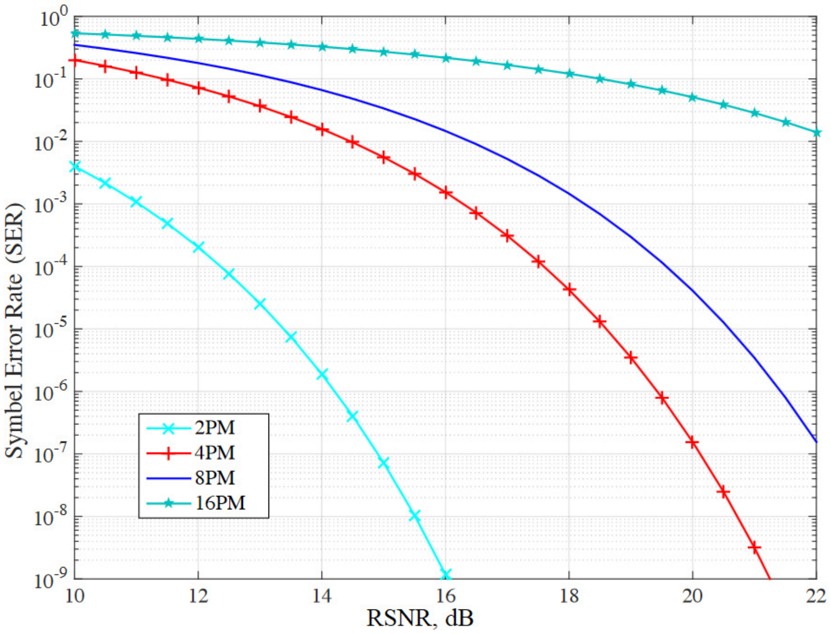


Fig. 5.13. *Theoretical value of SER for MPM modulation in AWGN link channel*

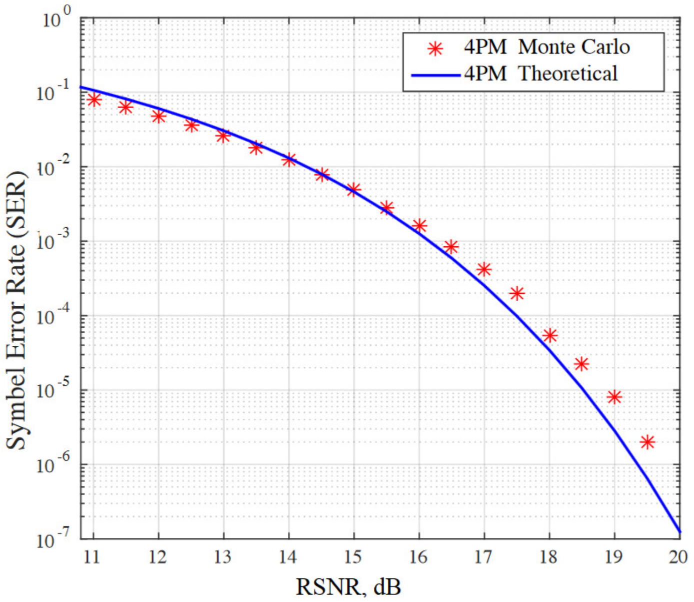


Fig. 5.14. *Theoretical value of SER for 4PM modulation and the Monte Carlo simulation in AWGN channel using MLD scheme*

PM and DPSK incoherent demodulation are compared in terms of SER, and the results are shown in Fig. 5.15.

It can be seen that the SER for BPM and DBPSK are almost the same and QPM needs approximately 3dB higher RSNR value than QDPSK for the same SER probability. When the modulation order increases, the BER characteristics of 8PM and 16PM are better than those of 8DPSK and 16DPSK, respectively. However, the signal must pass through a nonlinear high power amplifier (HPA) before transmission to the satellite communication system. The non-linearity of the HPA will generate intermodulation components.

The intermodulation interfering signals have the same polarization state in the PM system and the transmitted signals are immune to the nonlinear effect of the power amplifier. In DPSK systems, an attenuation must be set (typically by 6dB for satellite HPA), i.e. PM RSNR would be higher than DPSK by about 6dB at the receiver for the same noise environment. Considering the circumstances, the performance of any PM modulation is much better than DPSK, so PM is more suitable for nonaccurate carrier recovery. In addition, φE is calculated from the two orthogonal signal differences at the receiver, making PM modulation robust to phase noise.

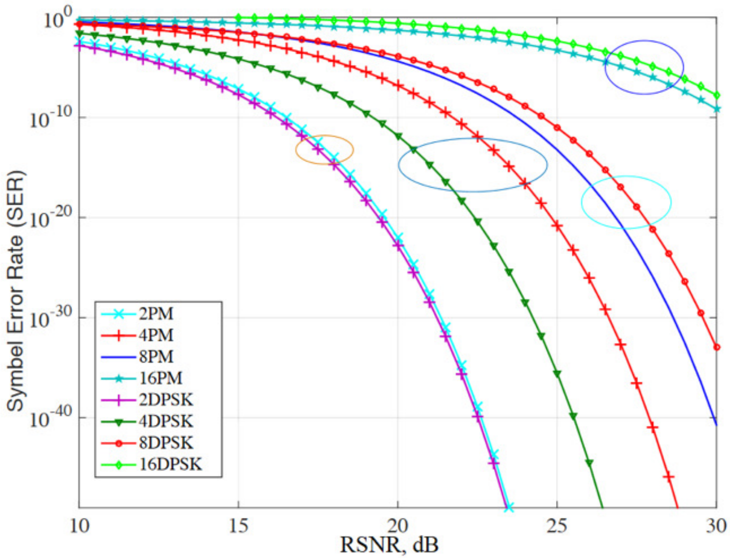


Fig. 5.15. *SER for MPM and MDPSK incoherent demodulation that do not need exact timing*

5.3. Conclusions to Chapter Five

1. A satellite network for providing Internet services with QoS support was examined and analyzed. The satellite network architecture with MF-TDMA and QoS support is presented. Through the performance evaluation, it is proven that factors such as traffic load and spectral efficiency should be considered in the QoS policy for delay-tolerant and delay-sensitive services in the satellite network. The estimation of the required resource to provide QoS must be considered for the service using RBDC. Small data size can reduce QoS performance in the satellite network. The derived factors should be considered in QoS policy and control techniques to estimate the required resources in order to improve QoS performance in satellite networks.

2. The effectiveness of a polarization modulation scheme to overcome HPA nonlinearity and achieve better performance than DPSK incoherent demodulation in cases without carrier recovery, such as high frequency narrowband or high dynamic satellite communication, is presented and investigated. The SER coefficient for the polarization modulation is derived and compared with a Monte Carlo simulation in a satellite AWGN channel. PM is one way to exploit the dual polarization channel capability available in satellite communications and coherent modulation techniques that reduce spectral efficiency loss.

III. CONCLUSION

Summary conclusions

The search and experimentation of new orbits and improvement of channel coding, the use of new modulation schemes and expansion of the frequency spectrum lead to interesting results related to the improvement of efficiency and quality of connection. Choosing a channel code with a higher efficiency would allow to reduce the rate of the code used and to increase the multiplicity of the modulation used, while maintaining the error probability. This, in turn, leads to an increase in channel throughput. In order to obtain maximum noise immunity, it is necessary to optimize the parameters of the modulation constellation after optimizing the channel code. The optimization of the modulation constellations allows to achieve an optimal compromise between the noise immunity of the radio channel, the energy efficiency and the resistance to nonlinear distortions.

The dissertation work examines the possibilities of combining heterogeneous statistical analytical and software methods for data analysis and processing, and the means of information and communication technologies are used to ensure the transfer of satellite data and measurement setups with monitoring of the parameters of the satellite channel. The presented topic leads to the creation of methodologies from procedures related to correct approaches in monitoring and control in communication systems for satellite digital broadcasting, by determining optimal ranges of changes of specific technical parameters and criteria related to the effective operation and setting of satellite communication channels

Publications related to the dissertation work

Regarding the coverage of the results of the dissertation work, six publications at international conferences and scientific publications are presented, which fully meet the minimum requirements regarding the considered criterion. Three of the publications were presented at the International Scientific Conference "Unitech" and three – at a national conference and "TechCo", one of them being independent, and the other five being prepared in co-authorship with the scientific supervisor and research team. The publications were issued in peer-reviewed proceedings from the international scientific conference "Unitech" and the national conference "TechCo" in the academic period 2020-2022, actually representing nearly 2/3 of the content of the dissertation work.

IV. CONTRIBUTIONS TO THE DISSERTATION WORK

Scientific-applied contributions:

- ❖ Analytical models of the "satellite-earth" transmission communication channel have been synthesized, through which a comparative analysis is performed to determine the throughput of the transmission channel under different theoretically applicable variants of signal modulation.
- ❖ Simulation models were created in Matlab/Simulink virtual environment. Research has been done to comprehensively evaluate the degree of influence of individual configuration parameters and signal processing stages on the quality of service by evaluating the binary error rate (BER), the signal-to-noise ratio (SNR) in the transmission channel and the vector diagram of the signal in scenarios with different modulation formats and transmission power according to the DVB-S2 standard. The effectiveness of BCH and LDPC signal coding in a satellite DVB-S2 transmission channel has been evaluated. The signal-to-noise ratio (SNR) threshold levels for various combinations of encoder configuration parameters and code depth, respectively, have been established in order to ensure quasi-error-free signal reception for QPSK and 8-PSK modulation formats.
- ❖ A simulation model of a DVB-RCS satellite communication system for broadband data transmission with MF-TDMA time division multiple access and mesh topology is developed. Mechanisms for continuous resource allocation, rate-based dynamic capacity, and volume-based dynamic capacity have been evaluated for efficient frequency utilization and service quality maintenance. Research and comparative analysis of the performance (according to the network throughput criterion) of the DVB-RCS satellite communication system for broadband data transmission has been made in 3 different scenarios regarding the delivered services: for delay-tolerant services; for delay-sensitive services; performance evaluation against the number of users.
- ❖ A comprehensive model has been developed and studied for the analysis of the effectiveness of the application of polarization modulation in order to more optimally use the available frequency resources and accelerate the synchronization time in high-frequency narrowband or high-dynamic satellite communication. Conducted for quality of service evaluation studies by determining the SER value and its bounds under different PM and DBPSK modulation formats and benchmarking with Monte Carlo simulation in satellite AWGN channel.

Applied contributions:

- ❖ Practical experiments have been conducted and an approach has been proposed for the optimal selection of frequency parameters and construction equipment for a satellite communication system and ensuring quality broadcasting of satellite television programs.

❖ An experimental set-up of a communication channel for transmission with an artificial satellite of the "CubeSat" type with hardware transceiver modules and a module-emulator of a satellite communication channel was developed and studied in laboratory conditions. A study was conducted to evaluate the packet error rate in a communications channel for transmission with an artificial satellite of the "CubeSat" type, and graphical dependences were presented, providing information for the search for optimal solutions in the selection of the operating frequency range, altitude and parameters of the orbit, the transmission power, parameters of the receiving-transmitting antenna, as well as to evaluate the influence of the complex combination of these parameters.

V. LIST OF PUBLICATIONS RELATED TO THE DISSERTATION

A1. Angelov K., **Myumyunali S.**, Ivanov T., Sadinov S., Analysis and Evaluation of the Transmission Channel for Communication with Artificial Pico- and Nanosatellites, International Scientific Conference UNITECH 2020, 20-21 November 2020, Gabrovo, Proc. of Papers, Vol. I, pp. I-269-273, 2020, ISSN: 1313-230X.
A2. Kogias P., Sadinov S., **Myumyunali S.**, Malamatoudis M., Hristov H., Building and Configuration of a Playout Multiviewer Monitoring System. International Scientific Conference UNITECH 2020, 20-21 November 2020, Gabrovo, Proc. of Papers, Vol. I, pp. I-292-297, 2020. ISSN: 1313-230X.
A3. **Myumyunali S.,** Study and Analysis of the Efficiency of Polarization Modulation in Satellite Communication Systems, National Science Conference TechCo-2021, Lovech, Proc. of Papers, ISSN 2535-079X, pp. 77-82.
A4. **Myumyunali S.,** H. Hristov, S. Sadinov, Performance Analysis of Satellite Communication System for Data Transmission, National Science Conference TechCo-2021, Lovech, Proc. of Papers, ISSN 2535-079X, pp. 83-89.
A5. Kogias P., S. Sadinov, **S. Myumyunali**, A. Sindrakovska, B. Karapenev, Simulation Studies of Satellite Digital Television Signal According to DVB-S2 Standard, International Scientific Conference UNITECH 2021, 19-20 November 2021, Gabrovo, Proc. of Papers, Vol. I, pp. I-269-273, 2021, ISSN: 1313-230X.
A6. **Myumyunali S.**, H. Hristov, M. Tomov, K. Angelov, Development and Study of SDR-Based Frequency Down-Converter for Satellite Receiver According to DVB-S2 Standard, National Science Conference TechCo- 2022, Lovech, Proc. of Papers, pp. 59 – 64, 2022, ISSN: 2535-079X.

TITLE: „RESEARCH AND IMPROVE THE QUALITY OF SERVICE IN SATELLITE COMMUNICATION CHANNELS“

Author: m.eng. Seyhan Sadak Myumyunali

ABSTRACT:

The dissertation deals with simulation models for satellite communications are presented, research is carried out and contributions are defined related to the effective use of frequency spectrum, type of modulation and channel coding in order to obtain a higher quality of services on satellite communication channels. Test setups have been implemented and experiments have been made to evaluate the packet error in a communication channel for connection with an artificial satellite of the "CubeSat" type, and graphical dependences have been presented, providing information for the search for optimal solutions in the selection of the operating frequency range, altitude and orbit parameters. the transmission power, parameters of the receiving-transmitting antenna, as well as to evaluate the influence of the complex combination of these parameters.

The processes related to the processing, transmission and reception of satellite communication signals in satellite transmitters and receivers are studied - modulation, channel coding, multiplexing, polarization characteristics of the signal, synchronization, configuration, adjustment and coordination of the transceiver equipment. As criteria for determining the quality of service, various evaluation parameters and quality indicators such as equivalent isotropic radiated power (EIRP), field strength, spectral and vector characteristics of the signal and the signal-to-noise ratio were used in criteria of maximum permissible values of the modulation error rate (MER), binary (BER) and packet (PER) error rates, etc.

Keywords: Satellite communication, DVB-S/S2, QAM, PSK, QPSK, Polarization modulation (PM), MER, BER, SER, PER, EIRP, Pico- and Nanosatellite, CubeSat, Satellite communication channel, Satellite network, free space path loss, QoS, Simulation Matlab, SNR, BCH, LDCP.