PERFORMANCE EVALUATION OF DOWNLINK SATELLITE BROADCAST STREAM UNDER RAINY CONDITIONS IN A LABORATORY-CONTROLLED ENVIRONMENT

Hung NGUYEN MANH, Marie RICHTEROVÁ, Tomáš BŘINČIL

Abstract: The attenuation induced by rain greatly impacts the performance in the satellite communication at Ku band. In fact, it is very challenging to measure parameters of the satellite channel under rainy conditions in the laboratory environment. Due to the complex in terms of design, development, management and maintenance of the system and the dynamic characteristics of the satellite channel with respect to operators utilizing this frequency band, it becomes essential to study the key effects and causes of the signal attenuation. In order to have the accurate evaluation in the satellite channel, end-to-end performance of the system based on a description of the standard document under raining conditions was modelled by the Rician distribution and K-factor. The average bit error rate used for the performance evaluation of the system by the experimental test. Obtained results in the satellite channel condition are evaluated, analyzed and discussed. Moreover, specific future planned work is also mentioned in the article.

Keywords: Digital Broadcast Video; Sum-of-sinusoids principle; Rician distribution; Rain attenuation; Channel impairments.

1 INTRODUCTION

Digital Video Broadcasting - Satellite - Second Generation (DVB-S2) [1] standards address broadband interactive satellite systems for mainly providing high data rate multimedia services to fixed terminals. The candidate frequency bands of the DVB-S2 system based broadband satellite systems to fully support are the Ku-band in the Europe. Simulation of a suitable general model in a laboratory-controlled environment is very important to address an issue of the system. Space communication and navigation test-bed on the International Space Station provided an opportunity to evaluate the performance of the DVB-S2 system, as well as demonstrated advanced features of the system could be integrated and operated. Reliability of the DVB-S2 system such as variable and adaptive coding and modulation was evaluated. The test-bed [2] was based on the commercial gateway product, DVB-S2 modulator, demodulator and a channel simulator for emulating communication channels, that demonstrated that a DVB-S2 system can be operated close to saturation in quadrature phase shift keying (QPSK), 8-ary phase-shift keying (8-PSK) and 16-ary Amplitude Phase Shift Keying (16-APSK).

Software-Defined Radio (SDR) provides flexible radio functionality to develop a flexible wireless laboratory platform. In [3], performance measurements of the symbol timing recovery of DVB-S2 receiver circuits over the Additive White Gaussian Noise (AWGN) channel was presented and measured for the clear sky period. Real DVB-S2 signal [4] with different parameters was analyzed for reception and measurement. In the practice, atmospheric effect is a one of the key factors in the design of satellite-to-earth links operating at frequencies above 10 GHz. In the atmosphere, raindrops absorb cause the signal attenuation and reduction of the system availability and reliability. Hence, the rainy factor in the satellite connection becomes more important in the successful connection. The Nakagami-m distribution is often modeled the satellite channel because of its advantages of a better fit for amplitude statistics. However, the Nakagami-m distribution alone, unlike the Rician model, has the disadvantage of being an amplitude only description, but even a slight phase error may lead to the problem of the simulation. X. Hao [5] and M. Cheffena [6] proved that the correlation exists between the atmospheric and the factor of Rician distribution. The practical scenario with a lot of parameters such as particularly the effects of different elevation angles, frequencies, geographical region, and weather parameters have not yet been described in the proposed correlation. Therefore, a modified reliable correlated equation that includes the effects of the mentioned parameters is led by Liolis [7] for filling the gap. The relationship between rain affects and the value of the K factor was showed in the following equation:

$$K_{rician} = K_{\mathrm{mod}} - K_{rain} \tag{1}$$

where K_{mod} is the factor before adding the atmospheric effects. K_{rain} is the factor based on the rainy statistical analysis was obtained by Crane's model [8] for temperate regions. Effective path average factors were estimated by observations of the point rain rate statistics, of the horizontal structure of rainfall, and of the vertical temperature structure of the atmosphere. If the signal is totally blocked, then the model signal in the satellite channel was usually represented by a Rayleigh distribution [9]. Flat Rayleigh model can represent the worst-case environment in terms of bit error rate degradation. To test the performance of the system, a test-bed consisting of SDRs and laboratory measurement instrument allows the research of rainy scenarios that arise in the satellite link. This experimental platform also provides an opportunity to demonstrate how the DVB-S2 system could be operated in the laboratory environment.

2 SIMULATION METHODOLOGY

2.1 System model

In the following part, the detail of the system model that we adopted for the end-to-end DVB-S2 system analysis. Based on the specification of European Telecommunications Standards Institute (ETSI), a simulation of the DVB-S2 system was simulated. Compared to the full described ETSI standard, we demonstrate in our simulator all key aspects impacting the physical layer performance. The time division multiple access technique with fade mitigation based on forward error correction codes id the access technique in the DVB-S2 system. Data frames of constant size are packaged and the coded-modulation used to adapt to the propagation conditions on each communication link. The system model that is utilized for the DVB-S2 system simulation. Fig. 1 shows the high-level system block diagram based on the specification [1].

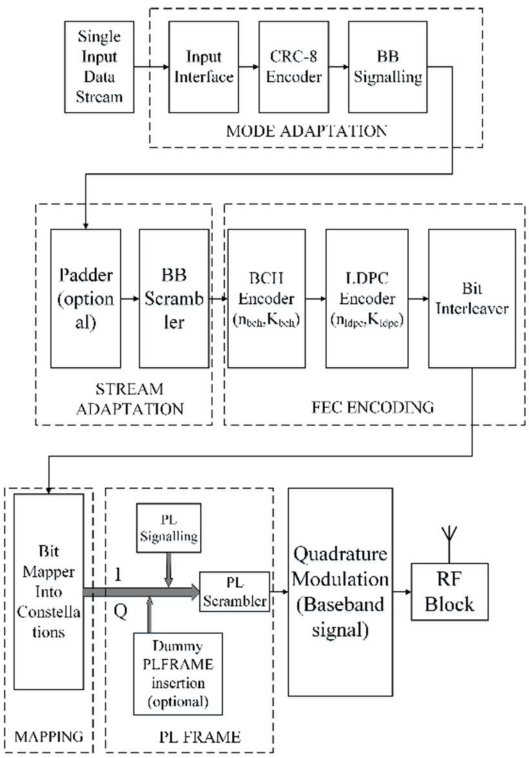

Fig. 1 Block diagrams of the DVB-S2 System
Source: [1].

Input data of the system is a single Moving Picture Experts Group (MPEG)-4 video stream. The output of the Forward Error Correction (FEC) encoding block is frames that have a fixed size of 64800 bits for long FECFRAME or 16200 bits for short FECFRAME. Modulation schemes with various code ratios are QPSK, 8-PSK, 16-APSK and 32-APSK. In the article, there is an assumption that non-perfect of the Radio Frequency (RF) block has not been mentioned. The first block in the chain of the signal is the Mode Adaptation block which is considered in detail in the next part of the article.

2.2 Mode and stream adaptation blocks

Unlike the standard DVB-S, Mode and Stream Adaptation blocks in the specification DVB-S2 process types of input such as MPEG-2 or MPEG-4. It provides a constant length base-band frame for the input of the next block. The output sequence of the Mode Adaptation block in the system is grouped into fix size frames, which is structured by base-band header (BBHEADER) and a DATA FIELD field. In the Stream Adaption block, the BBHEADER is randomized by a scrambler using the initial sequence is 100101010000000 for protecting data from unauthorized intruders.

2.3 FEC encoding block

In FEC encoding block, K_{bch} bits BBFRAME input stream is the input of Bose–Chaudhuri–Hocquenghem (BCH) encoder and Low-Density Parity-Check (LDPC) coders. Additional bits are appended after BBFRAME field with K_{bch} BCHFEC bits and K_{ldpc} LDPCFEC bits for interleaving. The Berlekamp algorithm used in the BCH encoder for correcting t-error. The generator polynomial of the BCH encoder is built by multiplying the first t-polynomials.

The system using LDPC codes over the satellite channel allowed to be set very close to the Shannon limitation. Ten different 1/4, 1/3, 1/2, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9, 9/10 LDPC inner codes and BCH outer codes are designed for the range of bandwidth efficiency from 0.5 bits/symbol up to 4.5 bits/symbol. The long FECFRAME used for all rates. The output using 8-PSK, 16-APSK, and 32-APSK modulation will be interleaved to against burst errors by random allocation of the data stream in time. Hence, an error correction capability of the DVB-S2 system can be up to 12 bits.

2.4 Physical layer frame

In this block, the output of Physical Layer (PL) Frame is a payload of 64800 bits for long FECFRAME or 16200 bits short FECFRAME with a PLHEADER. In the broadcasting mode, the length of FECFRAME is 64800 coded bits regardless of code rates and modulation schemes. FECFRAME is packaged by a PLHEADER field and slots. This PLHEADER field plays a role at the synchronization and signaling information configuration at the receiver. It is modulated independently by π/2-BPSK modulation schema for reducing the envelope fluctuation in comparison with the classical BPSK modulation. The PLHEADER field includes 26 bits Start of Frame (SOF) field on the left side of the

PLHEADER and 64 symbols linear binary code Physical Layer Signaling (PLS). PLS transports 7 bits of information with a minimum distance 32. 7 bits signaling information inform receivers the modulation scheme, code rates, pilot configuration, and the length of the LDPC coded data: 5 bits MODCOD field, one bit shows the length of frame is long or short and one bit expresses the status of pilot bits is in the frame or not. 64 bits PLSCODE is further scrambled by the scrambling sequence for improving the autocorrelation property and energy dispersal.

The standard DVB-S2 allows two operating modes: pilotless and pilot. Pilot signal consists of 36 symbols in every 16 slots for a priori knowledge of the satellite channel and carrier recovery. The number of slots in the frame is determined by the length of FECFRAME and the modulation type.

2.5 Modulation block

Unlike DVB-S that supports only QPSK modulation, Quadrature phase-shift keying (QPSK), 8-ary phase-shift keying, 16-ary amplitude and phase-shift keying (16-APSK) and 32-ary amplitude and phase-shift keying (32-APSK) modulations are supported in the DVB-S2 standard for the transmitted payload. In the broadcast applications, QPSK and 8PSK schemas are typically selected because of constant envelope modulations and satellite transponders may be operated near saturation. Baseband raised cosine filter using roll off factor 0.2; 0.25 or 0.35 is applied before the IQ modulation for reducing the inter-symbol interferences. QPSK modulation operates in the Signal-to-Noise Ratio (SNR) range below 6 dB while the 16-APSK and 32-APSK performs well in SNR levels between 8 and 16 dB. The following table demonstrates code rates and modulation schemas in the DVB-S2 system.

2.6 Satellite channel model under the rainy condition

In fact, in case of large variations of the atmospheric attenuation mainly due to the presence of rain, a tremendous waste of resources of the system for a great time percentage of the service can be strongly affected. Crane's assumption for an effective rain height and the convective raincell model to describe the horizontal variation of the rainfall structure is used. However, the variation of the elevation angle of broadband satellite systems is rather small and thus, the rain attenuation modeling assumptions that the main impact of rainfall on the channel is the amount of rainy water. Under the above assumptions, the definition of the Rician K-factor can be accordingly modified as the following formula that simply explains well how for rain attenuation parameter to be distributed in the satellite channel:

$$K_{rician} = 16.88 - 0.04R \quad (2)$$

where K_{rician} is the Ricean K-factor (in decibels), and R is the rainfall rate (in mm/h). The equation shows that the K-factor with a negative sign is proportional to rain rate. This is expected because as the rain rate increases, the coherent power decreases and the incoherent scattered power increases. Therefore, pdf of the rain attenuation in the channel was derived on the rain attenuation random variable. This random variable is presented by Rician distribution variable. Rician processes were simulated by various simulators such as Sum of Sinusoids simulators [10] or Filtered Gaussian Noise (FGN) simulators [11], [12]. The channel model is approximated by using the sum of sinusoids method to generate the set of complex path gains ak for the number of expected multipath components and these are uncorrelated with each other. At the receiver, we have the following received band-pass signal:

$$r(t) = h(t) * s(t) + w(t) \quad (3)$$

where s(t) is the source signal, w(t) is the band-pass noise, h(t) is the band-pass channel impulse response which have the set $\{h_{Fi}\}$ of tap weights given by:

$$h_{Fi} = \sum_{k=1}^{K} a_k \sin c\left[\frac{\tau_k}{T_s} - n\right] \quad (4)$$

where T_s is the input sample period to the channel, $\{\tau_k\}$, where $1 \le k \le K$, is the set of path delays, K is the total number of paths in the Rician channel, $\{a_k\}$ with $1 \le k \le K$ is the set of complex path gains of the channel, N_1 and N_2 are chosen so that $|h_{Fi}|$ is small when n is less than $-N_1$ or greater than N_2.

3 EXPERIMENTAL TEST

DVB-S2 simulation model in Matlab faces a lot of limitations, due to the ambition to raise significantly the data rate and non-perfect transmitter/receiver with the asynchronous carrier. In this part of the paper, the research presents and establishes a design of the test bed for evaluating DVB-S2 system.

The DVB-S2 channel consists of the rainy attenuation and noise in the path from a satellite to a user terminal is simulated over-the-air in the anechoic chamber room. Satellite communication system imperfections beside the noise, the transceiver imperfections are included in the form of carrier phase and frequency errors. The nonlinear distortion also occurring in radio frequency amplifiers is taken into account, but it has not yet been mentioned here.

An experiment test-bed was built to study the performance of the DVB-S2 system over the satellite channel under the rainy condition in the laboratory environment:

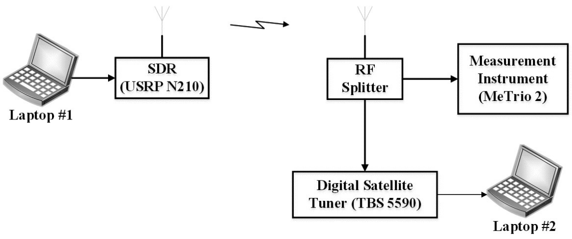

Fig. 2 General block of experimental test
Source: authors.

At the satellite receiver in Europe, the received broadcast signal is in Ku-band, while a low noise amplifier (LNB) converted signal from Ku-band to an Intermediate Frequency (IF) falling between 950 MHz and 2150 MHz. Therefore, a design of the satellite broadcast system operating at the IF frequency band is built from scratches for proving the validity of the proposed model. The experimental test uses software defined radio solutions that offer flexible software support for the specification and functions. We created an environment to prove the validity of the proposed model based on real-world radio propagation.

The RF environment was simulated in an anechoic chamber for isolating an undesirable noise. To test the proposed model, we use a testbed consisting of the first SDR is USRP N210 connected to a Linux laptop by the Ethernet interface as the transmitter. The transmitter on this first SDR sends the DVB-S2 signal with the fading channel to the received part. A program based on GNURadio application at the first laptop controls the signal on this SDR. Rayleigh channel takes in the Doppler frequency shift as a normalized value, non-line-of-sight parameters that is either true or false value. The Bit Error Rate (BER) performance of system was measured by the measurement instrument. The transport stream of the DVB-S2 system is observed by a digital satellite tuner as TBS 5590 with software applications. The measurement instrument furnishes general information at the RF level, such as IF polarization, SNR, symbol rate and modulation type as well as BER. SDR configured for using the sampling frequency is 10 Msps and the carrier frequency is 1.18 GHz. We assume that there are not non-linear effects of connectors, cable for concentrating the fading channel effect.

4 RESULTS

In the DVB-S2 standard, modulation schemas using various code rate correct the error for effective transmission. In this simulation, the article only focus on the analysis of modulation schemas using three code rates: highest correction level using code rate 1/4, lowest correction level using code rate 9/10 and middle correction level using code rate 3/4. Fig. 3 demonstrates the BER performance of system using QPSK with code rates in the clear sky and rainy conditions.

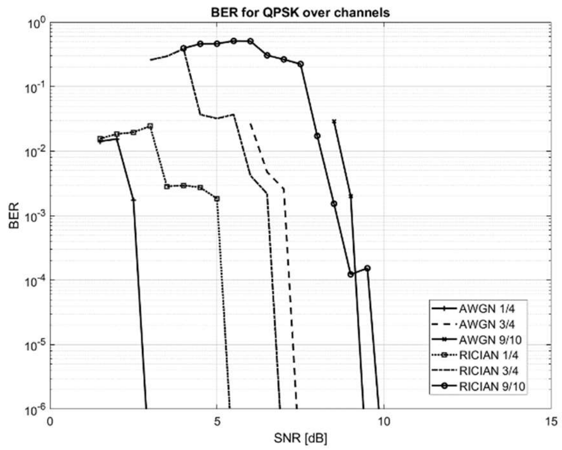

Fig. 3 QPSK
Source: authors.

SNR was changed in the range from 0 to 15 dB. The figure palpably noticed that QPSK modulation using the same rate code in the clear sky condition

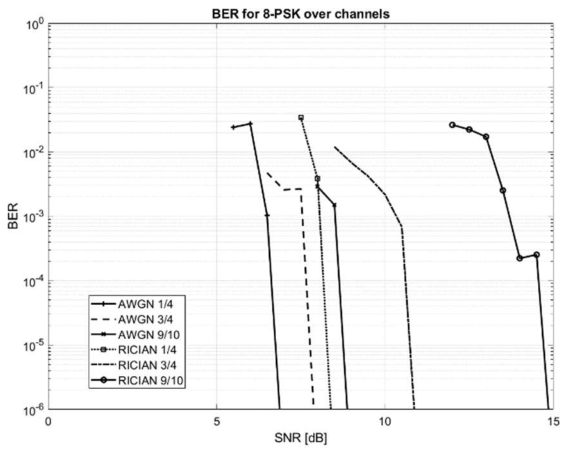

Fig. 4 8-PSK
Source: authors.

works well at BER values larger than 3 dB when system operates in the rainy environment. In the case 8-PSK, the system increases overall system performance by FEC codes at SNR higher than 6.5 dB.

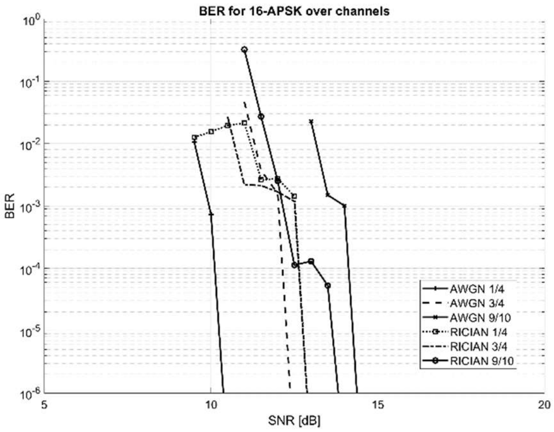

Fig. 5 16-APSK
Source: authors.

Fig. 5 shows the simulated BER performance for 16-APSK modulation with SNR in the range from 5 dB to 20 dB. In the rainy condition, the minimum desired BER of 10^{-2} is observed at SNR higher than approximate 10 dB of the system using the rate code 1/4.

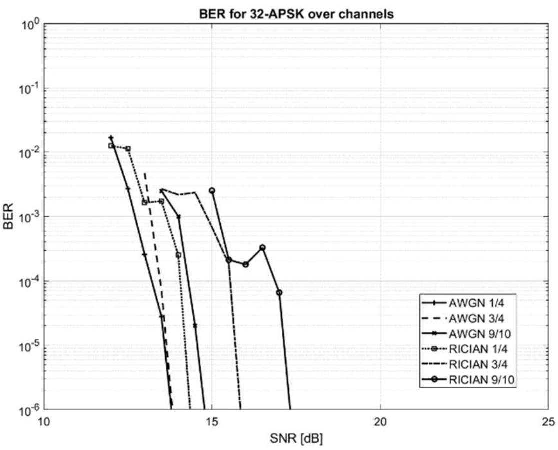

Fig. 6 32-APSK
Source: authors.

For the sake of comparison, the highest order modulation of DVB-S2 system with rate codes was introduced in the Fig. 8. SNR in the range from 10 to 25 dB was analyzed. It can be seen that the highest code rate saved the SNR ratio approximation 1 dB to 4 dB respectively compared to the same conditions. Moreover, comparing with simulation results [13] on Matlab, the result of the proposed model shows the quality of the signal is significantly decreased in the practical environment. It is logical that this model covers the basic aspects of the complex satellite system as well as some limitations of simple tranceivers using SDR. However, the system is enough precision and reliability for the evaluation in the laboratory environment and testing satellite-to-Earth scenarios in the dynamic environment of the propagation path.

5 CONCLUSION

In this article, the basic technical features and principles of the DVB-S2 system were analyzed and the performance BER of system in the rainy condition was simulated over-the-air in the anechoic chamber room. As it can be seen from the results, BER performance of satellite signal was strongly influenced in the rain but reasonable code rate is the one of good solutions for against the environment condition. Results are analyzed and used to propose future research to discover optimal code rates and modulation schemas as well as its influence on the entire signal transmission.

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Dipl. Eng. Hung **NGUYEN MANH**
PhD student at Department of Communication Technologies, Electronic Warfare and Radiolocation
Faculty of Military Technology
University of Defence
Kounicova 65
662 10 Brno
Czech Republic
E-mail: manhhung.nguyen@unob.cz

Assoc. Prof. Dipl. Eng. Marie **RICHTEROVÁ**, PhD.
Department of Communication Technologies, Electronic Warfare and Radiolocation
Faculty of Military Technology
University of Defence
Kounicova 65
662 10 Brno
Czech Republic
E-mail: marie.richterova@unob.cz

Bc. Dipl. Eng. Tomáš **BŘINČIL**
PhD student at Department of Communication Technologies, Electronic Warfare and Radiolocation
Faculty of Military Technology
University of Defence
Kounicova 65
662 10 Brno
Czech Republic
E-mail: tomas.brincil@unob.cz

Hung Nguyen Manh was born in HaNoi, Vietnam. He received the M.Sc. degree in Electronic Engineering from PaiChai University, Korea, in 2012. He is PhD. candidate at the Department of Communication Technologies, Electronic Warfare and Radiolocation, Faculty of Military Technology, University of Defence since 2017. His research interests include sensor network, digital signal processing, signal analysis and modulation recognition.

Marie Richterová was born in Vyskov, Czech Republic, in 1965. In 1989, she graduated at the Faculty of Electro Engineering Technical University in Brno in branch Electrotechnology. Her scientific degree PhD. was obtained in the year 2002 at the Military Academy in Brno. Since 2009, she has been become the associate professor at the Department of Communication Technologies, Electronic Warfare and Radiolocation, Faculty of Military Technology, University of Defence. Her specialties are modulation recognition, special signal analysis and methods of pre-processing.

Tomáš Břinčil was born near Prague in 1991. In 2014 he got bachelor degree on Czech Technical University in Prague, Faculty of Electrical Engineering, Communications, in program Cybernetics and Robotics with focus on Sensors and Instrumentation. Since 2017 he studies his PhD. at the Department of Communication Technologies, Electronic Warfare and Radiolocation, Faculty of Military Technology, University of Defence in Brno. He is licensed radioamateur specialized on satellites communication.