Bulletin of Electrical Engineering and Informatics
Vol. 12, No. 3, June 2023, pp. 1502-1512
ISSN: 2302-9285, DOI: 10.11591/eei.v12i3.4713

Improving FEC layer frame for DVB-S2 link system based on 5G NR polar coding

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Article Info

Article history:

Received Sep 5, 2022
Revised Oct 6, 2022
Accepted Oct 24, 2022

Keywords:

Bit error rate
Bose-chaudhuri-hocquenghem
Cyclic redundant check
Forward error correction
Low-density parity-check
Polar coding
Signal-to-noise ratio

ABSTRACT

Within the scope of this investigation, the MATLAB simulation code for digital video broadcasting–for satellite–second generation (DVB-S2) has been constructed. Forward error correction (FEC) rates as 3/5, 2/3, and 3/4 across additive white Gaussian noise (AWGN) and Rayleigh fading channels are used to evaluate the system's performance, mainly while working on quadrature phase-shift keying (QPSK), 8-ary phase-shift keying (8PSK), 16-ary amplitude phase-shift keying (16APSK), and 32-ary amplitude phase-shift keying (32APSK) official modulation types. The system's redesign has been achieved to investigate high performance and reliability based on a cascade of new radio (NR) fifth generation (5G) Polar coding with low-density parity-check (LDPC). Some signal-to-noise ratio (SNR) levels were changed when evaluated in contrast to the conventional model. It has been determined that five iterations of the LDPC decoder were performed. In comparison to the traditional model. The proposed design's performance accomplished the highest possible value for reducing the bit error rate (BER) value and investigated better-transmitted power gain for most testing cases.

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1. INTRODUCTION

Standardization for satellite broadband services has been increased as part of the digital video broadcasting initiative and given the designation digital video broadcasting–for satellite–second generation (DVB-S2) [1], [2]. This categorization makes it possible for satellite activities to take place, including access to the internet, digital satellite news gathering (DSNG), and the transmission of television and radio shows. DVB-S2 has three characteristics: a sufficiently complicated receiver, complete adaptability, and the highest transmission performance possible up to the Shannon limit.

The low-density parity-check (LDPC) codes as channel coding techniques to improve the operation and performance of the system on non-linear satellite channels using quadrature phase-shift keying (QPSK), 8-ary phase-shift keying (8PSK), 16-ary amplitude phase-shift keying (16APSK), and 32-ary amplitude phase-shift keying (32APSK) as the newest modulation and coding schemes (MODCODEs) in combination, for worst-case low signal-to-noise ratio (SNR) configurations, the frame structure's maximum flexibility and synchronization are evaluated. Adaptive coding modulation (ACM) provides effective communication parameters in one-to-one networks. It is possible to use DVB S2-compatible decoders and receivers that may be used throughout the transition phase [3]. Among the aims of this study are to carry out a MATLAB code to simulate the standard DVB-S2 link system and redesign the traditional system with new radio (NR) fifth generation (5G) polar coding as an outer encoder and test the two models with different types of modulations and code rates over additive white Gaussian noise (AWGN) and Rayleigh fading channels. The bit error rate (BER) is the essential factor in determining better performance with many ranges of SNR.

The outline of this article is as follows: section 2 covers the general explanation of the structure of the (DVB-S2) link system, followed by a basic literature review. Section 3 offered the suggested channel coding as an alternative to the outer encoder used in the standard model. Section 4 presented the parameter of the simulation along with the comparison results. Section 5 reveals the discussion results, and the conclusion and future works part are depicted in section 5.

2. GENERAL STRUCTURE OF DVB-S2 LINK SYSTEM

There are two kinds of frames in the DVB-S2 standard: the physical layer frame and the forward error correction (FEC) layer frame. The transport stream's FEC frame contains sent data in a structured format. Generic data is intended for transmission that is included inside the FEC framework. The data field layer's 80-bit base-band header is a component of this data field [4]. The base-band header and data field are then padded with the error prevention code rate. To safeguard against errors, a code rate is chosen and then extended into the data block using the base-band header, with the bose–chaudhuri–hocquenghem (BCH) code and LDPC code being attached. Figure 1 depicts a DVB-S2 FEC frame with a frame length of 64,800 or 16,200 bits.

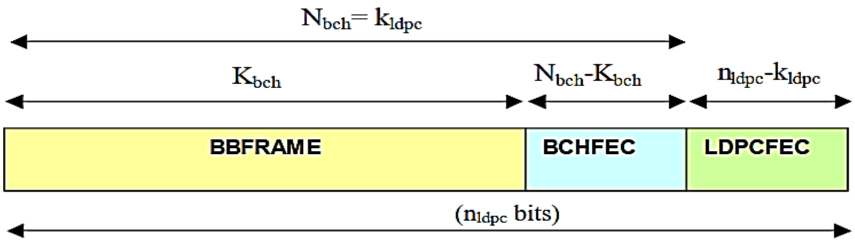

Figure1. The organization of the data before bit interleaving

2.1. Description of the simulation model in technical terms

The Standard (DVB-S2) Model was developed with MATLAB code (M-files), as shown in Figure 2. After being buffered in a BBFrame, incoming binary data is first encoded using a BCH outer encoder and then encoded again using an LDPC inner encoder. After being modulated by the generator code-word, the signal is interleaved using a general block interleaver and sent down the channel. These actions constitute the DVB-S2 BICM System's transmitter. Following the transmission of the signal across the channel, the signal is initially received by a soft-decision De-modulator, followed by a De-interleaver, which delivers the data to the LDPC and BCH decoders, respectively. The data-word returns to the BBFrame-Unbuffering in order to receive an approximation of the transmitted data.

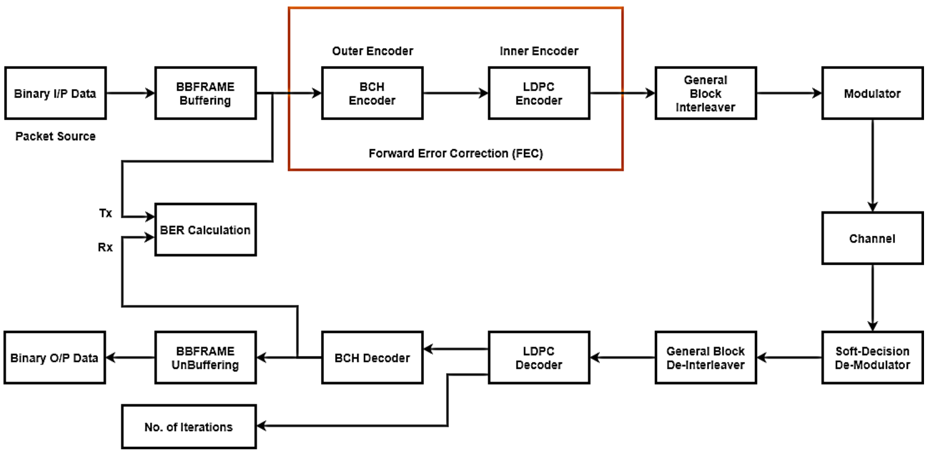

Figure 2. General block-diagram of (DVB-S2)

2.1.1. Base-band frame buffering/unbuffering

At the transmitter, the baseband header (BBHEADER) and data fields in the input stream are received by the buffering function block; at the receiver, the un buffering block generates MPEG transport stream (MPEG-TS) as an output. In (4) demonstrates how the rate of FEC influences the size of a data field [5]:

$$Data\ Field = K_{BCH} - 80 \quad (1)$$

where K_{BCH} input for the BCH encoder in the next stage has a length and a bit header size of 80.

2.1.2. Bose–chaudhuri–hocquenghem encoder/decoder

To produce a FEC frame (FECFRAME), we will use the base-band frame (BBFRAME) as input to the BCH encoder [6], and the parity check bits will be added concerning the coding rate to generate a FECFRAME that has the length of n is the input length for BCH encoder in next step, and 80 is header length in bits. Bits of LDPC. BCH handles decoding and error correction of input from LDPC encoders at the receiver. The output of this module will be transmitted to the Unbuffering function at the receiver.

2.1.3. Low-density parity-check encoder/decoder

The received K_{ldpc} bits will be encoded using the LDPC technique to obtain the n_{ldpc} encoding bit FECFRAME. Under Table 1 of the European telecommunication standard institute (ETSI). The parameters for a 64,800-bit FECFRAME are provided.

Table 1. Normative FECFRAME coding parameters [1]

LDPC (R_C)	BCH data-word (k_{bch})	BCH code-word N_{bch} LDPC data-word $(K)_{ldpc}$	BCH error detection and correction	LDPC code-word n_{ldpc}
1/2	32,208	32,400	12	64,800
1/3	21,408	21,600	12	64,800
1/4	16,008	16,200	12	64,800
2/5	25,728	25,920	12	64,800
2/3	43,040	43,200	10	64,800
3/4	48,408	48,600	12	64,800
3/5	38,688	38,880	12	64,800
9/10	58,192	58,320	8	64,800
5/6	53,840	54,000	10	64,800
8/9	57,472	57,600	8	64,800
4/5	51,648	51,840	12	64,800

2.1.4. Interleaver/deinterleaver

Using the FECFRAME encoder will allow you to interleave the LDPC-encoded data prior to transmitting it for modulation (FEC). The receiver must deinterleave the signal before the demodulator's output can be processed by the LDPC decoder. This is a necessary condition before the receiver can process the signal.

2.1.5. Modulator/demodulator

Rather than using a log-likelihood ratios (LLR) only decoder, we opted for a soft decision-demodulator since the LDPC decoder would only take LLR values as input. The received signal's LLR must be determined based on the (2):

$$LLR(b) = log\left[\frac{(Pr(b=0| \ r=(x,y))}{(Pr(b=1| \ r=(x,y))}\right] \quad (2)$$

2.1.6. Additive white Gaussian noise channel

Gaussian distribution, often known as the normal distribution or Gaussian distribution, is a kind of distribution. Because it contains all frequencies with a white spectral content, it is referred to as white noise [7]. It's called white noise or wide sense stationary (WSS) noise since it has a constant power density. No multiplication is required for defining additive noise, which is the noise that only adds to the signal rather than multiplying it.

$$y = h.x + n \quad (3)$$

where x is the transmitted signal, h represents the channel-impulse-response (CIR), n is the noise level. White noise is a kind of power with consistent spectral density across all frequencies.

2.1.7. Rayleigh fading channel

In a communication system, the sent signal must travel over all of the channel's possible paths before it reaches the recipient. In the case of transmission across a narrowband with a single carrier, the signal will undergo frequency-flat, Rayleigh fading channels [8]. Rayleigh fading channel can be represented by (4):

$$y = h_f . x + n \tag{4}$$

where h_f is the Rayleigh random variable, and (n) represent the noise, Rayleigh fading's probability distribution function is given as a [8]:

$$P(y \mid x) = \frac{1}{[2\pi\sigma^2]^2}\left[e^{\left(-\frac{n^2}{\sigma^2}\right)}\right] \tag{5}$$

2.2. Related works

Numerous DVB-S2 techniques have been employed, and the bulk of them are based on processing real-world system behavior according to a study of these tactics, El-Abbasy *et al.* [9] improved MATLAB simulation model is used to evaluate the performance of the second generation of satellite (DVB-S2). Also included is a comparison of findings from the simulation model to actual field measurements, which validates the model. While the according to Gagan *et al*. [10] achieved a BCH and LDPC concatenated coding. The design draws on the previous connected coding technique to improve the cascade region's error reduction capacity while maintaining a low error floor.

Data transmission reliability and bit rate have been boosted to improve the wireless communication channel [6]. FEC codes reed-solomon (RS) and (BCH) have been used in a proof of concept to compare their BER performance. According to the findings, the wireless multipath components enhance FEC's performance considerably. Research by Alsaadi and Serener [11] showed that both in AWGN and fading channels, DVB-S2 technology is better than DVB-terrestrial (DVB-T) for electrocardiogram (ECG) transmission in DVB-S2. On the other hand, satellite transmission is known to have a higher rate of delay and degradation than terrestrial transmissions. Therefore, a trade-off exists in which DVB-T technology may be utilized instead for a quicker ECG transmission signal if performance loss can be accepted.

A resilient concatenated orthogonal frequency division multiplexing-quadrature amplitude modulation (OFDM-QAM) coding platform is established in [10] for AWGN channel. LDPC is used as the inner coding in our suggested concatenated coding scheme at the FEC coding unit. Interleaver inclusion is an essential factor in improving system performance in this model. According to Bala *et al*. [12] MATLAB simulations will be used to evaluate the BCH and LDPC codes, and AWGN will use a concatenation of LDPC and BCH codes at typical DVB-S2 code rates of 1/2 and 9/10 to create digital transmission systems based on QPSK, 8-PSK, and 16-QAM (16-APSK). To obtain BERs and other performance measurements, simulations were run and compared to Shannon's information capacity theorem parameters.

To evaluate the system performance [13], the FEC's interest rates of 3/5, 3/4, and 9/10, along with (LDPC) codes chained with (BCH) codes for effective transmission, were used. The energy per symbol noise ratio (es/no) was modified to analyse the application's performance. Whereas research by Horbatyi and Yashchyshyn [14] proposed amplitude modulation of multiple components (AMMC) signals rather than 8PSK and amplitude-phase shift keying (APSK) signals and AMMC modulator and demodulator as a means of modernizing the DVB-S2 standard equipment were suggested. The symbol error rate in a communication channel may be reduced by using AMMC.

Two-way communication with the DVB-S2 is examined in a complete examination of the DVB-S2 standard used in the DSNG connection [15]. A MATLAB/Simulink toolkit for implementing the communication mechanism. Instead of an AWGN channel, a radio frequency satellite channel was employed, which adheres to the DVB-S2 standard. The simulation findings reveal that digital video television broadcasts in DVBS2 base-band frames may carry communication signals. According to Mohammed and Hussein [16] MATLAB/Simulink environment was used to develop and implement satellite fir- and second-generation digital video transmission of binary data, pictures, and audio. In addition, the signal's BER will be calculated. This system has been meticulously crafted to reduce performance mistakes, boost data transmission rates, and ensure the security of all sent data.

3. FIFTH GENERATION NEW RADIO POLAR CODING

For the 5G NR communications system. Polar codes were selected as the channel coding method for control channels [17], [18]. Enhanced mobile broadband (eMBB) and the broadcast channel use it for downlink and uplink control information (DCI/UCI).

3.1. Polar encoder

The message was polar-encoded and returned as a binary column vector. The data type of the encoder is determined by the message it receives from the sender. The polar-encoded message's length, N, is a square root of two [19]. Polar encoding employs an SNR-independent technique where the dependability of each subchannel is estimated offline. This sequence may be utilized for any code rate and code length less than the maximum code length due to nested polar codes [20]. In this project, we used the approach shown in Figure 3 instead of the BCH outer encoder, which came with a cascade with an LDPC encoder in the transmit section of the DVB-S2 link system. The following procedures are carried out for each frame processed:

- Random bits are created using K-crcLen.
- Each of these bits receives a cyclic redundancy check (CRC), which is then added to the end.
- Polar coding encodes the added bits of the CRC to the mother code block size.
- Transmission of E bits requires the use of rate-matching.

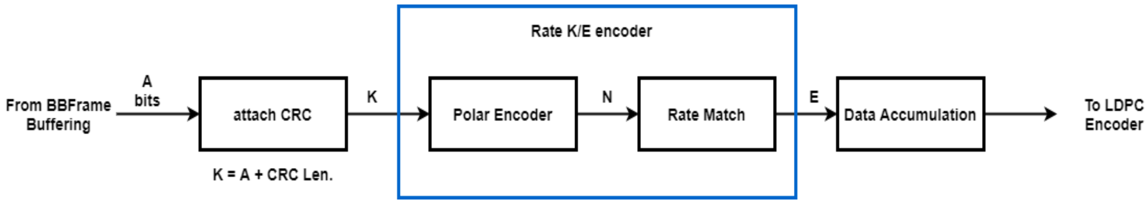

Figure 3. Block-diagram of polar encoder

3.2. The rate matching and the rate recovery

Bits encoded in polar coordinates (N) are rate-matched to output (E) bits for resource element mapping [21]. Sub-block interleaved bits are transferred to an N-bit circular buffer. Depending on the desired coding rate and specified values of K, E, and N, the output bits are either repeated $(E >= N)$ or punctured (E, N).

- E bits are snipped off the tip and used for puncturing.
- E bits are omitted from the beginning to reduce the length of the code.
- E bits are repeated modulo N for repetition.

Once again, the selected bits are interleaved before being passed to the modulation mapper on the uplink. But just once on the downlink.

- In puncturing, the LLRs for the bits that were omitted were given zero values.
- In the case of shorting, the values of the corresponding LLRs for the omitted bits were raised.
- A collection of LLRs corresponding to the first N bits is selected based on recurrence.

The equations used to perform rate-recovery processing are provided (6)-(9):

$$R = \frac{K_P}{E_p} \quad (6)$$

$$\frac{E_s}{N_o} = \frac{E_b}{N_o} + 10log10(bps) \quad (7)$$

$$SNR(dB) = \frac{E_s}{N_o} + 10log10(R) \quad (8)$$

$$noise\ variance = \frac{1}{10^{\left(\frac{SNR(dB)}{10}\right)}} \quad (9)$$

where (bps) refers to (pit-per-symbol) and is equal to 2 for QPSK modulation, 3 for 8PSK, 4 for 16APSK, and 5 for 32APSK.

3.3. Polar decoder

The implicit CRC encoding of downlink (DCI or BCH) or uplink (UCI) message bits necessitates the use of CRC-aided successive cancellation list decoding (CA-SCL) [22]. The CA-SCL decoding algorithm eliminates any pathways with an erroneous CRC from an input message with a concatenated CRC [23]. This extra information aids the final route selection process compared to SCL decoding. A CRC of 24 bits for the downlink and CRCs of 6 and 11 bits are provided for the uplink, depending on the value of K [24], [25]. In this project, we use the decoder approach, as shown in Figure 4, as a final stage before data arrive at the BBFrame unbuffering.

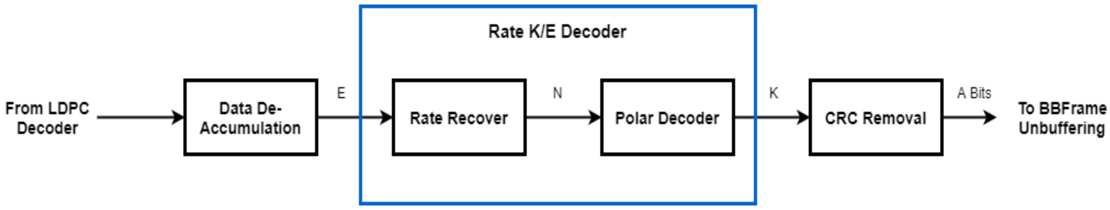

Figure 4. Block-diagram of polar decoder

To restore the heart rate, one may pierce, shorten, or repeat as necessary. The reconstructed LLR values are polarly decoded with the CA-SCL algorithm, which involves deinterleaving. By comparing the decoded bits with the initially broadcast K-crcLen bits, we can gain a better understanding of the block-error-rate (BLER) and BER metrics.

4. SIMULATION RESULTS

In this project, we construct a MATLAB code with overall simulation parameters, as shown in Tables 2 and 3, to simulate the standard DVB-S2. We then make a redesign for the system with 5G NR polar coding as the outer encoder instead of BCH coding to improve the FEC layer frame. The flux diagram for the improved system is shown in Figure 5. Finally, we present and discuss our findings.

The two models were evaluated in the same setting using official forms of modulation QPSK, 8PSK, 16APSK, and 32APSK with varying levels of coding rate (Rc) 3/5, 2/3, and 3/4 across two distinct channels. The results of these evaluations were compared and contrasted (AWGN and Rayleigh fading channel). The findings have been determined following the BER parameter, as well as a wide range of SNR in decibels (dB), to determine the value of gain in statistics, regardless of whether the mitigate is measured in BER or the power of the signal. The results of testing the simulation MATLAB code for the standard and modified DVB-S2 system under (AWGN) and Rayleigh channels with QPSK modulation type and 3/5 coding rate are shown in Figures 6 and 7.

Table 2. Simulation parameters for standard DVB-S2 link system

Variables	Values
Data Input	Binary random
BBFrame buffering	38,688, 43,040, and 48,408
BCH encoder out	38,880, 43,200, and 48,600
LDPC encoder out	64,800
Rc	3/5, 2/3, and 3/4
Interleaver out	64,800
Modulation types	QPSK, 8PSK,16APSK, 32APSK
Channel types	AWGN and Rayleigh fading channel
De-interleaver out	64,800
LDPC decoder out	64,800
No. of iterations for LDPC decoder	5
BCH decoder out	38,880, 43,200, and 48,600
BBFrame unbuffering	38,688, 43,040, and 48,408

Figure 6, the range of SNR (0–4) (dB) via AWGN channel. The value of BER for the standard (DVB-S2) link system is equal to (1,393×10^{-3}) at SNR, equal to (4 dB), whereas the value of BER for the modified (DVB-S2) system is equal to (2,214×10^{-5}) at SNR equal to (3 dB). The range of SNR (dB) for a Rayleigh fading channel is shown in Figure 7. The performance of the modified system is only marginally better than the performance of the standard system for the SNR range of (4 to 8 dB). At a SNR of (10 dB), the value of BER for the conventional system is equal to ($6,403\times10^{-6}$), whereas the value for the modified system is equal to ($5,281\times10^{-5}$).

Table 3. Simulation parameters for modified DVB-S2 system

Variables	Values	
Data input	Binary random	
BBFrame buffering	38,688, 43,040, and 48,408	
Message length (K_p)	50	
The rate matched output length (E_p)	128	
List length (L)	8	
A number of CRC bits for DL (CRC len.)	24	
CRC polynomial	24C	
Number of parity check bits (nPC)	0	Down link (DL) scenario
The maximum value of n (n_{max})	9	K≥36
Interleave input (iIL)	True	
Interleave coded bits (iBIL)	False	
The number of CRC bits for DL (CRC len.)	11	
CRC polynomial	11C	
Number of parity check bits (nPC)	0	Up-link (UL) scenario
The maximum value of n (n_{max})	10	K>30
Interleave input (iIL)	False	
Interleave coded bits (iBIL)	True	
BBFrame buffering	38,688, 43,040, and 48,408	
LDPC encoder out	64,800	
Rc	3/5, 2/3, and 3/4	
Interleaver out	64,800	
Modulation types	QPSK, 8PSK,16APSK, 32APSK	
Channel types	AWGN and Rayleigh fading channel	
De-interleaver out	64,800	
LDPC decoder out	64,800	
No. of Iterations for LDPC decoder	5	
BBFrame unbuffering	38,688, 43,040, and 48,408	

The results of tests conducted on standard and modified systems using AWGN and Rayleigh fading channels are shown in Figures 8 and 9. These tests used 8PSK as the modulation type and (3/5) as the coding rate. At (SNR=15) dB, the BER performance of the conventional (DVB-S2) system over the AWGN channel is (5.24×10^{-4}), as shown in Figure 8. In the same channel environment with (SNR=8 dB), the BER performance of the modified (DVB-S2) system equals (10^{-6}). According to Figure 9, the BER value for the conventional (DVB-S2) system is ($1,857\times10^{-4}$) at (SNR=19 dB) and ($1,448\times10^{-4}$) for the modified (DVB-S2) link system at (SNR=16 dB) when testing is done over a Rayleigh fading channel.

Figures 10 and 11 depict the results of a second simulation test designed to compare two distinct system strategies. The coding rate was modified to (2/3), and the modulation type was changed to 16APSK. Figure 10 shows the BER performance of a traditional (DVB-S2) system over an AWGN channel, which is equal to ($4,521\times10^{-4}$) when the SNR is equal to (11 dB). In comparison, the BER performance of a modified (DVB-S2) system is equivalent to ($8,198\times10^{-6}$) when the SNR is equal to (8 dB) at the same channel. On the other hand, Figure 11 displayed the results of a simulation test conducted on the two systems while operating under a Rayleigh fading channel. The BER value for a conventional (DVB-S2) system is equal to ($4,173\times10^{-4}$) when the SNR is equal to (13 dB), but the BER value for a modified approach is equivalent to ($5,142\times10^{-2}$) when the SNR is equal to (12 dB).

The final test of the simulation was carried out in the manner shown in Figure 8 using (32APSK 3/4) MODCODE. As seen in Figure 12, the BER performance of the conventional (DVB-S2) system is ($1,655\times10^{-5}$) at an SNR equal to (13 dB) for an AWGN channel, but at (SNR=12 dB) for the modified (DVB-S2) system, it is ($1,066\times10^{-4}$). Figure 13 illustrates the simulation test performed on the two approaches while operating in a fading environment. The BER value of the standard (DVB-S2) system is ($1,866\times10^{-4}$) when the SNR is (15 dB), whereas the BER value of the modified (DVB-S2) system is ($1,488\times10^{-4}$) when the SNR is (14 dB).

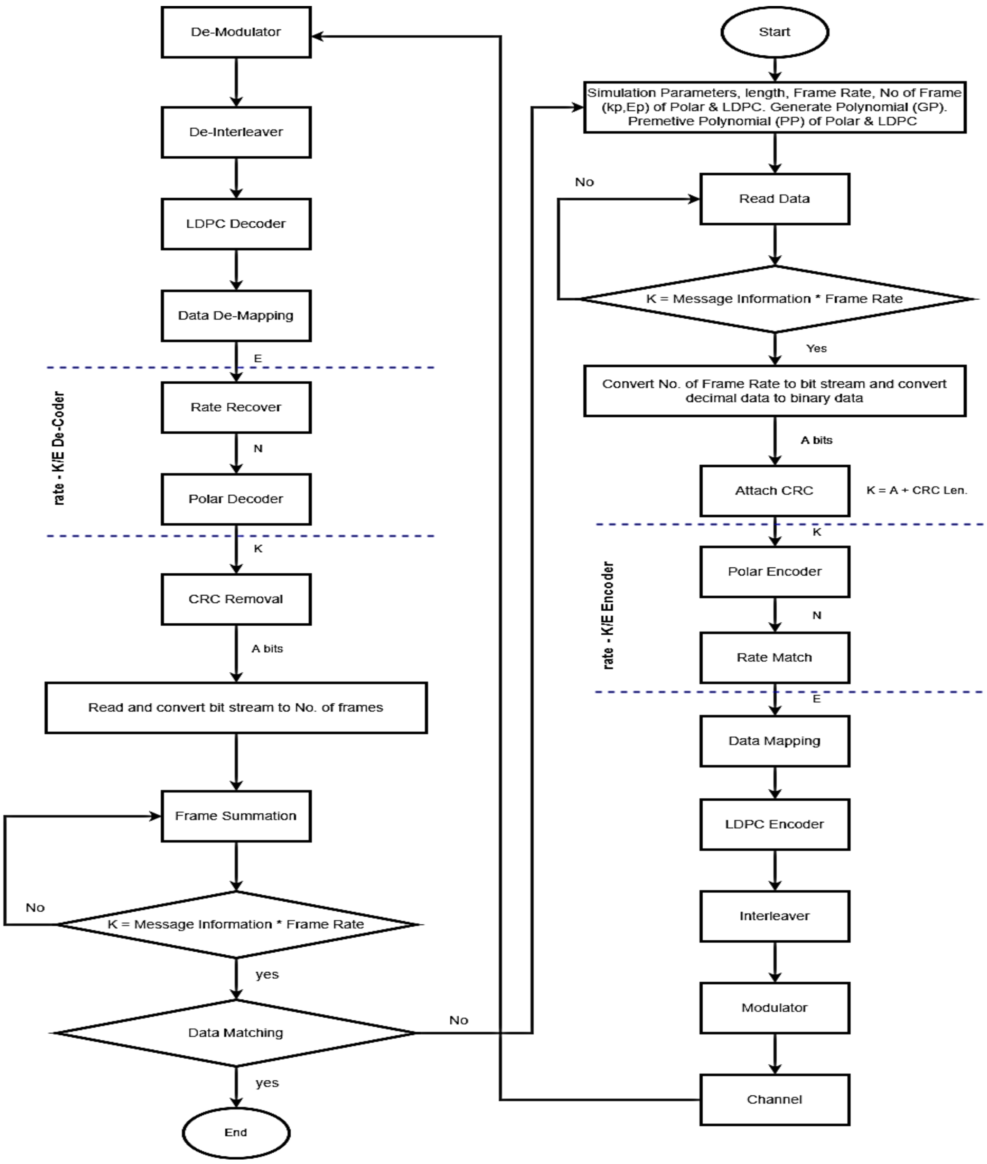

Figure 5. MATLAB flux diagram modified model

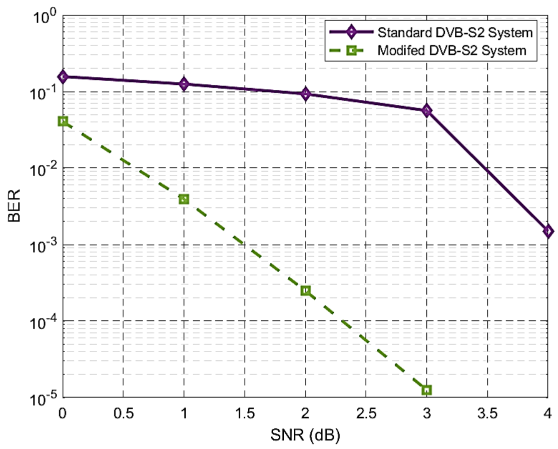

Figure 6. BER vs SNR (dB) comparison for standard and modified DVB-S2 link system with QPSK 3/5 MODCODE over AWGN channel

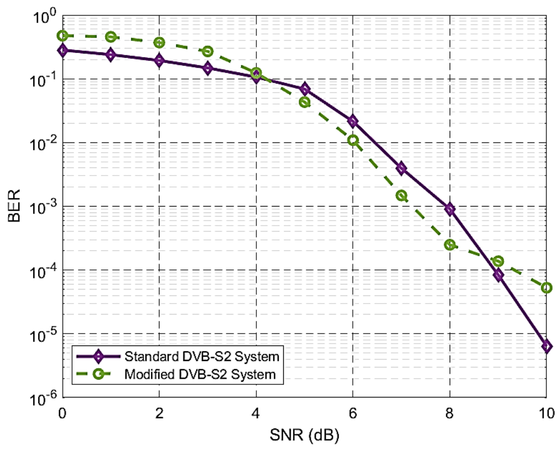

Figure 7. BER vs SNR (dB) comparison for standard and modified DVB-S2 link system with QPSK 3/5 MODCODE over Rayleigh fading channel

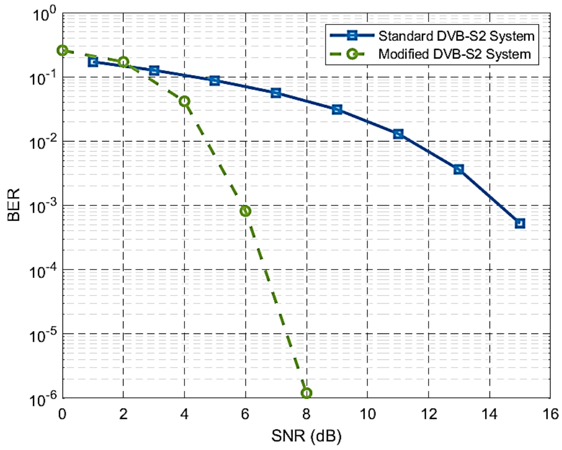

Figure 8. BER vs SNR (dB) comparison for standard and modified DVB-S2 link system with 8PSK 3/5 MODCODE over AWGN channel

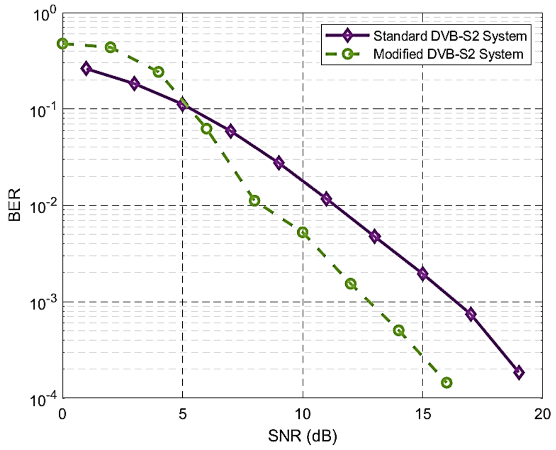

Figure 9. BER vs SNR (dB) comparison for standard and modified DVB-S2 link system with 8PSK 3/5 MODCODE over Rayleigh fading channel

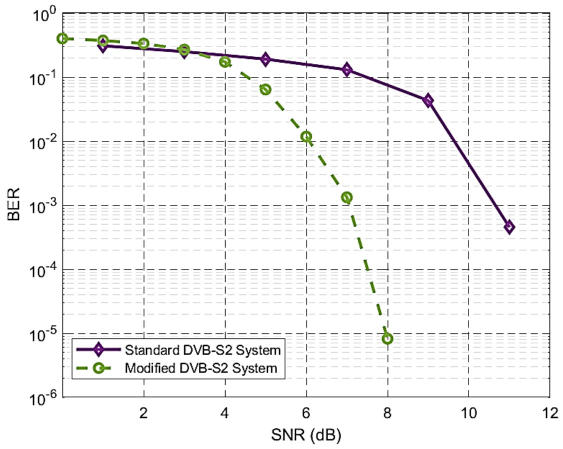

Figure 10. BER vs SNR (dB) comparison for standard and modified DVB-S2 link system with 16PSK 2/3 MODCODE over AWGN channel

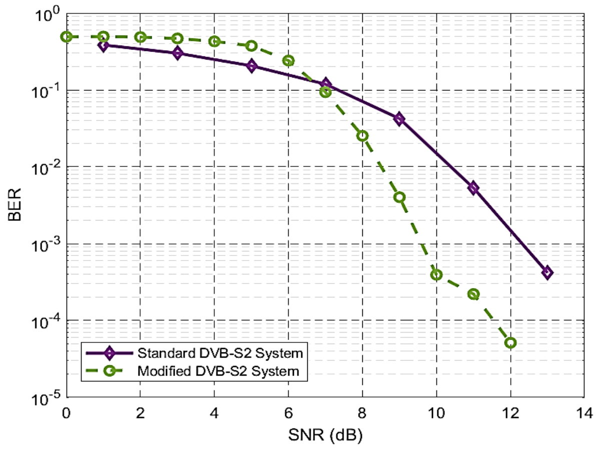

Figure 11. BER vs SNR (dB) comparison for standard and modified DVB-S2 link system with 16PSK 2/3 MODCODE over Rayleigh fading channel

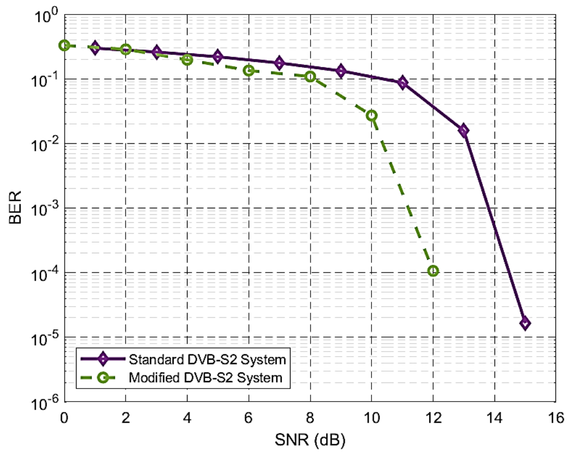

Figure 12. BER vs SNR (dB) comparison for standard and modified DVB-S2 link system with 32APSK 3/4 MODCODE over AWGN channel

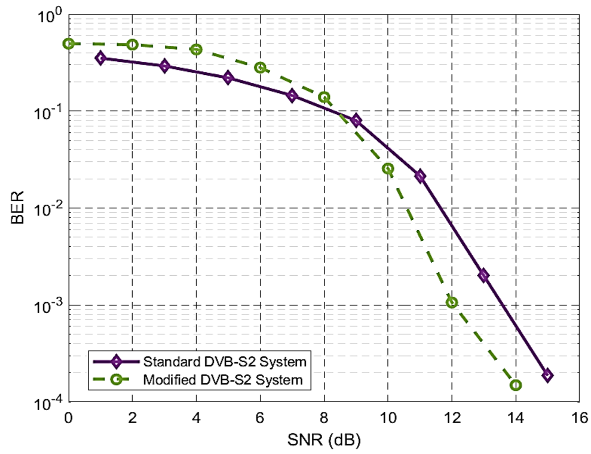

Figure 13. BER vs SNR (dB) comparison for standard and modified DVB-S2 link system with 32APSK 3/4 MODCODE over Rayleigh fading channel

5. DISCUSSION

The suggested cascade of 5G NR polar coding (outer encoder) with LDPC (inner encoder) in terms of FEC provided a higher level of reliability for the (DVB-S2) link system while maintaining the same level of computational complexity (CC). The BER concerning the signal noise ratio was the primary factor used to quantify this performance. Table 4 displays the findings achieved for the power gain and the reduction in BER for both the conventional and modified system configurations.

Table 4. The findings are drawn from the redesigned system

Case no.	MODCODE	Channel type	Power Gain in (dB)	BER mitigation
1	QPSK 3/5	AWGN	1	1.37086×10^{-3}
2		Rayleigh fading channel	-	-
3	8PSK 3/5	AWGN	7	5.228×10^{-4}
4		Rayleigh fading channel	3	4.09×10^{-5}
5	16APSK 2/3	AWGN	3	4.43902×10^{-4}
6		Rayleigh fading channel	1	3.6588×10^{-4}
7	32APSK 3/4	AWGN	3	-
8		Rayleigh fading channel	1	3.78×10^{-5}

6. CONCLUSION AND FUTURE WORKS

An investigation of the efficacy of the DVB-S2 link system was conducted, and the findings are summarized and discussed in this project. Several alternative modulations and coding rates were examined in two separate channel configurations. The 5G NR polar with LDPC coding technique suggested here outperformed the traditional model in the identical environment settings, particularly in QPSK, 8PSK, and 16APSK, by a significant margin. At the lowest possible SNR, a BER that is about equivalent to 10^{-6} has been shown to provide the best results.

This strategy's adaptability was highlighted by a simulation of the architecture of the (DVB-S2) link system. Integration of the tail biting convolutional code (TBCC) with (LDPC) code might be the subject of future research in this particular field of study. In addition, the option of using more sophisticated modulation types such as offset quadrature amplitude modulation (OQAM) with higher order to mitigate the transmission latency. It is also possible to employ several other interleaver algorithms instead of the bit-interleaver for the (DVB-S2) system to be developed.

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