Design and Performance Evaluation of Concatenated Coding for Future DVB-S Systems

By

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ABSTRACT

It is imperative to maximize bandwidth efficiency and achieve low probabilities of bit errors over satellite channels which suffer large noise effect. Digital Video Broadcasting (DVB) describes a new coding and modulation schemes based on LDPC codes concatenated with BCH codes allowing a quasi-error free operation at about 0.7 dB to 1.0 dB close to Shannon's limit that permits greater flexibility and more efficient use of bandwidth capacity without significant increase of system complexity. This research intends to test the BCH and LDPC code using Mat Lab simulations and implement the QPSK, 8-PSK and 16-QAM (16-APSK) based digital transmission systems in AWGN with a concatenation of LDPC and BCH codes at standard DVB-S2 code rates of 1/2 and 9/10. Simulations are to be carried out to obtain BERs and other performance measures were carried out and these results were compared with specifications of Shannon's information capacity theorem.

Key words: DVB-S2, Concatenated codes, Forward Error Correction.

INTRODUCTION

Communication has been an integral and also an important part of human existence. It has also evolved and taken various forms and methods. Wireless communication dates back to pre-industrial age where the use of smoke signals, torch signaling, flashing mirrors, signal flares, or semaphore flags was common. [1]

The transfer of data over a point to point or point to multi-point communication channel is known as data transmission or digital communication. A communication channel is any medium used to transmit an electromagnetic signal from transmitter to receiver such as pair of wires, coaxial cable, beam of light and a band of radio frequencies. Communication channels have a certain capacity for transmitting information, often measured by its bandwidth in Hz or its data rate in bits per second. There are certain error characteristics caused by thermal noise and other impairments during transmission from the transmitter to the receiver which hinders reliable communication.

Many communication channels are subject to channel noise and thus errors may be introduced during transmission from the source to a receiver [2]

Wireless communication refers to the transmission of information over a distance without requiring wires, cables or any other electrical conductors. Wireless communication is one of the important mediums of transmission of data or information between devices. Data or information is transmitted through the air, without needing any cables, by using electromagnetic waves like radio frequencies, infrared, satellite, etc. The concept of data transmission over wireless channels was first actualized in 1901 when Guglielmo Marconi demonstrated transatlantic wireless communication using electromagnetic waves. [3]

The use of satellites in wireless communication started much later in 1958 with the launch of SCORE (Space Communications for Orbiting Relay Equipment) by USAF. Although SCORE was only a repeater, the use of satellite has greatly developed and advanced over the years and today satellite communication offers many services such as Digital Video Broadcasting-Terrestrial (DVB-T), Very Small Aperture Terminal (VSAT) networks, Global Positioning System (GPS) - land, sea and aeronautical- mobile services and earth imaging among others. In wireless communication, it is imperative to maximise bandwidth efficiency and achieve low probabilities of bit errors especially on channels with large noise effect. Satellite communication channels are characterised by long round trip distance and high bit error rates due to large free space loss (noise effect) among others, which cannot be manipulated to suit the requirement needed for reliable communication but rather, error control coding must be employed to achieve reliable communication [1].

The use of error control coding techniques such as Automatic Repeat reQuest (ARQ) and Forward Error Correction (FEC) coding for error detection and correction have become increasingly essential for most systems to perform at acceptably low probability of Bit Error Rate (BER). ARQ is an error control coding method that uses acknowledgements and timeouts to achieve reliable data transmission over unreliable services. If the transmitter does not receive an acknowledgment before a timeout occurs, it would keep retransmitting the unacknowledged packet (or frame) until the receiver sends an acknowledgment or it exceeds a predefined number of re-transmissions. ARQ does not correct errors, it only detects an error occurred due to packet loss, therefore it would be inefficient in systems where the propagation delay of the transmission medium is very large such as satellite links. The FEC coding is used for both detection and correction of errors in data transmission. FEC is very efficient and widely employed over unreliable or noisy communication channels (such as satellite links). It is pertinent to note that FEC is less reliable than ARQ because it can sometimes wrongly correct errors (as shall be elaborate in this report). [4]

Error Control and Coding

To ensure reliable communication over such unreliable communication channels, error control coding or channel coding techniques that enable reliable delivery of data, known as error detection and correction are often employed to control the effect of errors on transmitted data. Error control coding is a signal processing activity designed to improve communication systems performance by enabling transmitted signals to overcome the effects of channel impairments such as thermal noise, interference and fading [5]. Error detection techniques allow detecting of such errors, while error correction enables reconstruction of the original data transmitted.

Digital Video Broadcasting

Digital Video Broadcasting (DVB) project which dates back to 1994 established standards enabling digitally broadcast and satellite-delivered television to the public. DVB-S describes the modulation and channel coding system for satellite digital multi programme Television (TV)/High Definition Television (HDTV) services to be used for primary and secondary distribution in Fixed Satellite Service (FSS) and Broadcast Satellite Service (BSS) bands. Digital satellite transmission technology has evolved considerably since the publication of the original DVB-S specification. In the past decade, with the advent of turbo codes and the rebirth of Low Density Parity Check (LDPC) codes, the second-generation DVB-S (DVB-S2) was proposed. [6]

Concatenated Coding System

Concatenation is the natural decomposition of a coding system into to parts. A good example of this is when a communication system is 'decomposed' into Encoding and Modulation. Here we can consider the modulation to be an inner code while the encoding to be an outer code. Now applying this same idea to strictly error control codding where we now have an inner code and an outer code. Note, there are different error control schemes which have their advantages and disadvantages. Concatenation seeks to combine the benefits of two or more error correcting schemes. [7]

LITERATURE REVIEW

Claude Shannon in 1948 pioneered the field of 'coding theory' with his information capacity theorem which postulates that it is possible to achieve a Quasi-Error-Free (QEF) transmission over noisy channels through coding, as long as the transmission rate does not exceed a certain limit called the 'channel capacity' [8]. This has prompted many research efforts over the years into techniques that can allow error correction without retransmission by introducing redundancy. This technique which is a class of error control coding is known as Forward Error Correction (FEC) coding [5]. FEC coding is basically an error correction coding technique which adds redundant bits to the transmitted data in order to detect and often correct symbols received in error without the need for retransmission. This technique is used in systems where a reverse channel is not available for requesting retransmission and the propagation delay of the transmission medium is large. FEC coding can be classified into block codes and tree codes. The main difference in both codes is the presence or absence of memory in their encoders [9].

[10] worked on a concatenated coding platform for Orthogonal Frequency Division Multiplexing (OFDM) with Quadrature Amplitude Modulation (QAM) over Additive White Gaussian Noise (AWGN) channel. The proposed scheme's performance was investigated using MATLAB which involves the transmission of an image through a Forward Error Correction coding system whose integrity depends on OFDM with M-ary QAM transmitted through an AWGN channel. In this work polar coding system was investigated and it was seen polar codes diminishes the effect of error floor, simultaneously enhancing the coding system's error correcting capability. Polar codes inevitably leads to rate loss and decrease spectral efficiency, OFDM's inclusion compensates for the prior problem thus making it one of the most effective systems for present day and future solutions in digital video broadcasting applications.

[11] used Faster-than-Nyquist (FTN) signaling to measure the performance of DVB-S2. Simulating using MATLAB, the LDPC code as defined in DVB-S2 is used with block length of 64,800 bits and code rates of 2/3, 3/4, and 4/5. The modulation schemes considered were 4+12APSK, 8+8APSK, and 16QAM. Inferences from the numerical results showed that the BER performance for the FTN signaling is worse than that with Nyquist signaling. It was clearly seen that the BER performance gain is

as large as 0.3dB at code rate of 4/5 for 16QAM. Other modulation techniques showed similar promise. Though the FTN is considered a possible improvement and a candidate for satellite spectral efficiency in satellite broadcasting, it still battles with large BERs.

[12] DVB-S2 performance is conducted for various modulations and code rates using field measurements. Then, a comparison between the simulation models with the field measurement is presented. Moreover, the simulation models for DVB-S2 and DVB-S2X systems were implemented and the simulation shows that the new APSK modulation techniques used in DVB-S2X provide more capacity or more bitrate for the same bandwidth but it needs a very high SNR. The variety of code rate ratios were added in DVB-S2X to achieve the maximum bit rate for a given SNR. The effect of the value for symbol energy is addressed and the results show that unit symbol energy constellation has better performance. The new optimized Modulation and Coding (MODCODs) was added in DVB-S2X for the linear region of operation in amplifier used in satellite, which provides high performance. Finally, the new roll-off factors were added in DVB-S2X which increase the symbol rate for more capacity in same bandwidth. This technique looks promising but the drawback is that it requires a high complex hardware design to overcome Inter Symbol Interference (ISI).

[13], were able to first hand observe the effects of BCH only and LDPC only and also when concatenated. For a BER of 10-5 the SNR should be maximum, meaning the signal strength should be very high. Also, it was observed that for better result the code rate should be changed instantaneously. Also, for LDPC to achieve a BER of 10-5, the number of iterations needed should be high which will lead to high execution time. The complexity of the inter-leave was a major drawback to this research work and a simpler inter-leaver can be used that will reduce the execution time without compromising the BER.

From the above review, it is seen that the DVB-S2 system is a PSK based transmission systems with a FEC scheme powerful enough to mitigate the effects of using higher modulation schemes such 8-PSK, 16-APSK and 32-APSK.

The question is what if BCH and LDPC are concatenated in QPSK, 8-PSK and 16-APSK (16-QAM)? Are we going to observe anything similar to what (Gagan, 2017) discovered with polar codes and OFDM or are they going to be different? To the best of my knowledge, no literature has answered this question even though BCH and LDPC are among the most commonly used coding systems.

Therefore, there is need to test and see how BCH and LDPC will independently perform and how they will perform when concatenated.

First the BCH and LDPC coding schemes were independently implemented and the performances tested. Simulations using different code rates in AWGN were executed. Then BCH and LDPC were concatenated and investigated. All these using MATLAB.

METHODOLOGY

BCH Coding Scheme

This research is limited to the normal FECFRAME (n_{ldpc} = 64800) as identified in the DVB-S2 standard [6]. A t-error correcting BCH (N_{bch}, K_{bch}) code is applied to each BBFRAME (K_{bch}) to generate an error protected packet. The DVB-S2 standard specifies that the generator polynomial of the t-error correcting BCH encoder is obtained by multiplying the first t polynomials below.

$g_1 = 1+x^2+x^3+x^5+x^{16}$
$g_2 = 1+x+x^4+x^5+x^6+x^8+x^{16}$
$g_3 = 1+x^2+x^3+x^4+x^5+x^7+x^8+x^9+x^{10}+x^{11}+x^{16}$
$g_4 = 1+x^2+x^4+x^6+x^9+x^{11}+x^{12}+x^{14}+x^{16}$
$g_5 = 1+x+x^2+x^3+x^5+x^8+x^9+x^{10}+x^{11}+x^{12}+x^{16}$
$g_6 = 1+x^2+x^4+x^5+x^7+x^8+x^9+x^{10}+x^{12}+x^{13}+x^{14}+x^{15}+x^{16}$
$g_7 = 1+x^2+x^5+x^6+x^8+x^9+x^{10}+x^{11}+x^{13}+x^{15}+x^{16}$
$g_8 = 1+x+x^2+x^5+x^6+x^8+x^9+x^{12}+x^{13}+x^{14}+x^{16}$
$g_9 = 1+x^5+x^7+x^9+x^{10}+x^{11}+x^{16}$
$g_{10} = 1+x+x^2+x^5+x^7+x^8+x^{10}+x^{12}+x^{13}+x^{14}+x^{16}$
$g_{11} = 1+x^2+x^3+x^5+x^9+x^{11}+x^{12}+x^{13}+x^{16}$
$g_{12} = 1+x+x^5+x^6+x^7+x^9+x^{11}+x^{12}+x^{16}$

Hence, the generator polynomial of the *t*-error correcting BCH encoder

for $t=8$

$g(X) = x^{128} + x^{124} + x^{123} + x^{122} + x^{114} + x^{113} + x^{112} + x^{109} + x^{106} + x^{104} + x^{102} + x^{100} + x^{99} + x^{98} + x^{97} + x^{96} + x^{94} + x^{93} + x^{92} + x^{88} + x^{85} + x^{82} + x^{81} + x^{80} + x^{79} + x^{76} + x^{74} + x^{73} + x^{72} + x^{71} + x^{69} + x^{68} + x^{67} + x^{66} + x^{64} + x^{60} + x^{59} + x^{56} + x^{55} + x^{54} + x^{53} + x^{52} + x^{51} + x^{50} + x^{46} + x^{45} + x^{43} + x^{42} + x^{40} + x^{38} + x^{37} + x^{36} + x^{34} + x^{32} + x^{26} + x^{23} + x^{22} + x^{21} + x^{20} + x^{19} + x^{16} + x^{14} + x^{13} + x^{10} + x^9 + x^5 + x^3 + x + 1$

for $t=10$

$g(X) = x^{160} + x^{158} + x^{157} + x^{148} + x^{146} + x^{144} + x^{139} + x^{138} + x^{135} + x^{134} + x^{133} + x^{131} + x^{130} + x^{128} + x^{127} + x^{126} + x^{125} + x^{124} + x^{123} + x^{122} + x^{117} + x^{115} + x^{113} + x^{109} + x^{108} + x^{105} + x^{104} + x^{100} + x^{99} + x^{98} + x^{97} + x^{96} + x^{94} + x^{93} + x^{91} + x^{89} + x^{86} + x^{85} + x^{84} + x^{83} + x^{78} + x^{76} + x^{74} + x^{73} + x^{72} + x^{65} + x^{64} + x^{63} + x^{62} + x^{61} + x^{59} + x^{58} + x^{57} + x^{56} + x^{55} + x^{54} + x^{52} + x^{48} + x^{45} + x^{41} + x^{40} + x^{32} + x^{31} + x^{29} + x^{28} + x^{27} + x^{23} + x^{21} + x^{20} + x^{19} + x^{17} + x^{16} + x^{14} + x^{13} + x^{10} + x^8 + x^7 + x^4 + 1$

for $t=12$

$g(X) = x^{192} + x^{190} + x^{187} + x^{186} + x^{185} + x^{181} + x^{178} + x^{177} + x^{171} + x^{170} + x^{169} + x^{167} + x^{161} + x^{160} + x^{159} + x^{154} + x^{150} + x^{148} + x^{147} + x^{146} + x^{142} + x^{140} + x^{136} + x^{132} + x^{131} + x^{130} + x^{126} + x^{124} + x^{119} + x^{118} + x^{115} + x^{114} + x^{113} + x^{112} + x^{109} + x^{107} + x^{106} + x^{103} + x^{102} + x^{100} + x^{99} + x^{95} + x^{94} + x^{92} + x^{91} + x^{90} + x^{85} + x^{84} + x^{82} + x^{80} + x^{75} + x^{71} + x^{67} + x^{64} + x^{57} + x^{56} + x^{54} + x^{50} + x^{49} + x^{48} + x^{47} + x^{42} + x^{40} + x^{39} + x^{38} + x^{37} + x^{36} + x^{34} + x^{33} + x^{32} + x^{30} + x^{29} + x^{26} + x^{25} + x^{17} + x^{14} + x^{12} + x^{10} + x^8 + x^7 + x^6 + x^5 + x^2 + x + 1$

BCH encoding of information bits onto a codeword will be executed as follows;

- Multiply the message polynomial m(X) by X^{n-k}
  $X^{n_{bch}-k_{bch}}$ m(X) = m_{kbch-1} $X^{n_{bch}-k_{bch}}$, m_{kbch-2} $X^{n_{bch}-k_{bch}}$, . . ., m_1X, m_0.
- Divide $X^{n_{bch}-k_{bch}}$ m(X) by the required generator polynomial g(X) and obtain a remainder d(X) = $d_{nbch-kbch-1}$ $X^{n_{bch}-k_{bch}-1}$ + . . . + d_1X + d_0. The remainder d(X) is the parity polynomial.
- The codeword polynomial is; c(X) = $Xnbch^{-k_{bch}}$ m(X) + d(X).

The transmitted codeword c(X) is divisible by g(X) without a remainder. At the receiver, the codeword or received block will be divided by the generator polynomial g(X) and a non-zero remainder will indicate that an error has occurred and the decoding will be carried out in the following steps;

- Evaluation of the syndrome for the received vector.

- Determine the error locator polynomial from and the syndromes the number of errors *t*.
- Calculate the roots of the error location polynomial to find the error locations.
- Determine the error value and correct the errors.

Matlab Implementation of Bch Encoder/Decoder

MATLAB 2017a communication toolbox is the simulation platform for this research. The communication toolbox has modules and functions which simulates the BCH encoder, LDPC encoder, inter-leaver, modulator, as well as their counterparts in the receiver, according to the DVB-S.2 standard. There are functionalities that collects the error rate at the demodulator, LDPC decoder, and BCH decoder outputs, determines the distribution of the number of iterations performed by the LDPC decoder, and shows the received symbol constellation, [14]. The MatLab BCH Encoder object creates a BCH code with specified message and code word lengths. H = comm. BCH Encoder (Name, Value) creates a BCH encoder object H, with each specified property such as code word length and message length set to the specified value.

The primitive polynomial for the BCH codes is defined over the GF (2^m) where $m \geq 3 \leq 16$, however MatLab sets m a maximum of 9, but allow a flexibility for users to set the primitive polynomial with the allowable limits. The primitive polynomial source is set to 'Property', this allows the primitive polynomial to be set to a desired value. The generator polynomial source is also set to 'Property', this allows a user specify the generator polynomial for encoding as a binary, double-precision row vector or as a binary Galois row vector that represents the coefficients of the generator polynomial in order of descending powers. The length of the generator polynomial requires a value of N_{bch}-K_{bch}+1.

The BCH Decoder recovers a binary message vector from a binary BCH codeword vector. For proper decoding, the codeword and message length values in this object must match the properties in the corresponding BCH Encoder block.

MATLAB Implementation of LDPC Encoder/Decoder

The fec.ldpcenc (H) function creates an LDPC encoder for a binary symmetric LDPC code with parity check matrix H, where H is a sparse (0-1) matrix. n and n-k are the number columns and rows respectively. MatLab has a define function dvbs2ldpc(r), which is the parity-check matrix of the LDPC code with code rate r from the DVB-S.2 standard with possible values of r for 1/4, 1/3, 2/5, 1/2, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9, and 9/10. The block length of the code is 64800.

The MatLab funchion fec.ldpcdec (H) constructs an LDPC decoder object (where H is the same as in the encoder) with the following properties; specifies 'Decision Type', 'Output Format', 'Do Parity Checks', and 'Num Iterations' which specify settings for the decoding operation. The 'Do Parity Checks' determines whether the parity checks should be verified after each iteration, and whether the decoder should stop iterating if all parity checks are satisfied, while the 'Num Iterations' sets the number of iterations to be performed for decoding one code word.

Implementation of (BCH – LDPC) Concatenated Codes

It was envisaged that to successfully implement the DVB-S2 FEC, the BCH and LDPC codes must be concatenated to produce a more powerful coding scheme than the individual codes. First the BCH and LDPC coding schemes were independently implemented and their performances tested with existing theoretical expectations and literature results. Having certified that the individual coding schemes have been separately implemented and performing as expected, the concatenated code were then implemented. Simulations using different coding schemes specified by DVB-S2 standard (except 32-APSK) in AWGN were carried out, the effect of interleaving was also tested by testing the concatenated code with and without interleaving.

Implementation

As we have earlier established that to get a better BER in LDPC a greater number of iterations should be introduced which inherently introduces delay. This is one advantage of concatenated coding, [15]

In this coding scheme the outer encoder is BCH encoder and Inner Encoder is LDPC encoder. That is one block of data is first encoded by outer BCH encoder and then encoded BCH codeword is partitioned into 'X' equal sized segments, and each segment is encoded by the inner LDPC encoder. Let N_{BCH} and N_{LDPC} be the code rate of outer BCH code and inner LDPC code respectively. Then the overall code rate is

given by:

$$N_t = N_{BCH} * N_{LDPC} \qquad 1$$

If all the inner code word from LDPC decoder is decoded properly then it is not necessary to used BCH decoder for decoding. Because of LDPC code mis-correction at the waterfall region it is necessary for the BCH decoder to be used to detect the error.

So each MBCH symbol will be processed by forward error correction encoder to generate KLDPC symbol codeword. The KBCH - MBCH parity check symbol of the systematic BCH encoder shall be added after MBCH symbol and the KLDPC – MLDPC parity symbol of LDPC encoder are inserted after MLDPC.

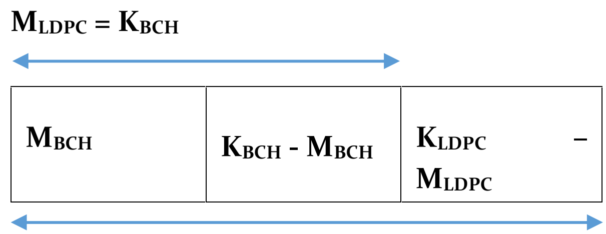

Figure 1: Format of Data after Encoding

EVALUATION AND ANALYSIS OF RESULTS

Results of all simulations carried out independently for BCH and LDPC codes to observe the error correction performance of each code. Detailed below are the results of these simulations.

BCH and LDPC Simulations Result

To ensure the concatenated would perform as prescribed by DVB-S2 standard, the BCH FEC codes to be implemented is compared with theoretical BCH BER and established literature results of BER for BCH codes simulated with BPSK. The BER output of a BPSK detector in a binary transmission system can be obtained with the equation below;

$$BER = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \qquad (2)$$

If the output bit stream of this detector is put through a (n, k), t error correcting decoder, the final BER is improved as to;

$$BER_{coded} = \frac{1}{n}\sum_{j=t+1}^{n} j \binom{n}{j} BER^j (1 - BER)^{n-j} \qquad (3)$$

With equations (1) and (2), the required graph of BER versus E_b/N_o was obtained by choosing values of E_b/N_o in the specified range (3 to 11 dB) and obtaining values of BER equation (1). These values of BER are then used in equation (2) to obtain the decoded BER

(BER_{coded}). The performance of simulated BCH (31,16,3) is compared with both the theoretical uncoded BPSK results and theoretical BCH performance results obtained by Ifiok Otung in his work 'Short Course in Digital Communications - 2nd Edition'.

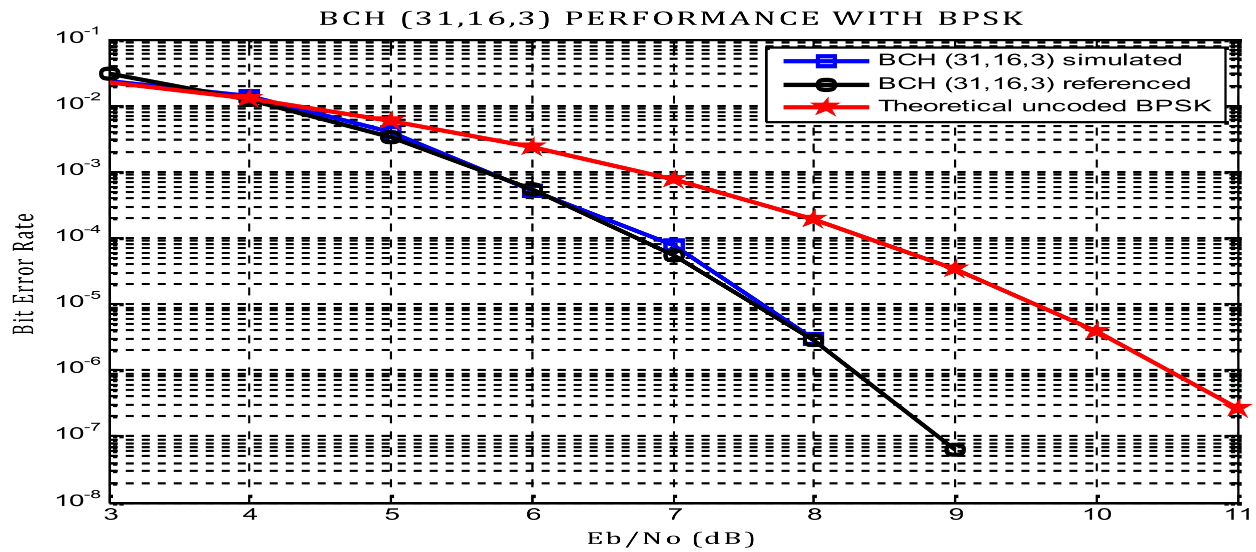

Figure 2

Again, the performance of BCH (255,239) was also simulated using BPSK and compared with both the theoretical uncoded BPSK results and BCH (255,239) simulated with BPSK literature results obtained in [16]

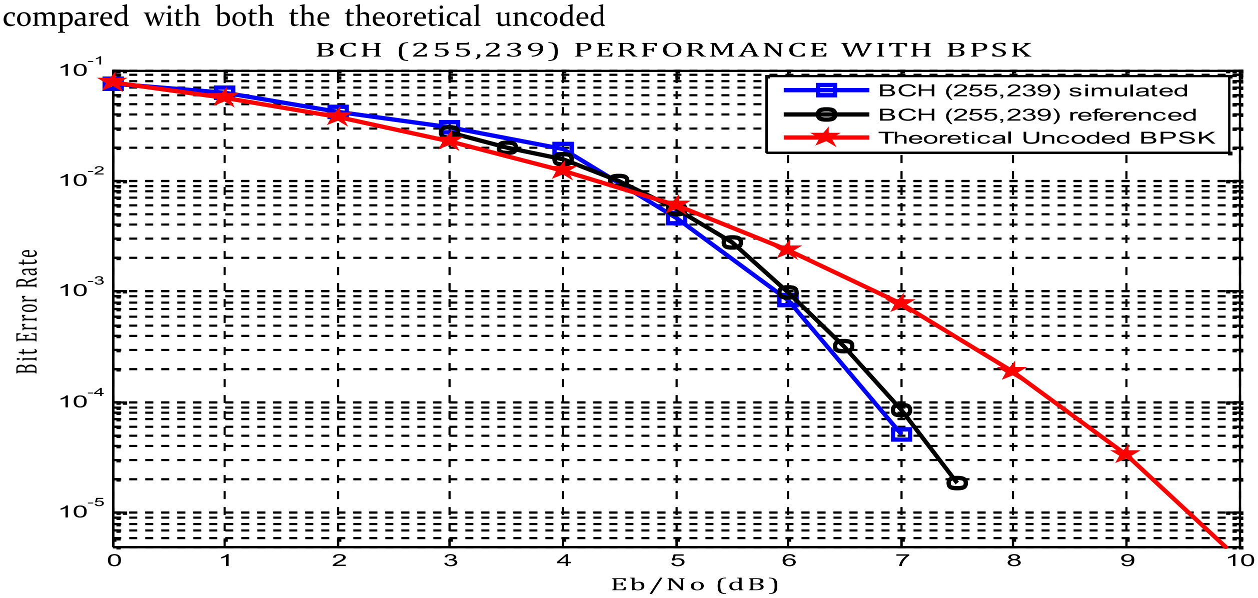

Figure 3

The performance of the simulated BCH codes performed close to expect theoretical BCH performance and established literature values. Hence BCH simulations are expected to perform correctly for all values of N_{bch} and K_{bch} to be implemented in this research.

LDPC Codes Performance

The performance of LDPC codes is remarkably overwhelming at low code rates because of the large amount of parity bits. Figure 4 below depicts the remarkable error correction capability of simulated BPSK with LDPC coding. A block length n = 64000 bits and a code rate R = ½ provides very large parity check bits $n - k$ = 32400 bits.

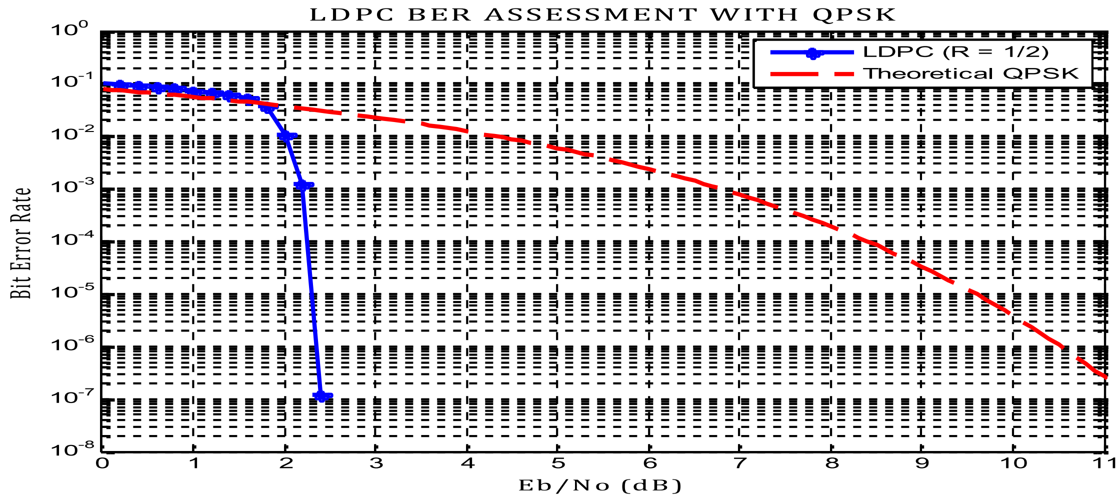

Figure 4

With a coding gain of about 8 dB at 10^{-6} the LDPC (R = ½) codes looks very promising to achieve the effect anticipated by the DVB-S2 developers. As the coderates of LDPC codes are increase, it is found that LDPC does not perform as efficiently as it does at lower values of R. Figure 5 shows the results of LDPC (R = 9/10) over a BPSK transmission channel.

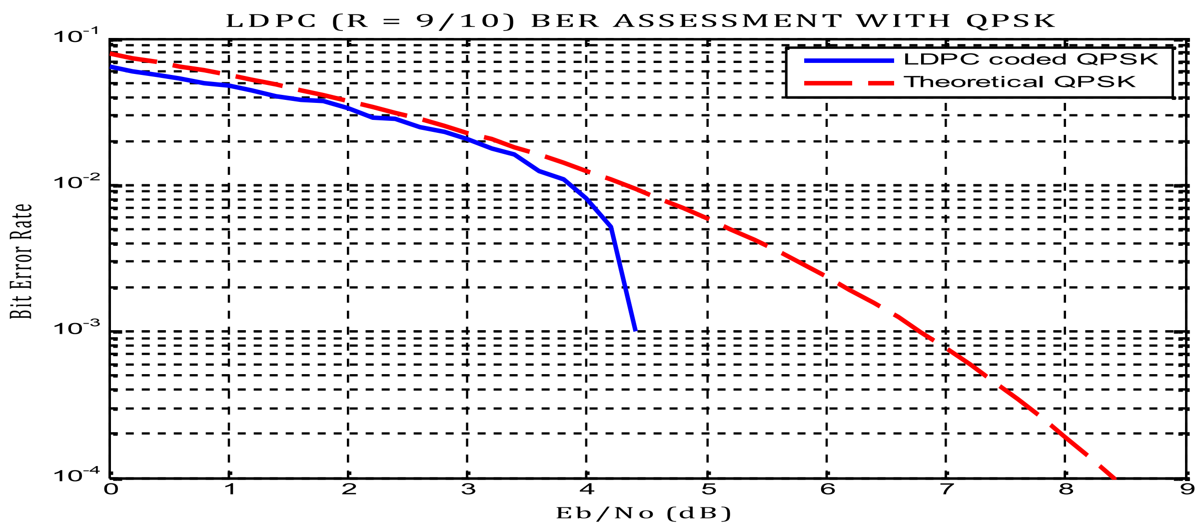

Figure 5

It can be observed that the BER performance for the LDPC (R = 9/10) is not lower than 10^{-3} at 4 dB. This result seemed quite poor since the simulation sort to find a 100 bits error over 1 billion bits transmission for every value of E_b/N_o. The number transmitted bits were increased to 10 billion to provide a sufficiently large number of trial events which should improve the error performance and provide an informed conclusion on the error performance of LDPC (R = 9/10).

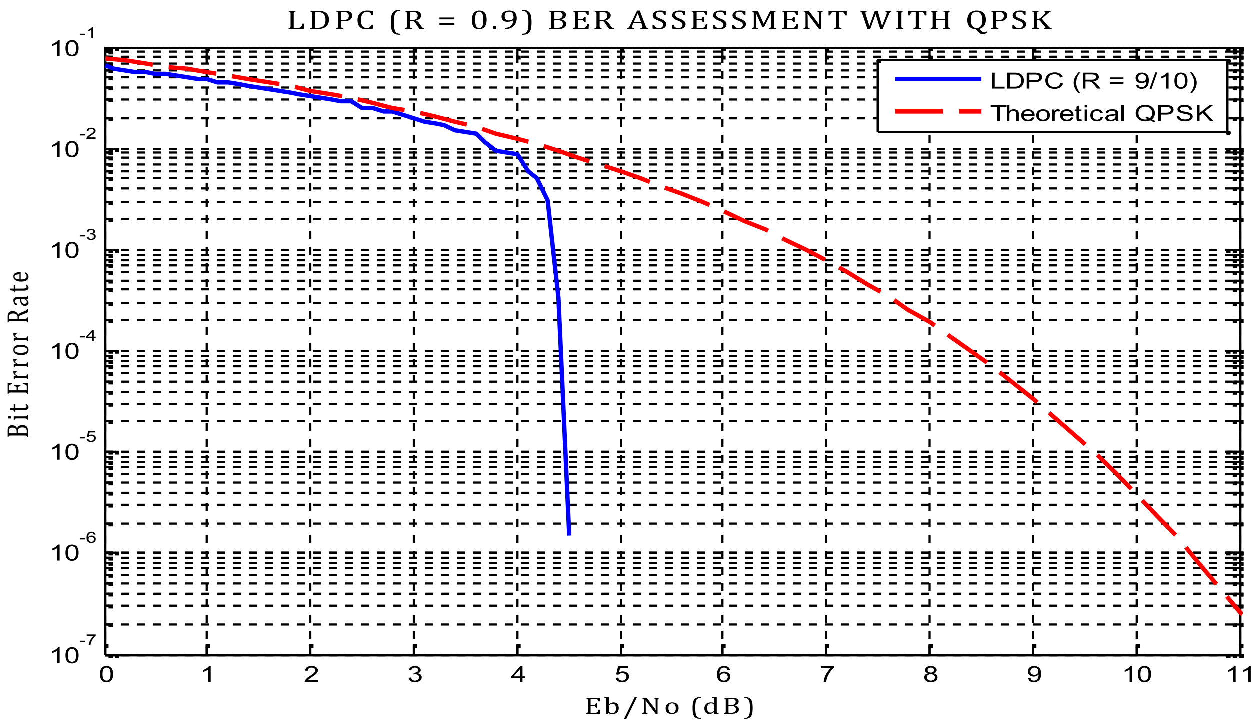

Figure 6

With an increased number of transmitted bits, the performance of LDPC (*R* = 9/10) shows a little improvement but a BER of 10^{-7} is not attainable. Conclusively, the LDPC performs best at lower coderate. The concatenation of LDPC with the BCH codes should be able to improve this performance of the LDPC at higher coderates.

DVB-S2 FEC Systems

The simulations for DVB-S2 concatenated FEC codes were limited to QPSK, 8-PSK and 16-PSK modulation schemes and only FEC coderate R = ½ and R = 9/10 were implemented over AWGN transmission channels. Results and analysis of these simulations are detailed below.

DVB-S2 FEC with QPSK

This research examined the impact of interleaving using QPSK, to understand why the DVB-S2 standard specifies that there should be no interleaving for QPSK modulation. Analysis of coding gain and comparison of its performance with Shannon's information capacity were also evaluated.

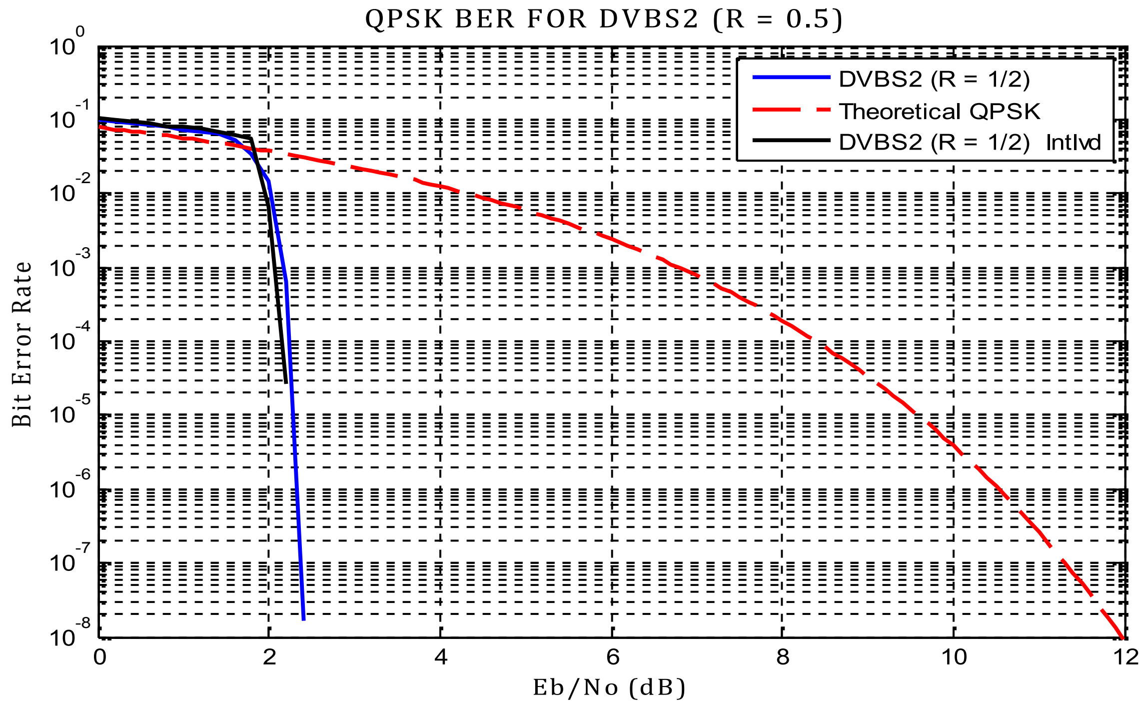

Figure 7

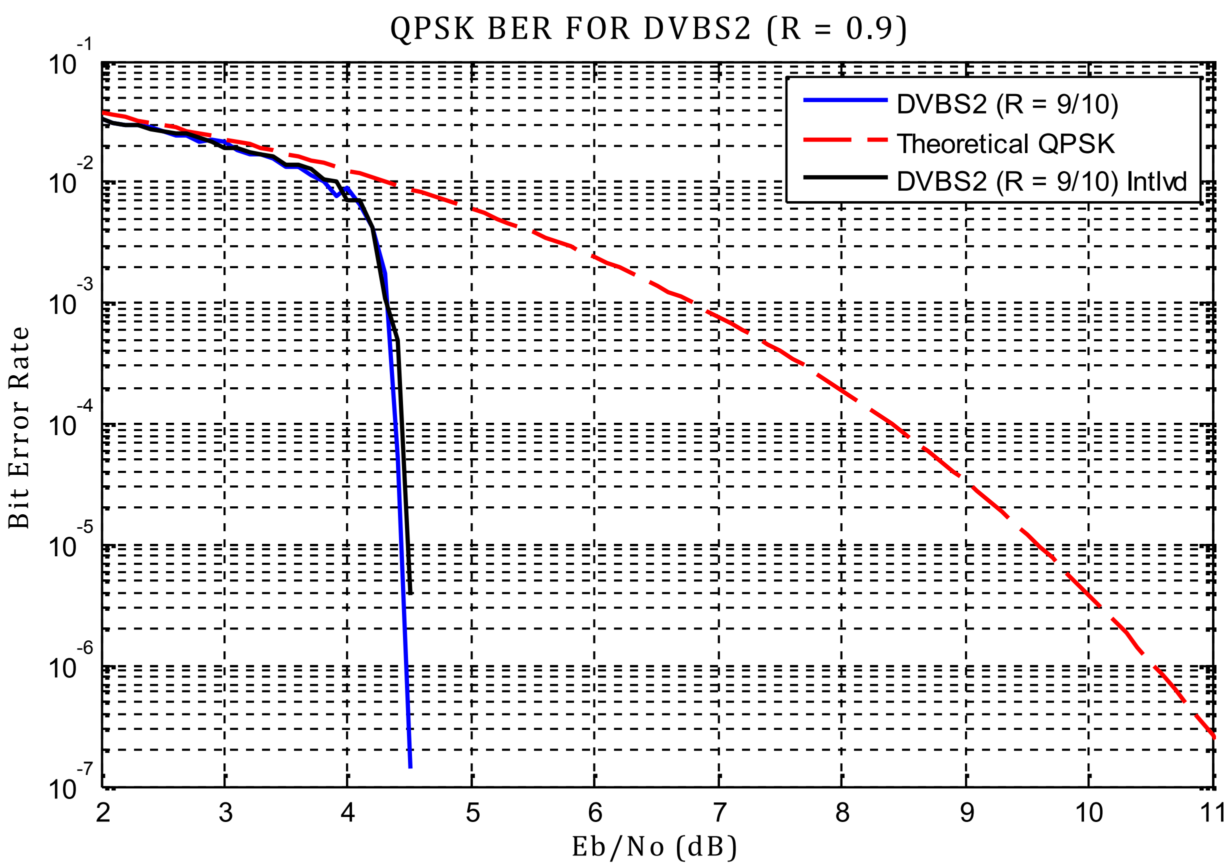

Figure 8

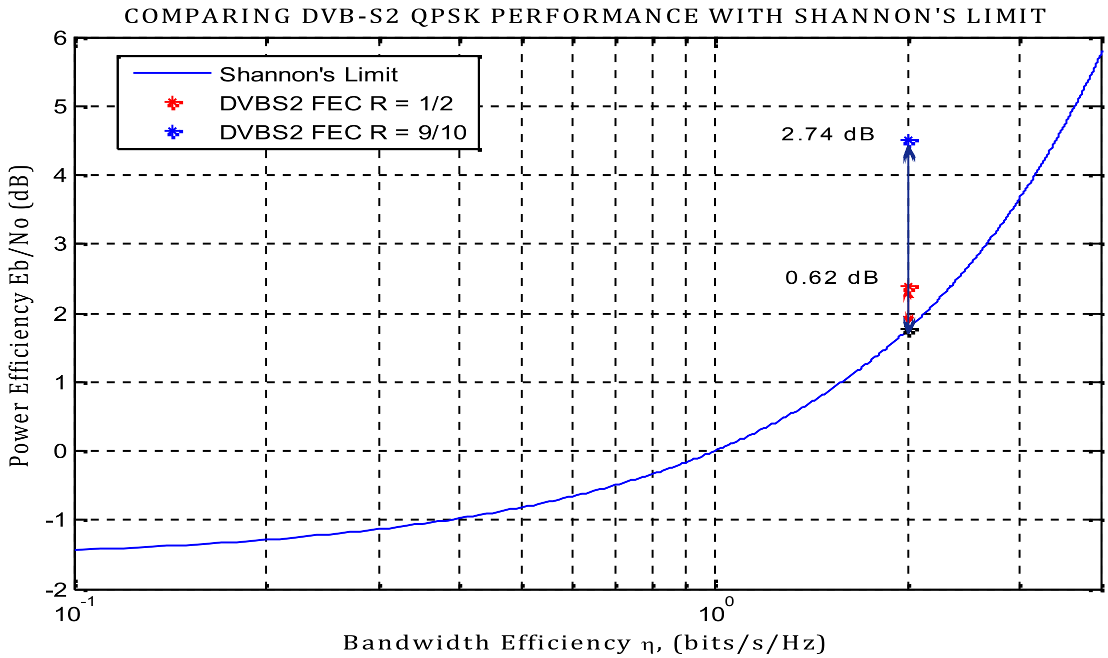

Figure 9: QPSK η=2; BER = 10-6; Eb/No = 2.38 dB(R=1/2); Eb/No = 4.5 dB(R=9/10)

It can be observed in Figure 7 that the error performance of the un-interleaved DVB-S2 QPSK yields BERs as low as 2 x 10^{-7}, with a coding gain of about 8 dB at 10^{-6} over the theoretical uncoded QPSK results. Figure 8 shows a similar error performance of BER as low as 2 x 10^{-7} for the un-interleaved DVB-S2 QPSK and a coding gain of about 6 dB at 10^{-6}. It is noticeable that both figures (Figures 7 and 8) show the interleaving DVS-S2 FEC with QPSK does not perform as well as the un-interleaved coding. The impacts of interleaving limit the error performance for QPSK, this is because the number of transmitted bits per symbols (which is 2 bits) is sufficient to mitigate the possibility of error burst and by interleaving, and the problem being avoided is then created. The impact of interleaving would be further tested in higher modulation schemes. Figure 9 shows that DVB-S2 QPSK FEC coderate *R* = ½ is 0.62 dB less power efficient than Shannon's stipulation and 2.74 dB less power efficient for coderate *R* = 9/10. The analysis of this finding will be discussed below.

DVB-S2 FEC with 8-PSK

It can be observed in Figures 10 and 11 that the impact of interleaving using 8-PSK is virtually similar to the un-interleaved graph unlike with QPSK. Interleaving is supposed to be effective in the presence of burst errors. However, because this transmission is simulated over an AWGN channel, which is 'memoryless' and generates random errors, the effect of the interleaving will not be noticed. Modulation schemes higher than QPSK would apply interleaving because symbols are transmitted in larger chunks than that of the QPSK and satellite transmission would ideally be through a burst error prone channel. The coding gain at an acceptable BER = 10^{-6} for the FEC coderate R=1/2 is about 8.4 dB while for coderate R = 9/10 is about 6 dB. 8-PSK with DVB-S2 FEC offers 1.42 dB and 4.02 dB less power efficiency than Shannon's information capacity at coderates R=1/2 and R = 9/10 respectively.

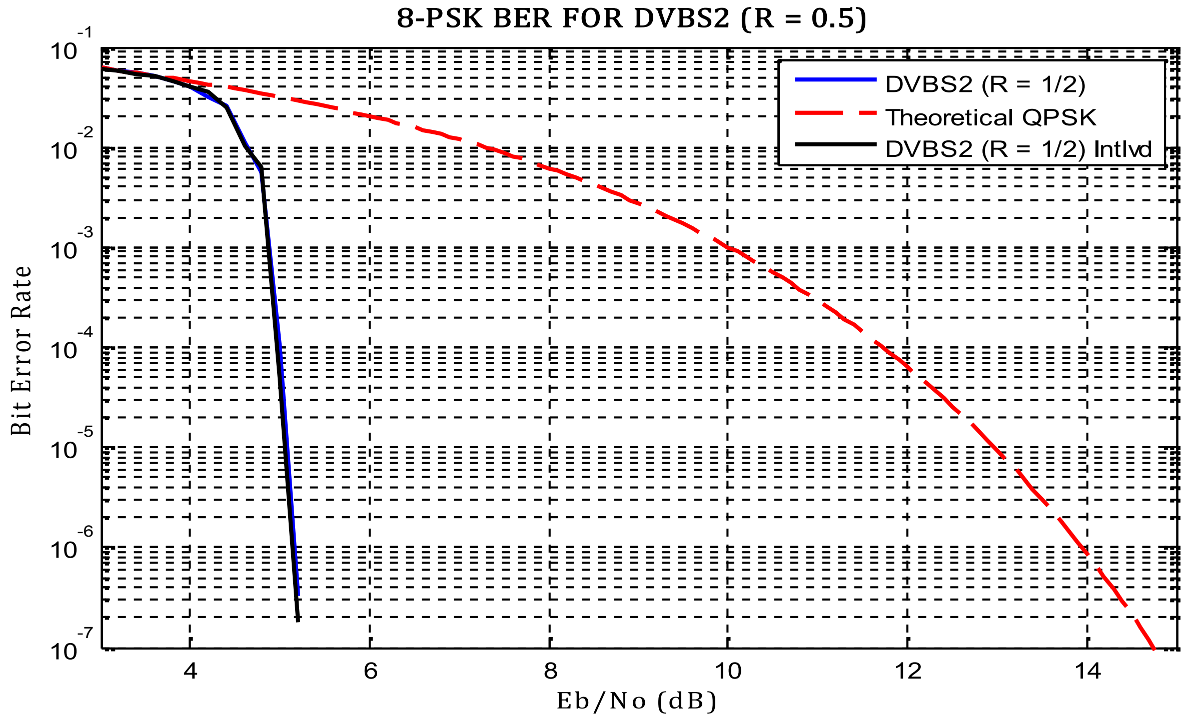

Figure 10

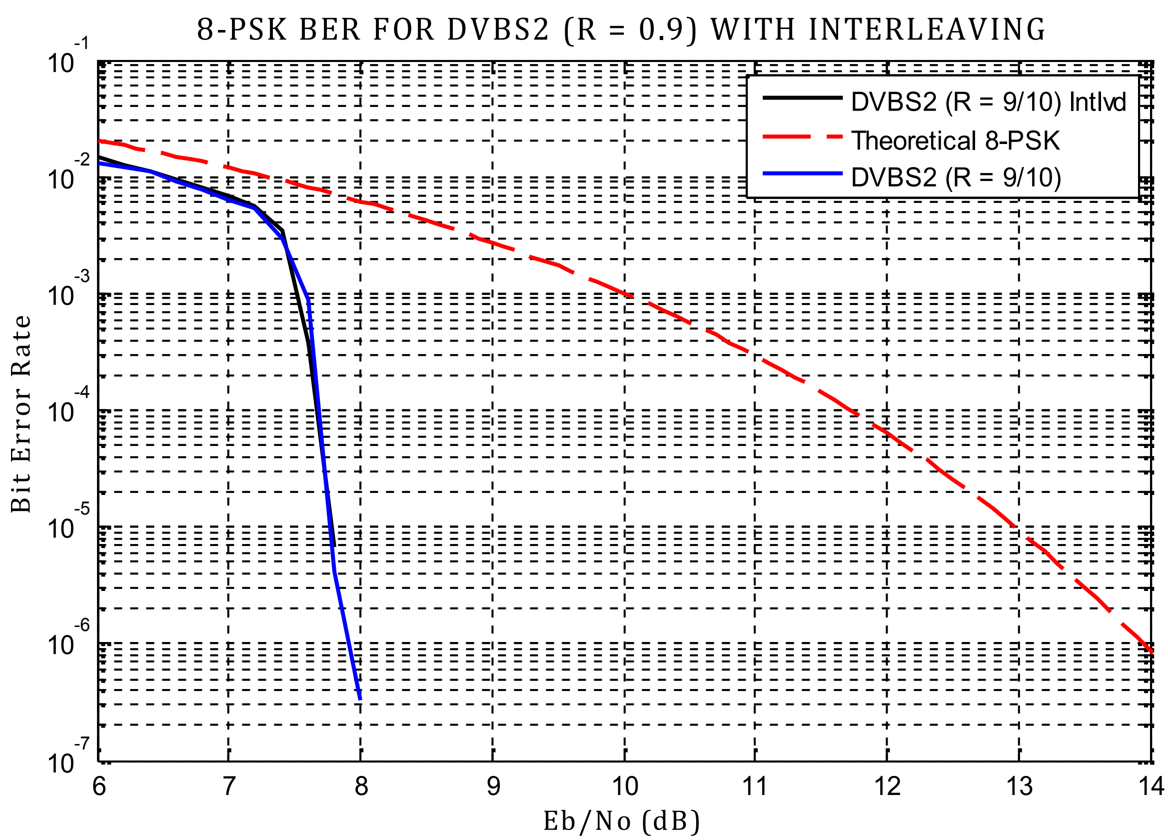

Figure 11

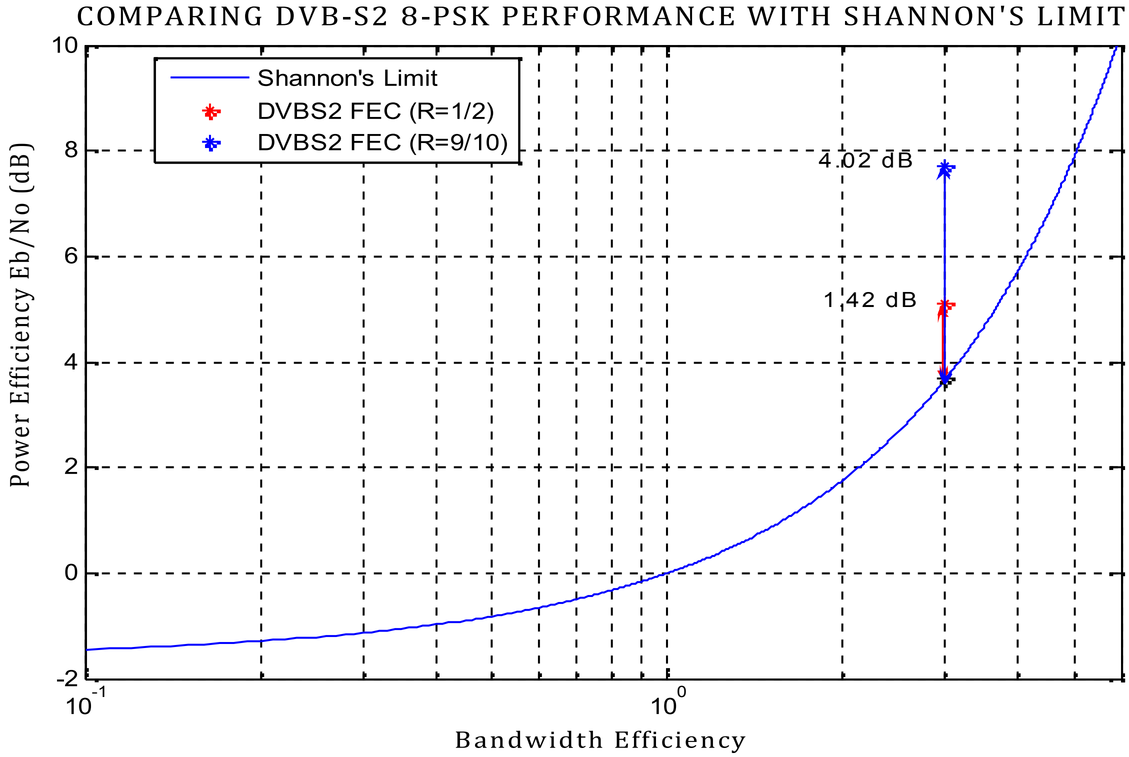

Figure 12: 8-PSK η=2; BER = 10-6; Eb/No = 5.1 dB(R=1/2); Eb/No = 7.7 dB(R=9/10)

DVB-S2 FEC with 16-QAM

The 16-APSK is not as power-efficient as the other modulation schemes above, but the spectrum efficiency is much greater. The 16-APSK constellation has been optimized to operate over a non-linear transponder by placing the points on 2 circles. Its performance on a linear channel is comparable with 16-QAM (as seen in Figure 13), which has been used for this simulation.

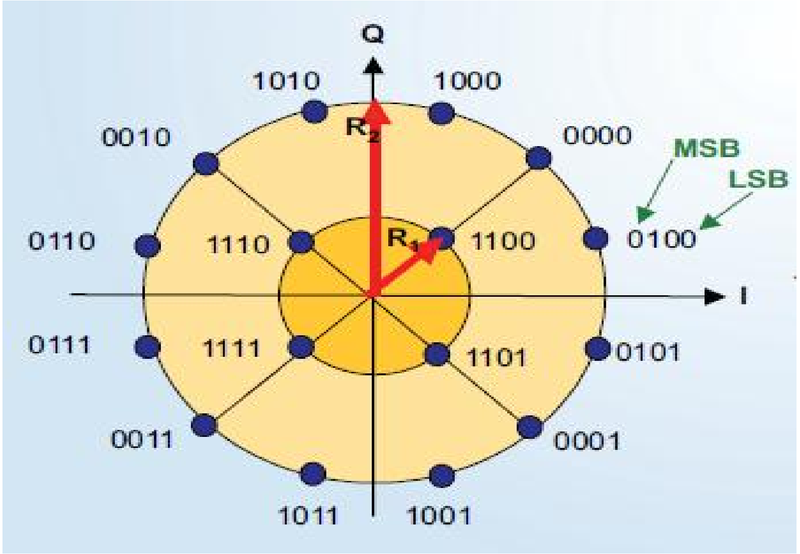

Figure 13: DVB-S2 16-APSK Constellation

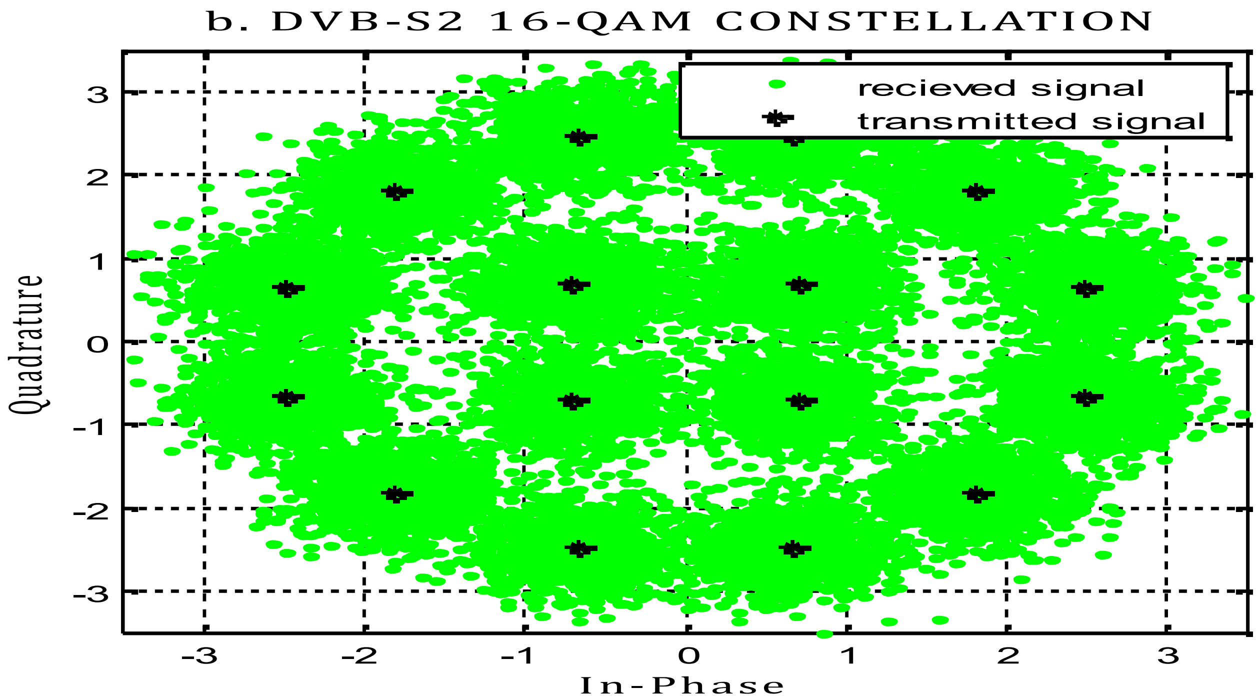

Figure 14

It can be observed in Figures 13 and 14 that the coding gains at an acceptable BER = 10^{-6} for the FEC coderate R=1/2 is about 8 dB while for coderate R = 9/10 is about 6.4 dB. 16-QAM with DVB-S2 FEC offers 0.84 dB and 2.96 dB for coderate R=1/2 and R = 9/10, less power efficiency than Shannon's information capacity.

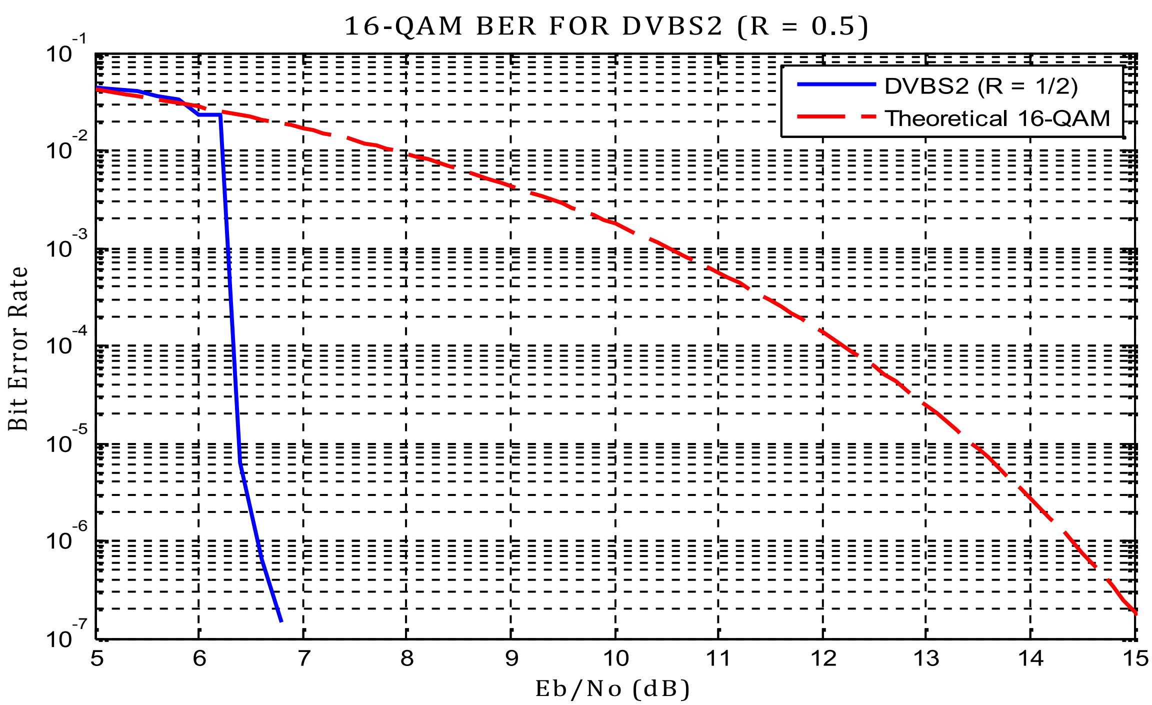

Figure 15

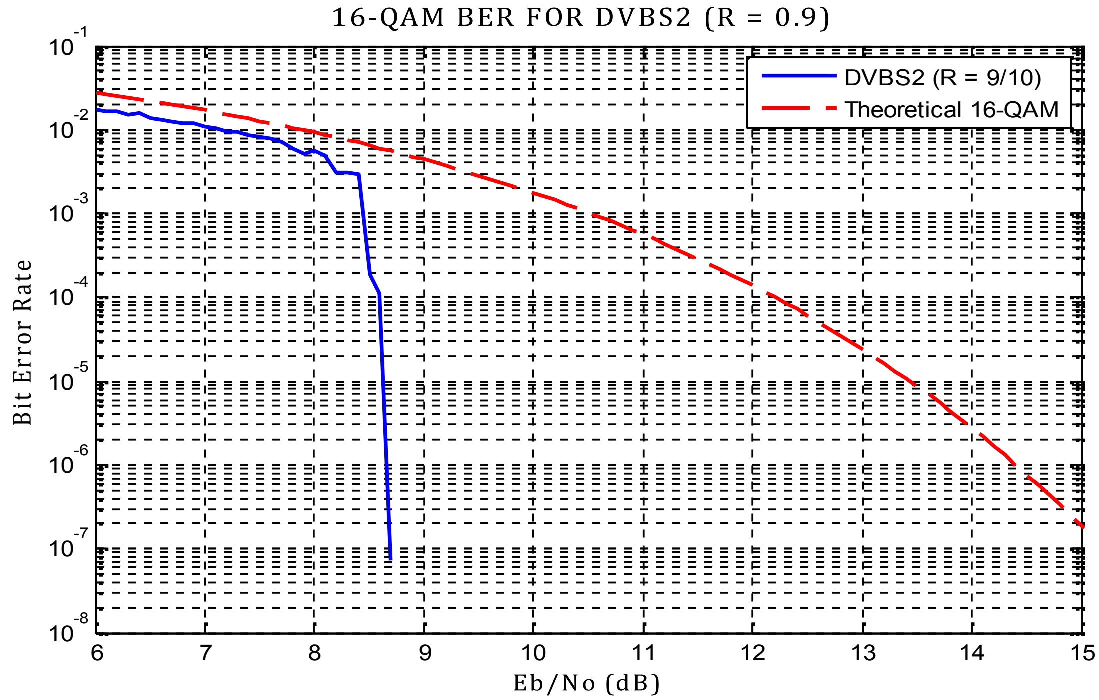

Figure 16

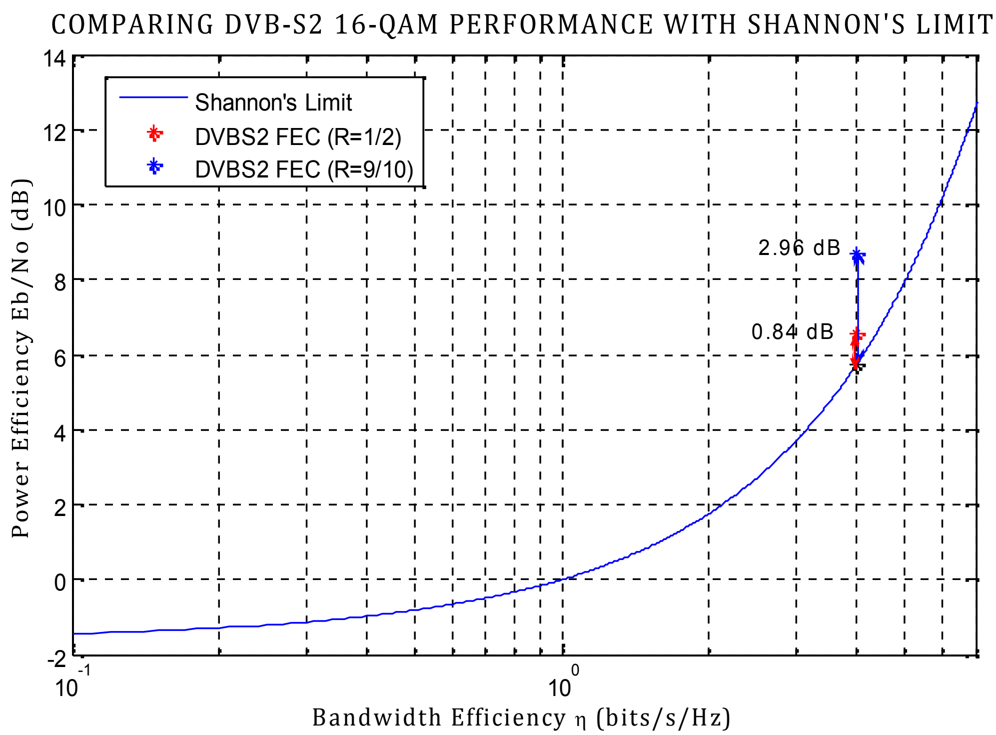

Figure 17

General Analysis and Implications of Results

Figure 7 shows DVB-S2 (*R*=1/2) performing similar to the LDPC (*R*=1/2) and Figure 9 show a better improvement of DVB-S2 (*R*=9/10) than the LDPC(*R*=9/10), what this implies is that at low coderates the LDPC codes have very large parity check bits and are powerful enough to dominate the DVB-S2 but at higher coderates the LDPC code have a smaller amount of parity check bits and cannot be efficient. Here the BCH code is seen to compensate for the inefficiency of the LDPC code. The concatenation of both codes has produced an FEC scheme that is powerful at a variety of coderates. This is especially useful to the DVB-S2 system which seeks to implement ACM.

Error Correction Capability

From the results gathered above, it is observed that at DVB-S2 FEC is capable of allowing a QEF transmission with its capacity to achieve low BER of at least 3×10^{-7} with any of the system parameters implemented in this research. However, not at all the coderates did the system performed as close enough to Shannon's limit as expected by DVB-S2 designers. The AWGN channel simulated is a minimal memory or memoryless channel where bit errors are random, that is why interleaving has no positive effect here. Although the memory channel has not been implemented in this research, the Rayleigh Channel models the fading characteristic of a typical memory channel. Results of simulations of the DVB-S2 FEC system in a Rayleigh fading channel will clearly show the impact of interleaving in the concatenated FEC scheme.

Power Efficiency and Tradeoffs

A range of bandwidth efficiency 2 bits/s/Hz (QPSK), 3 bits/s/Hz (8-PSK) and 4 bits/s/Hz (16-QAM) of the DVB-S2 FEC subsystem were experimented over the FEC coderates R=1/2 and R=9/10. At FEC coderate R=1/2, the system performed within the theoretical expectation (0.7 dB to 1.2 dB) close to Shannon's limit, but at R=9/10 the simulated results were not as power efficient as expected theoretically. At coderate R=9/10, the redundancy of the FEC code is 11.1% and the bandwidth expansion is only 1.1, that is a little increase in bandwidth requirement for transmission. Unlike FEC coderate R=1/2 with a redundancy of 100% and bandwidth expansion of 2, which is double the bandwidth requirement. As such the low power degradation of power efficiency of the FEC coderate R=9/10 (as compare with Shannon's limit) is the price paid for bandwidth efficiency of the FEC code.

Practical Implications on DVB-S2 Design

From the results obtained above, the power performance of the 3 coded modulation schemes implemented are 0.62 dB to 2.74 dB (for QPSK), 1.42 dB to 4.02 dB (for 8-PSK) and 0.84 dB to 2.96 dB (for 16-QAM) close to Shannon's limit. This is assuming since R=9/10 is the highest possible coderate, all other coderates would yield power efficiencies within the performance above (except R=1/4). If this is the case it is advisable for DVB-S2 system designers to maximize the use of the QPSK for moderate and 16-QAM (16-APSK) large data transmissions. The use of 8-PSK should be used for large data transmission during unfavorable conditions. The use of QPSK should be maximize because it offers a better power efficiency

CONCLUSION

DVB-S2 system is a PSK based transmission systems with a FEC scheme which is expected to be powerful enough to mitigate the effects of using higher modulation schemes such 8-PSK, 16-APSK and 32-APSK. This research has been limited to the normal FECFRAME (n_{ldpc} = 64800). A t-error correcting BCH (N_{bch}, K_{bch}) code shall be applied to each BBFRAME (K_{bch}) to generate an error protected packet. First the BCH and LDPC coding schemes were independently implemented and the performances tested. Simulations using different coderates R=1/2 and R=9/10 in AWGN were executed. This research found that at low coderates the LDPC codes have very large parity check bits and are powerful enough to dominate the DVB-S2 but at higher coderates the LDPC code have a smaller amount of parity check bits and cannot be efficient. The BCH code compensates for the inefficiency of the LDPC code and by concatenating both codes an FEC scheme that is powerful at a variety of coderates is produced. This is especially useful to the DVB-S2 system which seeks to implement ACM.

The error performance of the DVB-S2 QPSK yields BERs as low as 2 x 10^{-7}, with a coding gain of about 8 dB at BER=10^{-6} over the theoretical uncoded QPSK results. It was observed that interleaving limits the error performance for QPSK, this is because the number of transmitted bits per symbols is sufficient to mitigate the possibility of error burst and by interleaving, and the problem being avoided is then created. The 8-PSK achieves BERs as low as 2 x 10^{-7} and its performance is the same with and without interleaving. This is because interleaving is only effective in the presence of burst errors while this entire research was based on AWGN channel which is memoryless. 16-QAM which is comparable with the performance 16-APSK on a linear channel was used for this simulation. It achieves BERs as low as 3 x 10^{-7}. From the results gathered, DVB-S2 FEC is capable of allowing a QEF transmission with its capacity to achieve low BER of at least 3 x 10^{-7}. However, not at all the coderates did the system exactly performed close enough within 0.7 dB to 1.0 dB of Shannon's limit as expected.

Over the bandwidth efficiencies 2 bits/s/Hz (QPSK), 3 bits/s/Hz (8-PSK) and 4 bits/s/Hz (16-QAM), the DVB-S2 FEC subsystem performed acceptably within the theoretical expectation (0.7 dB to 1.0 dB) to Shannon's limit mostly at low coderates. At coderate R=9/10, the redundancy of the FEC code is 11.1% hence little increase in bandwidth requirement for transmission. The coderate R=1/2 on the other hand has a redundancy of 100% and bandwidth expansion of double the bandwidth requirement. The degradation in power efficiency of the FEC coderate R=9/10 (as compare with Shannon's limit) is the price paid for bandwidth efficiency of the FEC code. With power efficiency of 0.62 dB to 2.74 dB close to Shannon's limit, QPSK is the most power efficient modulation scheme and its use should be maximized. The 16-QAM (16-APSK) has proven to be more power efficient than the 8-PSK as compared to Shannon's limits as such, the use of 8 PSK should be limited to unfavourable transmission conditions.

The AWGN channel simulated is a memoryless channel where bit errors occur randomly as such interleaving is inconsequential in these simulations. Although the memory channels have not been implemented in this research, the Rayleigh Channel models the fading characteristic of a typical memory channel. Results of simulations of the DVB-S2 FEC system in a Rayleigh fading channel will clearly show the impact of interleaving in the concatenated FEC scheme. Such simulations are likely to show an improvement in performance expectations.

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