Journal of Engineering and Development, Vol. 18, No.6, November 2014, ISSN 1813- 7822

Serially Concatenation of Forward Error Correction Codes for Real Time Applications

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Abstract:

This paper presents a scheme of serially concatenated codes. It is formed by Bose Chaudhuri Hocquenghem (BCH) as outer code and Low density Parity Check (LDPC) inner code in order to real time applications through get rid of the delay time stem from large number of iterations of LDPC decoder. Also analyzing the performance of each code individually by several example simulation using Matlab version R2012a tested by Additive White Gaussian Noise (AWGN) channel model with Binary Phase Shift Keying (BPSK) modulation to pick up appropriate parameters for this purpose. The proposed approach present high performance and reduce the Bit Error Rate (BER). A proposed parameters get nearly to zero BER at very low Signal to Noise Ratio (SNR).

Keywords; Index Terms- LDPC and BCH codes, Low BER, Real Time.

متسلسلة متوالية لمشفرات تصحيح ذاتي في تطبيقات الزمن الحقيقي

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الخلاصة:

تم في هذا البحث تقديم متسلسل متوالي من الشفرات. تتكون من شفرع نوع BCH استخدمت كمشفر خارجي ومشفر نوع LDPC كمشفر داخلي وذلك لاغراض تطبيقات الزمن الحقيقي بزمن تاخير قليل من خلال التخلص من التاخير الزمني الناتج من العدد الكبير من التكرار الخاص بكاشف LDPC. كذلك تحليل اداء كل مشفر على حده

باستخدام عدة امثلة للمحاكاة باستخدام برنامج ماتلاب فحصت باستخدام قناة ضوضاء كاوزين البيضاء ومضمن تزحيف الطوري BPSK لغرض اختيار عناصر مناسبة لهذا الغرض. المقترح الذي تم التوصل اليه اظهر اداء عالي وتم تقليل معدل الخطا BER. العناصر المقترحة حصلت على معدل خطا قريب من الصفر عند نسبة ضوضاء الى الاشارة SNR قليلة جدا.

1. Introduction:

Error correction coding techniques are used to ensure reliable delivery of digital data over unreliable communication channels. The theory of error correcting codes has presented a large number of code constructions with corresponding decoding algorithms. However, for applications where very strong error correcting capabilities are required these constructions all result in far too complex decoder solutions. An error correction coding technique which gives performance near Shannon's limit is LDPC Code. Low Density Parity Check code is a linear block code with a message passing decoding algorithm [1-3]. LDPC-only coding system may not be able to sufficiently handle burst errors if such burst errors cannot be detected/located by preceding read channel signal processing.

High performance and low-decoding complexity of LDPC codes represent their applications in concatenated codes. They are mainly combined with another type of block codes that aims to mitigate effects of random and burst errors. Two methods proposed codes constituted by LDPC and Bose RayChaudhuri Hocquenghem (BCH) codes as suitable for the magnetic storage and optical transmission systems [4- 5]. As non-binary codes, they are concatenated with Reed-Solomon (RS) codes to outperform single LDPC code [6]. In [7] he presents a new scheme of serially concatenated codes. It is formed by a combination of Euclidean Geometry (EG) Low Density Parity Check (LDPC) and Recursive Systematic Convolutional (RSC) codes linked by the row-column interleaver. A modification is proposed on the interleaver, which improves performance of concatenated codes. This is conducted by recognition of patterns producing low-weights for both LDPC and RSC codes. Simulation results confirm that with similar rates and less decoding complexity, newly designed codes outperform product codes constituted by two cyclic EG codes.

Because of the soft-decision probability-based nature of LDPC code decoding, LDPC-only coding solutions may not be able to achieve sufficient burst error tolerance [8]. Hence, in this paper it has been considered LDPC-centric concatenated coding systems in which LDPC code is used as an inner code. In particular, we focus on concatenated BCH-LDPC coding systems. As demonstrated in a recent study [9], concatenated BCH-LDPC coding tends to have three main advantages, including (1) it can be much easier to estimate the error correction performance down to very low sector error rate (SER) (e.g., and below), (2) it can effectively leverage the bit error number oscillations in case of inner LDPC code decoding failures to improve the overall error correction performance, and (3) the silicon implementation cost can be reduced. However, as pointed out earlier, LDPC code decoding may suffer from significant performance degradation in the presence of long burst errors. As a result, LDPC-centric concatenated coding is also severely sensitive to long burst errors.

2. Concatenated Codes:

The concatenated codes become widely used for efficient error correction coding. For example, within DVB-S2 standard, a highly efficient LDPC code is combined with an algebraic BCH code in order to remove any errors left over from LDPC code due to error floor zone. This idea is illustrated in **Figure.(1),** where the two codes and their associated coders and decoders are labeled inner and outer, respectively. Typically, the inner code which is a soft decision code follows the outer code that is a hard-decision code block [10].

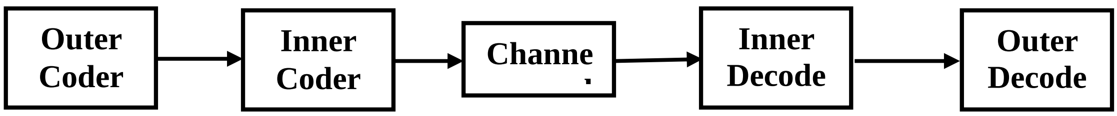

Fig .(1) Concatenated Codes

2.1 BCH Codes:

BCH codes are mainly used in communication systems requiring Forward Error Correction (FEC) as an error detector and corrector where data transmitted through communication channel are vulnerable to errors and erasures. These codes are used in the second generation satellite Digital Video Broadcasting (DVB-S2) [11].

For any positive integers, $m \geq 3$ and $t < 2^{m-1}$, there is a binary BCH code with the following parameters, (referred to as an (*n, k, t*) BCH code):

- Block length: $n = 2^m - 1$,
- Number of parity check bits: $n - k \leq mt$,
- Minimum distance: $d_{min} \geq 2t + 1$.

Each binary BCH code (*n, k, t*) can correct up to t-bit errors, and thus it is also referred to as a t-error-correcting code [11].

In BCH code, the message *m(x)* is divided by *g(x)* and remainder will be represented as check bits *r(x)*. Now whole encoded message *E(x)* will be represented as:

$$\boldsymbol{E(x) = m(x) + r(x)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

The decoding of BCH code is performed in three steps:

- Syndrome is calculated from the received codeword.
- Error location polynomial is found from a set of equation derived from the syndrome.
- Error location polynomial is used to identify and correct the errant bits[12].

2.2 LDPC:

LDPC codes are linear block codes defined by sparse parity check matrices. By optimizing the degree distribution, it is well-known that LDPC codes can approach the capacity of an AWGN channel [4]. Several algorithms have been proposed to generate LDPC codes for a given degree distribution, such as the ACE algorithm [3], and the PEG algorithm [10]. Designing LDPC codes with low error-floors is crucial for applications to flash memory since storage systems usually require block-error-rates lower than 10^{-15}.

Suppose that *G* is a graph with n left nodes (called message nodes) and *r* right nodes (called check nodes). The graph gives rise to a linear code of block length *n* and dimension at least *n-r* in the following way: The *n* coordinates of the codewords are associated with the *n* message nodes. The codewords are those vectors (c_1,.....c_n) such that for all check nodes the sum of the neighboring positions among the message nodes is zero [10].

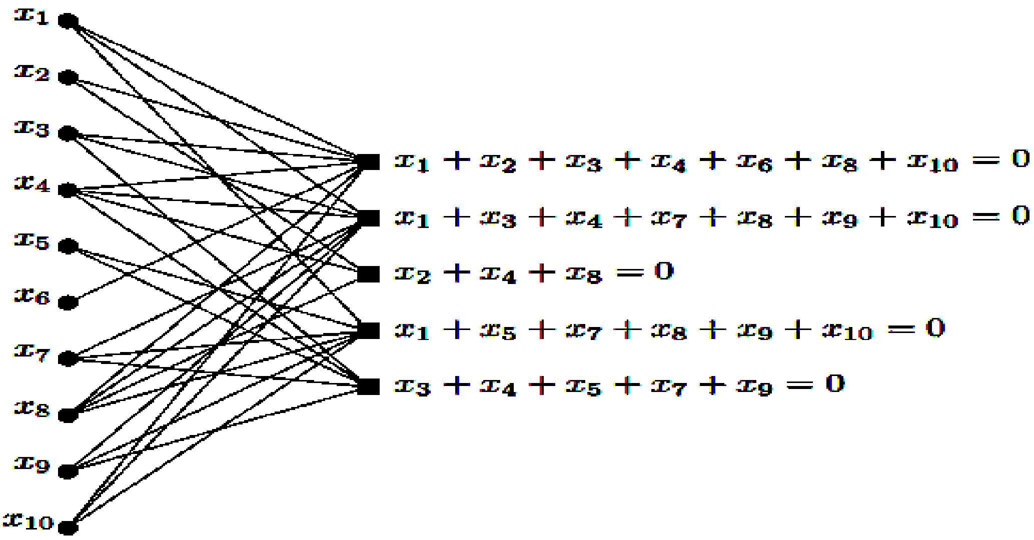

Fig .(2) LDPC Codes

The graph representation in Fig. 3 is analogous to a matrix representation by looking at the adjacency matrix of the graph: let H be a binary *r x n*-matrix (which is cold parity check matrix) in which the entry (*I*, *j*) is 1 if and only if the *ith* check node is connected to the *jth* message node in the graph. Then the LDPC code defined by the graph is the set of vectors c = (c_1,..., c_n) such that H ,c^T = 0 [12].

In this research the decoding of LDPC is don using message passing algorithm [13]. It exchanges soft-information iteratively between variable and check nodes which is called belief propagation (BP). The exchanged messages are assumed to be log-likelihood ratios (LLR). Each variable node of degree d_v calculates an update of message *k* according to [14]:

$$\gamma_k = \gamma_{ch} + \sum_{i=0}^{d_v-1} \gamma_i - \gamma_k^{old} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

with γ_{ch} the corresponding channel of LLR and γ_1 the LLRs of the incident edges.

3. Simulation and results:

The system that used for simulation in this research is shown in **Figure (3)**. The BCH is put as outer code while LDPC is inner code and to break up the burst error when the system is used for difficult environments an interleaver is insert between two codes. In this research has been to focus on reducing the number of iteration of LDPC decoder to avoid the delay time resulting from much iteration with the maintaining of low complexity.

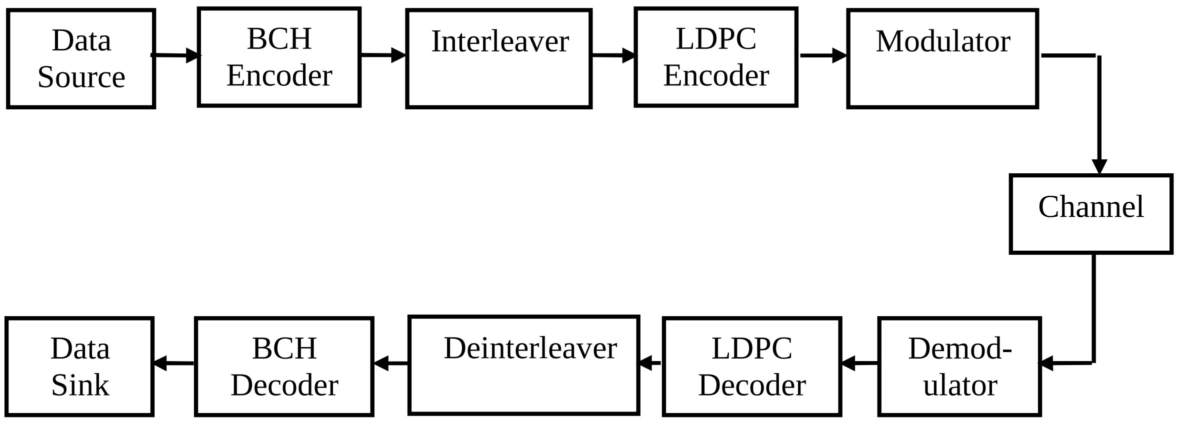

Fig .(3) The system model

The simulation is started with evaluation of each code individually to select the optimum parameters that suitable to approach research target the design of an effective and simplified system with very low Bit Error Rate (BER). We assume that Binary Phase Shift Keying (BPSK) transmission over Additive White Gaussian Noise (AWGN) channel in order to quickly get the results that the program needs a long time for implement.

3.1 BCH Code:

For simplicity it has been used narrow sense BCH code with fixed code rate (0.7) and variable codeword length (n) and variable message length (k) to evaluate the performance of such code to see the active parameters. **Figure (4)** illustrates the result of BER when using only BCH in the system of **Figure (3).**

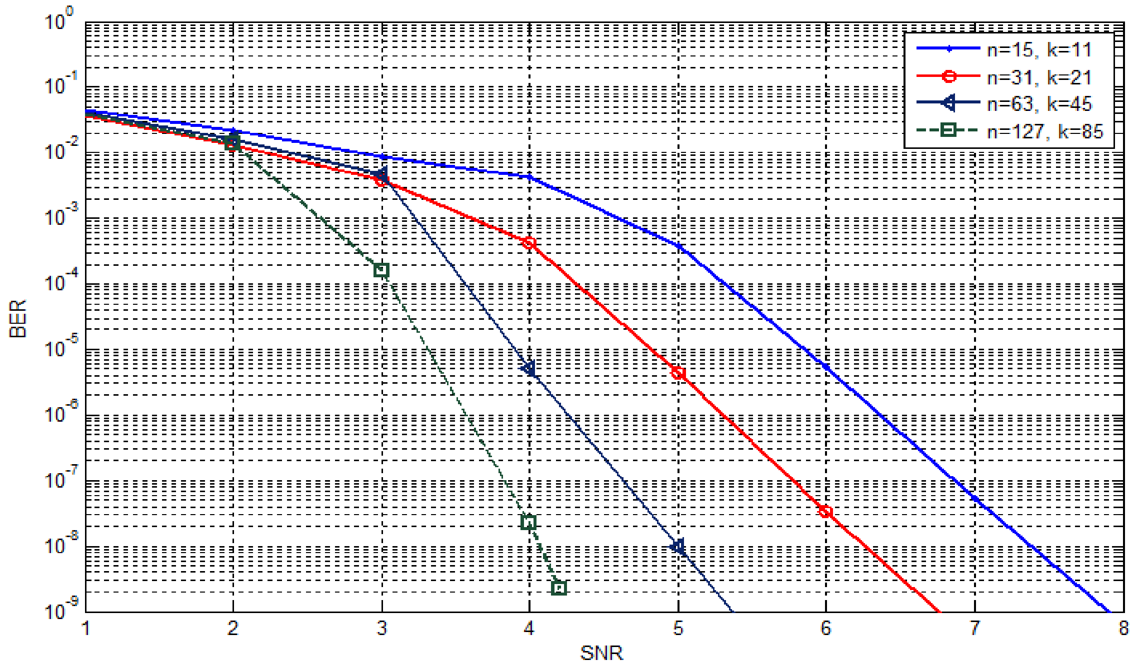

Fig .(4) the performance of BCH code with various codeword and fixed code rate

It is clear that the BER is improved by about 1dB when the codeword length is change from n=15 to 31, 63 and 127 while maintaining code rate at fixed value. On this point, we would like clarification that the BER can be improved by reducing the code rate, but that leads to reduce the spectral efficiency due to the increase of redundancy information of the code, so even to improve the performance it is prefer to increase the codeword length.

3.2 LDPC only:

The next step of such simulation is to test the LDPC code. The parity check matrix used here with dimension of (32400 × 64800), six ones in the first row, seven ones in the (2 to 32400) rows, eight ones in the columns of (1 to 12960) and three ones in the columns (1261 to 32400), while columns (32401 to 64800) form a lower triangular matrix. **Figure (5)** shows the performance of such code.

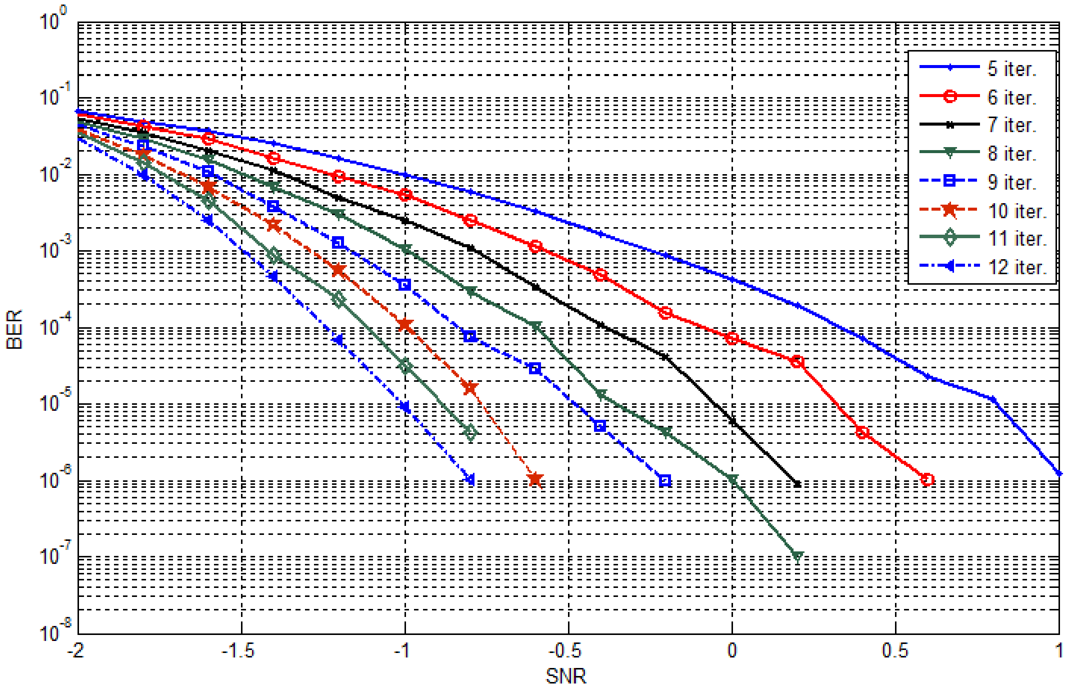

Fig .(5) The performance of LDPC with various number of iteration

It can be seen that the system of **Figure (3)** with LDPC code only can achieved good performance. It needs only 1 dB signal to noise ratio to achieve 10^{-6} BER with 5 iterations and it can be reduced more and more by increasing number of iteration, but the large increase here caused to delay time which make such system unsuitable for real time applications.

3.3 The proposed system:

Instead of using large number of iteration with LDPC decoder to get very low BER, it can be design a concatenation of two codes such as BCH and LDPC shown in **Figure. 3**. The length of code word for BCH code is n=127 while the message k=113 only so the code rate is very high (0.89) so it will not lead to reduced spectral efficiency but in return allows to reduce the number of iterations which can get good performance suitable to real time applications as will shown in Fig.6 which illustrates the results of proposed system.

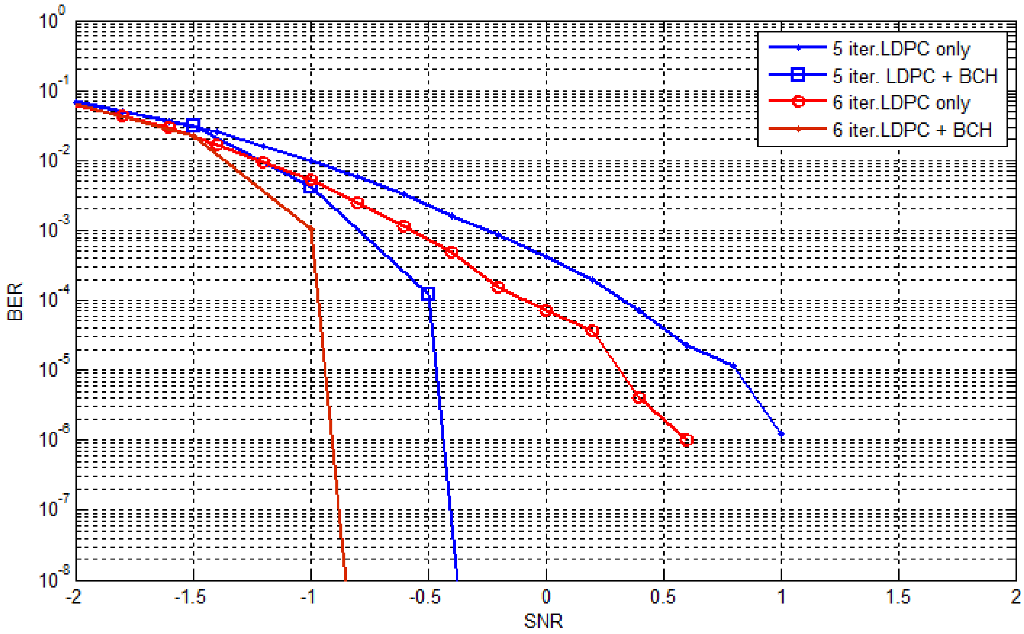

Fig .(6) The performance of proposed scheme

It is clear that such system achieve nearly to zero BER at about -0.5 dB with only 5 iterations, so the curve is become very sharp as seen in Figure. (6) which indicate more than 1 dB gain in contrast with the curve of LDPC only so that our system is success to get very low BER with low delay time.

4. Conclusions:

In this paper it has been analyzed the performance in term BER of BCH and LDPC codes individually to pick the suitable parameters that can be used for concatenation of BCH (outer code) and LDPC (inner code). The results show that such system is powerful channel code to achieve very low BER which suitable for real time applications. Such system gets near to zero BER and outperform the system with LDPC only by more than 1 dB at very low SNR. Which indicate that it is appropriate for real time applications. Also this scheme can overcome the error floor which is the important challenges facing most types of channel codes. Some of researcher such as [15] try to treat this problem by decreasing code rate of outer code, while the scheme of this research achieve waterfall shape of error performance as shown in **Figure (6).**

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