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Multilevel LDPC Codes Design for Multimedia Communication CDMA System

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We design multilevel coding (MLC) with a semi-bit interleaved coded modulation (BICM) scheme based on low density parity check (LDPC) codes. Different from the traditional designs, we joined the MLC and BICM together by using the Gray mapping, which is suitable to transmit the data over several equivalent channels with different code rates. To perform well at signal-to-noise ratio (SNR) to be very close to the capacity of the additive white Gaussian noise (AWGN) channel, random regular LDPC code and a simple semialgebra LDPC (SA-LDPC) code are discussed in MLC with parallel independent decoding (PID). The numerical results demonstrate that the proposed scheme could achieve both power and bandwidth efficiency.

Keywords and phrases: multilevel coding, BICM, LDPC, PID.

1. INTRODUCTION

In the next generation of code division multiple access (CDMA) system, the primary challenge is high-quality and high data rate multimedia communication. Normally, the mobile transmission systems deal with various kinds of information such as voice, data, and images. The volume of traffic required is therefore far higher than current voice or data-based applications. This increase in traffic rates is expected to become even more serious when full interactive multimedia transfers are required. As the information volume increases, so does the required instantaneous transmission rate. Table 1 shows an estimate of the bit rates required for various multimedia services. It implies that the next generation of CDMA transmission should be of higher data rate, multilevel, or multirate, such as wideband CDMA (WCDMA), adaptive modulation, and so on. Coded modulation is a good choice for multimedia communication CDMA system, since it can efficiently combine various rate channel coders into the modulation. Multilevel coding (MLC) [1] and semi-bit interleaved coded modulation (BICM) [2] are two well-known coded modulation schemes proposed to achieve both power and bandwidth efficiency. For instance, trellis-coded modulation (TCM) is a special case of MLC, which is widely used in 3G wireless and satellite systems. In [1], Wachsman et al. conclude that if we use Gray mapping and employ parallel independent decoding (PID) at each level separately, the information loss relative to the channel capacity is negligible if optimal component codes are used. Furthermore, it is recognized that Gray-mapped BICM provides mutual information very close to the channel capacity and is actually a derivative of the MLC/PID scheme. In this paper, we propose an MLC with semi-BICM scheme, which can efficiently reduce the number of component codes without performance degradation. On the other hand, low density parity check (LDPC) codes [3] have been shown to achieve low bit error rates (BERs) at signal-to-noise ratio (SNR) to be very close to the Shannon limit on additive while Gaussian noise (AWGN) channel. Especially, a semialgebra LDPC (SA-LDPC) code has attracted much attention because of its simple construction and good performance [4, 5]. Based on the optimal code rates from the capacity rule for MLC/PID, in this paper, the random regular LDPC codes and SA-LDPC codes are used as the component codes for the MLC/PID with semi-BICM scheme. The

Table 1: Typical application bit rates for multimedia services.

Types of data	Types of services	Bit rate
Voice/audio	CBR, low delay	8–256 kbps
Digital data	ABR/UBR, low error	0.1–10 Mbps
Video telephony (H261)	CBR, low error	64–384 kbps
Motion video (MPEG1/MPEG2)	CBR/VBR, low delay	1.5–6 Mbps

numerical results show that the proposed scheme can offer one lower rate channel and two higher rate channel in 8PSK transmission, and it can be applied for 256 kbps voice transmission and about 1 Mbps higher rate data transmission simultaneously with low error and low delay. For instance, when 256 kbps voice data is in $R = 0.510$ lower rate channel, the two parallel higher rate channels $R = 0.745$ can transmit about 900 kbps data for 8PSK modulation.

The outline of this paper is as follows. In Section 2, we introduce the system model and capacity results. In Section 3, we first discuss the concept of the proposed MLC/PID with semi-BICM construction and prove that the capacity of the proposed scheme is the same as that of the traditional designs. Next, we introduce the SA-LDPC code construction and its design criterion. Finally, Section 4 concludes the paper.

2. SYSTEM MODEL AND CAPACITY

The typical structures of the LDPC-coded MLC scheme and BICM scheme are shown in Figure 1. In the case of LDPC-coded MLC/PID, each option of bit c_i, $i = 0, 1, \ldots, m-1$, is protected by a different binary LDPC code of C^i length n and rate $R^i = k_i/n$, where k_i is the information word length in bits. The Gray mapping maps a binary vector $c = (c_0, \ldots, c_{m-1})$ to a symbol point $x \in A$, where A is the symbol set and $|A| = 2^m$, as shown in Figure 2. We consider a discrete equivalent AWGN channel model, where z and y are the channel noise and channel output, respectively. The spectral efficiency R_s (bit/symbol) of the scheme is equal to the sum of the component code rates, that is, $R_s = \sum_{i=0}^{m-1} R^i$. In [6], Hou et al. proposed an LDPC-coded MLC/PID which uses m LDPC component codes. In the case of BICM, normally, it requires only one encoder. The capacity of the BICM scheme is the same as the performance limit that can be achieved by the MLC/PID [1, 2, 6].

Since the c_i, $i = 0, 1, \ldots, m-1$, are independent of each other in the PID model, the capacity function can be shown as

$$\sum_{i=0}^{m-1} I(Y, C_i) \le I(Y, C_i \mid C_0, \ldots, C_{i-1}), \tag{1}$$

where Y presents the received signals, and the maximum individual rate at level i to be transmitted at arbitrary low error rate is bounded by

$$R^i \le I(Y, C_i), \quad i = 0, 1, \ldots, m-1. \tag{2}$$

Consequently, the total rate R_s is restricted to

$$\begin{aligned} R_s = \sum_{i=0}^{m-1} R^i &\le \sum_{i=0}^{m-1} I(Y, C_i) \\ &\le \sum_{i=0}^{m-1} I(Y, C_i \mid C_0, \ldots, C_{i-1}) \\ &= I(Y, C_0, \ldots, C_{i-1}). \end{aligned} \tag{3}$$

We consider here an AWGN channel characterized by a transition probability density function $p(y_k|x_k)$ given by

$$p(y_k \mid x_k) = \frac{1}{\pi\sigma^2} \exp\left(-\frac{d_{x,y}^2}{\sigma^2}\right), \tag{4}$$

where $d_{x,y}$ designates the Euclidean distance between the complex signals x_k and y_k, and σ^2 is the variance of complex zero mean Gaussian noise. In [6, 7] the independent PID subchannel capacity is given by

$$R^i = 1 - E_{c,y}\left[\log_2 \frac{\sum_{a \in A} p(y|a)}{\sum_{a \in A_{i,c_i}} p(y|a)}\right], \tag{5}$$

and then the total R_s can be obtained by

$$\begin{aligned} R_s = \sum_{i=0}^{m-1} R^i &= m - \sum_{i=0}^{m-1} E_{c,y}\left[\log_2 \frac{\sum_{a \in A} p(y|a)}{\sum_{a \in A_{i,c_i}} p(y|a)}\right] \\ &= m - \sum_{i=0}^{m-1} E_{c,y}\left[\log_2 \frac{\sum_{a \in A} \exp\left(-d_{a,y}^2/\sigma^2\right)}{\sum_{a \in A_{i,c_i}} \exp\left(-d_{a,y}^2/\sigma^2\right)}\right], \end{aligned} \tag{6}$$

where $E_{c,y}$ denotes expectation with respect to c and y, A_i, c_i designate the subset of all symbols $a \in A$ whose labels have the value $c_i \in \{0, 1\}$ in position i. Figure 3 shows the capacity results for a Gray-mapped 8PSK modulation on an AWGN channel [1, 6]. Note that $I(Y, C_1) = I(Y, C_2)$, since the Gray labeling for c_1 and c_2 differs only by a rotation of $90°$, as shown in Figure 2. According to the capacity results, the component code rate distribution at $R_s = 2$ bit/symbol is $R_0/R_1/R_2 = 0.510/0.745/0.745$ for PID [1, 6].

3. PROPOSED MLC/PID WITH SEMI-BICM SCHEME BASED ON LDPC CODES

In fact, the MLC/PID with BICM in Figure 1c cannot improve the performance much from the traditional MLC/PID scheme, since the bit interleaver before the LDPC code is the same as a permutation for the LDPC generator matrix. In the following, we propose an MLC/PID with semi-BICM scheme which can efficiently reduce the number of component codes without performance degradation. Generally, the component codes with the same code rate can be grouped easily for QAM or MPSK. In this paper, we use the 8PSK MLC/PID with semi-BICM scheme as an example, the block diagram is shown in Figure 4. In the proposed scheme, a $2n$ length LDPC encoder is substituted with $2n$ length LDPC encoders at the same rate $R = 0.745$ and the bit interleaver is set after the channel code, which is the same as the typical

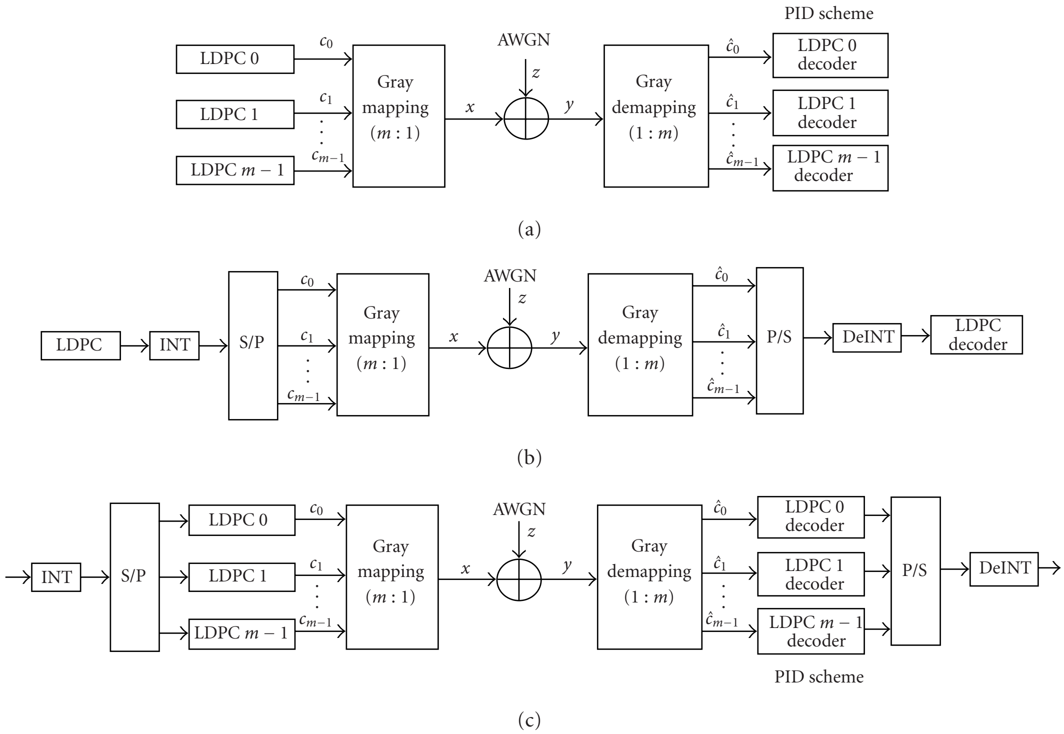

Figure 1: Structure of (a) MLC/PID, (b) BICM, and (c) MLC/PID with BICM by using LDPC codes.

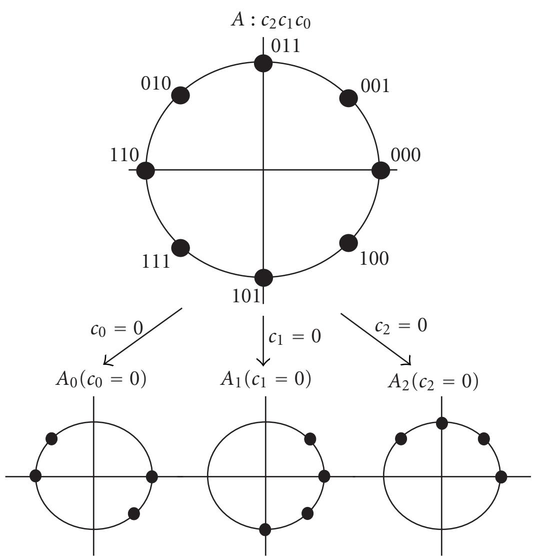

Figure 2: 8PSK Gray mapping.

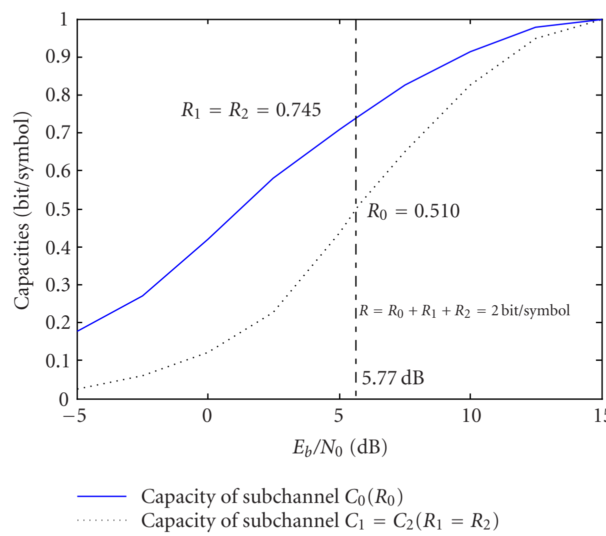

Figure 3: Capacities of the equivalent subchannels of an MLC/PID scheme based on 8PSK with Gray mapping over AWGN channels.

BICM design [2], to achieve the capacity of two equivalent channels. There are two advantages. First, we use a larger binary encoder (lower density) with the same rate as before; it can improve the performance well. The number of component codes is reduced, but the demerits arise due to the double length of codeword. Second, the bit interleaver after LDPC encoders can serve as a channel interleaver to permute the coded bitstream to achieve the time diversity. In addition, Hamming distance can be increased further by using bit-by-bit interleaving of the code bits prior to symbol mapping rather than symbol-by-symbol interleaving of the code symbols after symbol mapping. The numerical result demonstrates that the gain of LDPC code with bit interleaver can outperform well as the two times larger lower density

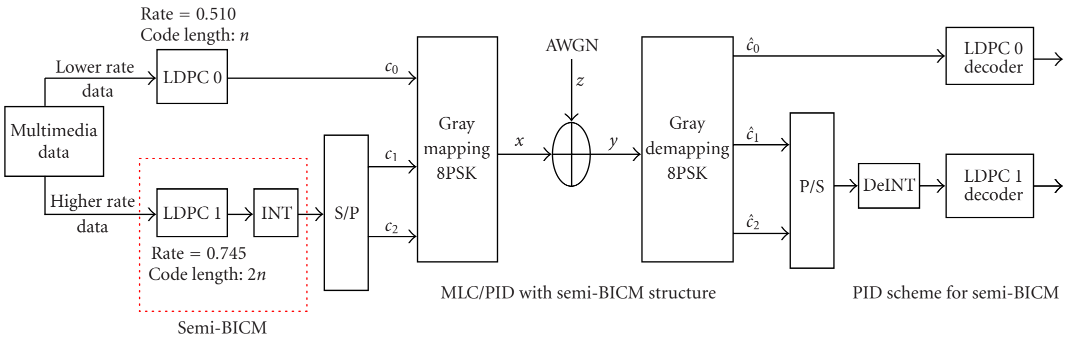

Figure 4: Structure of the MLC/PID with semi-BICM by using LDPC codes for 8PSK modulation.

Table 2: Comparing the gain from bit interleaver and lower density based on regular LDPC codes (PN interleaver, 8PSK Gray mapping, 1/2 code rate, column weight = 3, AWGN channel).

E_b/N_0	H (1536 × 3072) no interleaver	H (1536 × 3072) with bit interleaver	H (3072 × 6144) no interleaver, larger size
3 dB	BER = 0.2368	BER = 0.1491	BER = 0.1503
3.5 dB	BER = 0.1968	BER = 0.1288	BER = 0.1317
4 dB	BER = 0.1625	BER = 0.1069	BER = 0.1073
5 dB	BER = 0.0308	BER = 0.0129	BER = 0.0161
Benefits		Time diversity Hamming distance increased for modulation	Lower density

case, as shown in Table 2. For an 8PSK modulation, we can write the channel capacity of the proposed scheme as follows [2, 8]:

$$C_{\text{BICM}} = E_{c,y}\left(2 - \left[\log_2 \frac{\left(\sum_{a\in A}\exp\left(-d_{a,y}^2/\sigma^2\right)\right)^2}{\prod_{i=1}^{2}\sum_{a\in A_i,c_i}\exp\left(-d_{a,y}^2/\sigma^2\right)}\right]\right), \tag{7}$$

where two equivalent BICM channels are used. In addition, the one residual channel according to MLC/PID can be presented as

$$C_{\text{MLC}} = 1 - E_{c,y}\left[\log_2 \frac{\sum_{a\in A}\exp\left(-d_{a,y}^2/\sigma^2\right)}{\sum_{a\in A_0,c_0}\exp\left(-d_{a,y}^2/\sigma^2\right)}\right]. \tag{8}$$

Thus the total capacity of the proposed scheme can be given by

$$\begin{aligned} C_{\text{proposal}} &= C_{\text{BICM}} + C_{\text{MLC}} \\ &= E_{c,y}\left(3 - \left[\log_2 \frac{\left(\sum_{a\in A}\exp\left(-d_{a,y}^2/\sigma^2\right)\right)^3}{\prod_{i=0}^{2}\sum_{a\in A_i,c_i}\exp\left(-d_{a,y}^2/\sigma^2\right)}\right]\right) \\ &= 3 - \sum_{i=0}^{2} E_{c,y}\left[\log_2 \frac{\sum_{a\in A}\exp\left(-d_{a,y}^2/\sigma^2\right)}{\sum_{a\in A_i,c_i}\exp\left(-d_{a,y}^2/\sigma^2\right)}\right], \end{aligned} \tag{9}$$

it is the same as the capacity of the 8PSK BICM and MLC/PID which were shown in [1]. The advantage from lower density is shown in Figure 5; the simulation results demonstrate that the two times larger LDPC code can get about 0.2 dB improvement from the smaller LDPC code in BPSK-AWGN channel at the required BER = 0.0001.

SA-LDPC construction

To optimize LDPC component code in MLC/PID scheme, we now investigate a new construction which is called semialgebra LDPC code (SA-LDPC). In [9], a semistructure which can simply extend the regular LDPC code to an irregular case was introduced. Based on this idea, we extend algebra LDPC code [4] to an SA-LDPC to obtain a very good performance and reduce the encoding complexity [5]. Following the notations of [9] to describe the quasi-random matrix pattern, we can create parity check matrix composed of two submatrices, $H = \lfloor H^p | H^d \rfloor$. H^p is an $M \times M$ square matrix and H^d is an $M \times (n - M)$ matrix. The H^p matrix is a dual-diagonal pattern. An example is shown as

$$H^p = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}, \tag{10}$$

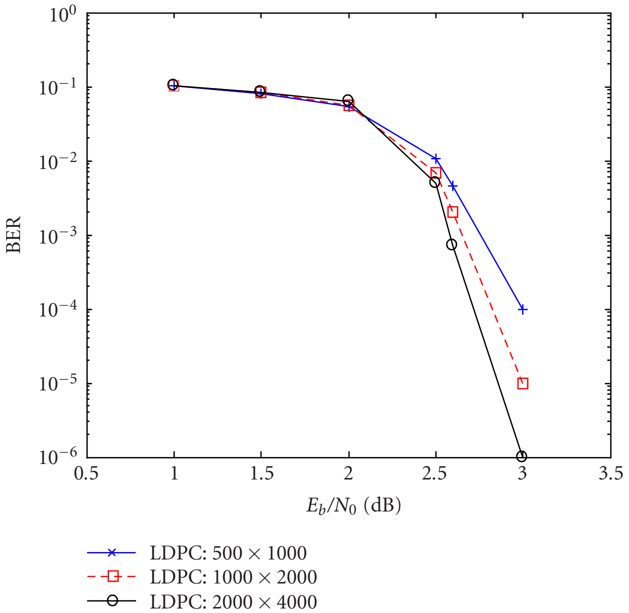

FIGURE 5: Regular LDPC codes with $r = 3$ and different matrix sizes.

where n is the code length and M is the parity bits length. Corresponding to the parity check submatrices are subvectors, u^p, the parity check vector, u^d, and the information vector of the codeword vector, u, such that

$$H^p u^p = H^d u^d. \tag{11}$$

Given an arbitrary information vector, we can generate codeword vectors by considering the *projection vector*, v,

$$H^p u^p = v = H^d u^d. \tag{12}$$

Especially, we can note that $[H^p]^{-1} = U^p$, where U^p is the upper triangular matrix and thus

$$u^p = U^p v. \tag{13}$$

In each case, we can obtain u^p by first calculating v and then transforming v. In the following, we develop a process to create H^d based on algebraic theory. We can partition H^d into blocks of $t \times t$ matrices, t is a *prime* integer. An $(r, l)H^d$ matrix with length $l \times t$, where r is the column weight and l is the row weight of H^d, can be designed as the following three steps [4].

(1) Let $B^i_{r,l}$ be an $I_{t\times t}$ identity matrix located at the rth block row and lth block column of parity check matrix having its rows shifted to the right $i \bmod t$ positions for $i \in S = \{0, 1, 2, \dots, t-1\}$.

(2) A q exists such that $q^l \equiv 1(\bmod t)$, S can be divided into several sets of L and one set containing the integer s, such as $L = \{s, sq, sq^2, \dots, sq^{m_s-1}\}$, where m_s is the smallest positive integer satisfying $sq^{m_s} \equiv s(\bmod t)$.

(3) The locations of 1's in H^d can be determined using the sets $L_1, \dots, L_r$ and the parameter t.

TABLE 3: Permutation numbers of sets.

s/m_s	$sq^{m_s} \equiv s(\bmod t)$	$L = \{s, sq, sq^2, \dots, sq^{m_s-1}\}$
$s = 0/m_s = 1$	$0 \cdot 2^{m_s} = 0(\bmod 31)$	$\{0\}$
$s = 1/m_s = 5$	$1 \cdot 2^{m_s} = 1(\bmod 31)$	$\{1, 2, 4, 8, 16\}$
$s = 3/m_s = 5$	$3 \cdot 2^{m_s} = 3(\bmod 31)$	$\{3, 6, 12, 24, 17\}$
$s = 5/m_s = 5$	$5 \cdot 2^{m_s} = 5(\bmod 31)$	$\{5, 10, 20, 9, 18\}$
$s = 6/m_s = 5$	$6 \cdot 2^{m_s} = 6(\bmod 31)$	$\{6, 12, 24, 17, 3\}$
$s = 7/m_s = 5$	$7 \cdot 2^{m_s} = 7(\bmod 31)$	$\{7, 14, 28, 25, 19\}$
$s = 9/m_s = 5$	$9 \cdot 2^{m_s} = 9(\bmod 31)$	$\{9, 18, 5, 10, 20\}$
$s = 10/m_s = 5$	$10 \cdot 2^{m_s} = 10(\bmod 31)$	$\{10, 20, 9, 18, 5\}$
$s = 11/m_s = 5$	$11 \cdot 2^{m_s} = 11(\bmod 31)$	$\{11, 22, 13, 26, 21\}$
$s = 12/m_s = 5$	$12 \cdot 2^{m_s} = 12(\bmod 31)$	$\{12, 24, 17, 3, 6\}$
$s = 13/m_s = 5$	$13 \cdot 2^{m_s} = 13(\bmod 31)$	$\{13, 26, 21, 11, 22\}$
$s = 14/m_s = 5$	$14 \cdot 2^{m_s} = 14(\bmod 31)$	$\{14, 28, 25, 19, 7\}$
$s = 15/m_s = 5$	$15 \cdot 2^{m_s} = 15(\bmod 31)$	$\{15, 30, 29, 27, 23\}$

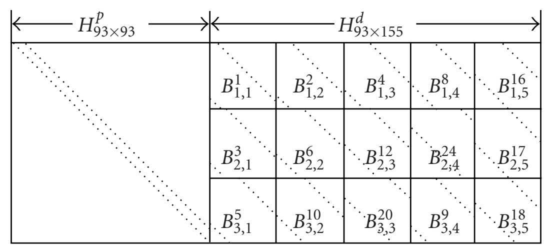

FIGURE 6: Example of the SA-LDPC code.

For example, we can design a SA-LDPC code with $r = 3$, $l = 5$, and $t = 31$. According to $q^t \equiv 1(\bmod t)$, we get $q = 2$ and the parity check matrix is

$$H = \left\lfloor H^p_{93\times93} \,\middle|\, H^d_{93\times155} \right\rfloor, \tag{14}$$

and its code rate is

$$\text{code rate} = \frac{n - M}{n} = 0.625. \tag{15}$$

Based on the second step of H^d construction, we can show the set L_i, $i = \{0, 1, 2, \dots, 13\}$, distributions in Table 3, and the location of 1's in H^d can be decided by L_1, L_2, $L_{r=3}$. As a result, the semialgebra parity check matrix is shown in Figure 6, where the dotted lines represent entries of 1 in H, while other entries are 0.

The simulation results of SA-LDPC codes are shown in Figure 7. It can be seen that the SA-LDPC can achieve about 0.5 dB enhancement from random regular LDPC codes [3] by using a very simple structure which only consists of several selected permutation matrices at the required BER $=$ 0.0001.

However, different from random construction regular LDPC code, the SA-LDPC code cannot be obtained randomly according to a given code rate for MLC/PID designs. Therefore, we list several parameters which should be satisfied in the proposed MLC/PID design for 8PSK modulation.

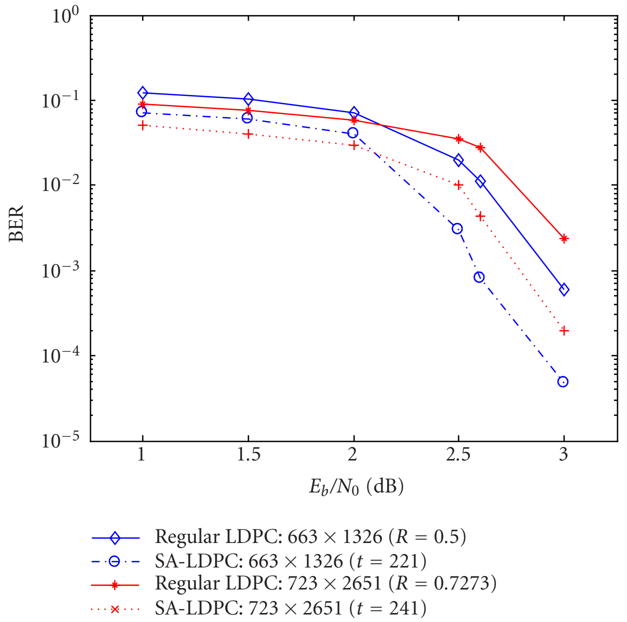

Figure 7: Performance of SA-LDPC codes compared with random construction regular LDPC codes.

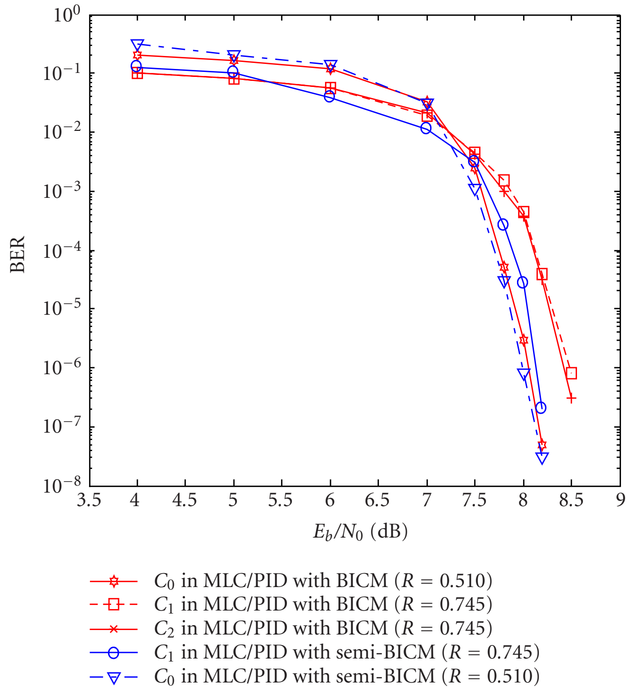

Figure 8: MLC/PID with semi-BICM scheme by using random construction regular LDPC codes (length of C_1 is 2800).

Since we cannot find a suitable SA-LDPC code for a given code rate, we now construct the SA-LDPC code with an approximate rate according to the given one. A code rate from the SA-LDPC can be written as

$$\text{code rate} = \frac{n-M}{n} = \frac{tl}{tl+tr} = \frac{l}{l+r}. \tag{16}$$

In the proposed scheme, we should have $R_0 = 0.510$ with code length n and $R_1 = 0.745$ with code length $2n$. Therefore, when $r = 3$, we have

$$\begin{aligned} R_0 &= \frac{l_0}{l_0+3} = 0.510, \\ R_1 &= \frac{l_1}{l_1+3} = 0.745, \end{aligned} \tag{17}$$

and thus we obtain $l_0 \approx 3$ and $l_1 \approx 8$. By considering the code length, we should calculate

$$\begin{aligned} t'_0 l_0 + t'_0 r &= \frac{t'_1 l_1 + t'_1 r}{2}, \\ t'_0(l_0+r) &= \frac{t'_1}{2}(l_1+r), \\ t'_0(3+3) &= \frac{t'_1}{2}(8+3), \\ \frac{t'_0}{t'_1} &= \frac{11}{12}, \end{aligned} \tag{18}$$

where t_0, t_1 are the nearest prime numbers from t'_0, t'_1, respectively. It also implies that we need to insert several zeros to keep the balance of the code length n. According to these parameters, we may design such SA-LDPC codes which can be suitable for the proposed MLC/PID scheme.

Simulation results

From signal y_k, the logarithm of likelihood ratio (LLR), $\Lambda(c_{k,i})$ associated with each bit $c_{k,i}$, $i \in \{0, 1, \ldots, m-1\}$, and $k \in \{0, 1, \ldots, n-1\}$, is computed and used as a soft decision in the binary LDPC decoder. Over an AWGN channel, the LLRs $\Lambda(c_{k,i})$ are obtained as

$$\begin{aligned} \Lambda(c_{k,i}) &= K \log \frac{\sum_{a\in A_i,\, c_i=0} p(y_k \mid a)}{\sum_{a\in A_i,\, c_i=1} p(y_k \mid a)} \\ &= K\left[\log \frac{\sum_{a\in A_i,\, c_i=0} \exp\left(-d^2_{a,y}/\sigma^2\right)}{\sum_{a\in A_i,\, c_i=1} \exp\left(-d^2_{a,y}/\sigma^2\right)}\right], \end{aligned} \tag{19}$$

where K is a constant, and in this paper we set $K = 1$. By applying the random regular LDPC codes, we set rate 0.510 smaller LDPC code with $r = 3$, $n = 700$, $M = 343$, rate 0.510 larger LDPC code with $r = 3$, $n = 1400$, $M = 686$, rate 0.745 smaller LDPC code with $r = 3$, $n = 1400$, $M = 357$, and rate 0.745 larger LDPC code with $r = 3$, $2n = 2800$, $M = 714$. Otherwise, in the case of SA-LDPC code, we set the lower rate code as $R_0 = 0.5$, $r = 3$, $l_0 = 3$, $t'_0 = 220$, and the nearest prime number $t_0 = 221$, $n = 1326$, $M = 663$, and higher rate code as $R_1 = 0.7273$, $r = 3$, $l_1 = 8$, $t'_1 = 240$, and $t_1 = 241$, $n = 2651$, $M = 723$. Therefore, by considering the balance of the code length, we should insert one zero after R_1 encoder when we use the SA-LDPC codes as the component codes. The simulation results show that the proposed MLC/PID with semi-BICM scheme get about 0.35 dB improvement at the rate 0.745 larger LDPC code, if the required BER $= 10^{-6}$ and similar performance at rate 0.510 from the MLC/PID with BICM, based on random construction regular LDPC codes, as shown in Figure 8. Moreover,

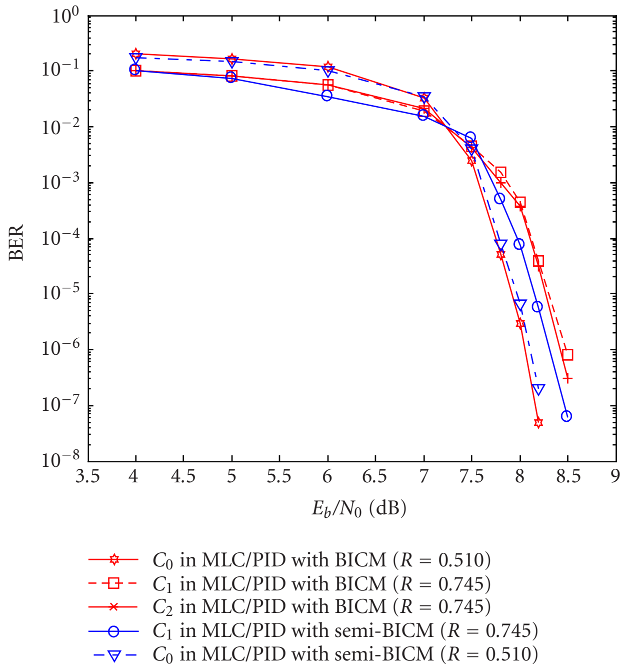

Figure 9: MLC/PID with semi-BICM scheme by using random construction regular LDPC codes (length of C_1 is 1400).

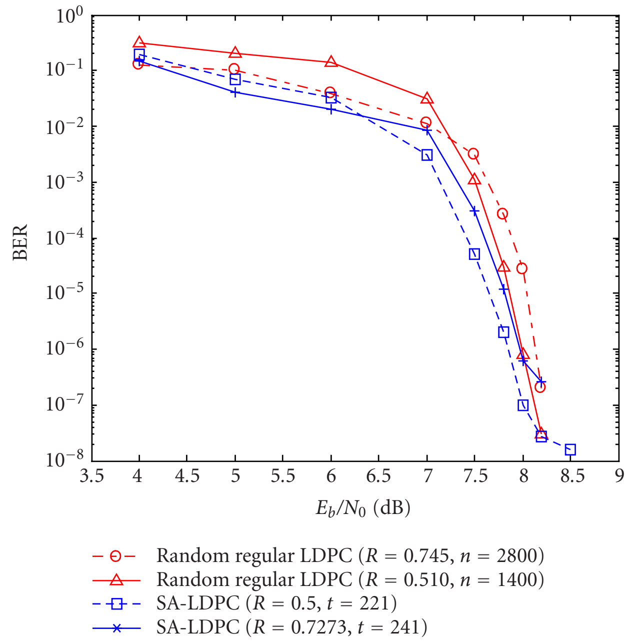

Figure 10: MLC/PID with semi-BICM scheme by using SA-LDPC codes over AWGN channel.

the numerical result demonstrates that the proposed scheme can achieve about 0.15 dB when a rate 0.745 smaller LDPC code is used as C_1, at the required BER $= 10^{-6}$, as shown in Figure 9. Otherwise, as shown in Figure 10, the SA-LDPC code can obtain much enhancement from random construction regular LDPC code, however, it should pay the loss of bandwidth efficiency, and its design parameters are hard to be decided. In the simulation, the lower rate code $R = 0.5$ and higher rate code $R = 0.7273$, code lengths are 1326 and 2651, respectively. Since the weight-two codes have the error floor, the SA-LDPC code in the proposed scheme cannot outperform sharply after 8.4 dB, as shown in Figure 10.

4. CONCLUSION

In this paper, we investigate a novel MLC/PID with semi-BICM scheme which could be applied for multimedia CDMA communication systems. Otherwise, a new SA-LDPC code construction is discussed. It is introduced in this paper to approach the Shannon limit and simple generator implementation over AWGN channel. However, for MLC/PID design, the parameters of SA-LDPC code are difficult to be decided. Generally, in the special case, the SA-LDPC code can be used to design MLC system with good performance and very simple implementation. Normally, the random construction LDPC codes can be widely used in MLC design to achieve the bandwidth efficiency for any given rates.

Moreover, the performance of the MLC/PID with semi-BICM scheme will be improved even though a turbo code is used, because a turbo code with large length has good performance due to the large size of a random interleaver. However, by comparing with turbo codes, the LDPC codes have simple decoding and better performance to approach the error correction capacity, as mentioned in [3, 6].

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REFERENCES

[1] U. Wachsmann, R. F. H. Fischer, and J. B. Huber, "Multilevel codes: theoretical concepts and practical design rules," *IEEE Transactions on Information Theory*, vol. 45, no. 5, pp. 1361–1391, 1999.

[2] G. Caire, G. Taricco, and E. Biglieri, "Bit-interleaved coded modulation," *IEEE Transactions on Information Theory*, vol. 44, no. 3, pp. 927–946, 1998.

[3] D. J. C. MacKay, "Good error-correcting codes based on very sparse matrices," *IEEE Transactions on Information Theory*, vol. 45, no. 2, pp. 399–431, 1999.

[4] M. M. Mansour and N. R. Shanbhag, "Low-power VLSI decoder architectures for LDPC codes," in *Proc. International Symposium on Low Power Electronics and Design*, pp. 284–289, Monterey, Calif, USA, August 2002.

[5] Y. Yi, J. Hou, and M. H. Lee, "Design of semi-algebraic low-density parity-check (SA-LDPC) codes for multilevel coded modulation," in *Proc. 4th IEEE International Conference on Parallel and Distributed Computing, Applications and Technologies*, pp. 931–934, Chengdu, China, August 2003.

[6] J. Hou, P. H. Siegel, L. B. Milstein, and H. D. Pfister, "Capacity-approaching bandwidth-efficient coded modulation schemes based on low-density parity-check codes," *IEEE Transactions on Information Theory*, vol. 49, no. 9, pp. 2141–2155, 2003.
[7] G. Ungerboeck, "Channel coding with multilevel/phase signals," *IEEE Transactions on Information Theory*, vol. 28, no. 1, pp. 55–67, 1982.
[8] S. Y. Le Goff, "Channel capacity of bit-interleaved coded modulation schemes using 8-ary signal constellations," *IEEE Electronics Letters*, vol. 38, no. 4, pp. 187–189, 2002.
[9] P. Li, W. K. Leung, and N. Phamdo, "Low density parity check codes with semi-random parity check matrix," *IEEE Electronics Letters*, vol. 35, no. 1, pp. 38–39, 1999.

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