International Journal of Signal Processing, Image Processing and Pattern Recognition
Vol.9, No.3 (2016), pp.1-10
http://dx.doi.org/10.14257/ijsip.2016.9.3.01

Unequal Error Protection in Image Transmission Based on LDPC Codes

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Abstract

This paper investigates the performance of image transmission with unequal error protection (UEP) schemes based on irregular Low-Density Parity-Check (LDPC) codes. Firstly, the UEP is achieved by mapping different bits of the image bytes to different positions of LDPC codes, i.e. the more important bits in the image are mapped to the variable node with higher degrees in irregular LDPC codes, after the channel coding, we map the information bits into a power efficient QAM constellation and map the parity check bits into a spectral efficiency 16QAM constellation. Simulation results show that the UEP scheme is effective.

Keywords*: unequal error protection (UEP); image transmission; LDPC codes*

1. Introduction

In wireless communication systems, especially in image transmission, the source data can be divided into several parts that have different degrees of significance. Traditional equal error protection approach is usually not the most efficient way to guarantee the transmission quality of the important data. Hence unequal error protection (UEP) is proposed to make the best use of the bandwidth. A practical approach to achieving UEP is based on modulation, for example, Seok-Ho Chang proposed a multilevel UEP system using multiplexed hierarchical quadrature amplitude modulation (QAM) [1]. Another way to achieve UEP is through channel coding with different coding rates. More powerful error-correction codes is applied to the more important data than the less important data [2]. Besides convolutional codes and turbo codes, low-density parity-check (LDPC) codes are now used widely in modern systems including the long term evolution advanced (LTE-A) cellular and DVB-S2 satellite communications standards [3]. Marco Baldi etc. studied the performance of LDPC codes for the Gaussian broadcast channel with confidential messages, they used the error rate as a metric, and proved that two different levels of protection against noise are needed for the public and the secret messages [4]. Carlo Condo etc. proposed a UEP approach by partial superposition transmission, the information sequence is distinguished as two parts, the more important part and the less important part, both of which are coded with binary LDPC codes [5].

In order to provide more efficient UEP, channel coding and modulation can be jointly employed [6], especially for image transmission. In this paper, we consider the modulation and the LDPC codes together to achieve UEP. In an irregular LDPC code, elements with high degree can be more likely decoded, which leads to the inherent UEP of an irregular LDPC code. We are motivated to find an effective method for irregular LDPC codes to achieve successful UEP mapping to meet the requirements of image transmission with different QoS. And we meet this challenge by two means: firstly, a

ISSN: 2005-4254 IJSIP

PEG method is employed to construct weight-increasing parity-check matrix [7], then we map different bits of the image bytes to nodes with different degrees, and the different modulation constellations are used for information bits and parity-check bits.

In the following section, we first give the system model of image transmission based on LDPC codes, and describe the UEP schemes in detail. In Section 3, system performance are achieved through computer simulation, some conclusions are drawn.

2. System Model

The proposed model of image transmission system is shown in Figure 1, we will explain each part in detail.

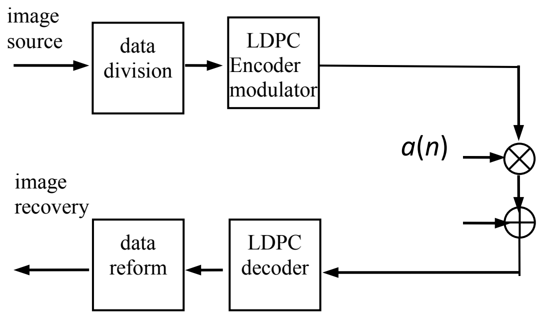


Figure 1. System Model

2.1. Low-Density Parity-Check Codes

LDPC codes are linear block codes, which are defined by very sparse parity-check matrices H. LDPC codes are usually represented by bipartite graphs, and the other set of nodes called check nodes corresponding to the set of parity-check constraints that define the codes. An LDPC code is called regular if every variable node participates in d_v check nodes and every check node involves d_c variable nodes, otherwise it is called irregular.

For an irregular LDPC code, the degrees of each set of nodes are chosen according to some distribution as following description. Given a degree distribution pair (λ, ρ),

$$\lambda(x) = \sum_{i=2}^{d_v} \lambda_i x^{i-1} \quad \rho(x) = \sum_{i=2}^{d_c} \rho_i x^{i-1} \tag{1}$$

Where $\lambda_i(\rho_i)$ is nonnegative and $\lambda(1)(\rho(1))$ equals one, $\lambda_i(\rho_i)$ specifies the variable (check) node degree distribution when the pair is associated to a sequence of code ensembles $C^n(\lambda, \rho)$. More precisely, $\lambda_i(\rho_i)$ represents the fraction of edges emanating from variable (check) nodes of degree *i*. The maximum variable degree and check degree are denoted by d_v and d_c respectively. When it comes to degree *i* in a parity-check matrix, it means the same as column weight *i*, which is defined as the number of nonzero elements in that column of the parity-check matrix.

A lot of research work has been done on searching good degree distribution of irregular LDPC codes, a PEG method was proposed to construct weight increasing irregular LDPC codes which performs better than Mackay's random code, especially for short block length [7].

It is well known that the computational decoding complexity of LDPC codes is very low and is essentially linear with block length n, but its encoding complexity per block increases quadratically by n^2. The most common approach is to exploit the sparseness of the parity-check matrix H to obtain an efficient encoding format, namely, a triangular or almost triangular parity-check matrix. Generally, there are two ways to construct such a matrix. One is straightforward, *i.e.*, building the matrix directly according to the degree distribution. The other is a little different, firstly building the matrix by random based on a certain degree distribution, then reordering the columns to form the weight-increasing matrix from left to right. We adopt the first method using PEG algorithm.

According to the linear-time-encoding principle, the codeword w and the parity-check matrix H are partitioned into w = [p, d] and H = [H^p, H^d], respectively, such that

$$[H^p, H^d]\, w^T = 0 \quad (2)$$

where the m×m component $H^p = \{h^p_{i,j}\}$ of the parity-check matrix is constructed to have the special form

$$H^p = \begin{pmatrix} 1 & h^p_{1,2} & \cdots & \cdots & h^p_{1,m} \\ 0 & 1 & & & \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ & & 0 & 1 & h^p_{m-1,m} \\ 0 & \cdots & 0 & 0 & 1 \end{pmatrix} \quad (3)$$

in which $h_{i,j} = 1$ for i = j and $h_{i,j} = 0$ for i > j. Hence, the parity-check bits p = {p_i} are computed according to

$$p_i = \left(\sum_{j=i+1}^{m} h^p_{i,j} p_j + \sum_{j=1}^{n-m} h^d_{i,j} d_j \right) \bmod 2 \quad (4)$$

where d = {d_i} is the systematic part (information bits) of the codeword, and $H^d = \{h^d_{i,j}\}$ is the $m \times (n-m)$ component of the partitioned parity-check matrix H. Equation (3) is computed recursively from i = m to i = 1. Clearly, the encoding process has become much simpler because the Gaussian elimination step is avoided.

Here is an intuitive explanation for UEP of irregular LDPC codes from Luby. For a variable node, the higher degree it has, the more information it can get from its check nodes, then the more accurately it can judge what its correct value should be, so in the iterative decoding procedure, variable nodes with higher degree will tend to their correct value quickly. These nodes then provide good information to the check nodes, which subsequently provide better information to lower degree variable nodes. As a result, the variable nodes with highest degree will have the opportunity to be more likely corrected in decoding and UEP appears for different bits in a codeword. And for LDPC codes with degree distribution of equation (1), the variable nodes with degree 15 have the strongest error correction ability.

The decoding scheme is performed as follows:

The first step: initialize

$$q_{ij}(0) = 1 - P_i = \Pr(x_i = +1 \mid y_i) = \frac{1}{1 + e^{-2y_i/\sigma^2}}$$
$$q_{ij}(1) = P_i = \Pr(x_i = -1 \mid y_i) = \frac{1}{1 + e^{2y_i/\sigma^2}} \quad (5)$$

The second step: operation on check nodes

$$r_{ji}(0) = \frac{1}{2} + \frac{1}{2} \prod_{i' \in R_{j \setminus i}} (1 - 2q_{i'j}(1))$$
$$r_{ji}(1) = 1 - r_{ji}(0) \quad (6)$$

The third step: operation on variable nodes

$$q_{ij}(0) = K_{ij}(1-P_i)\prod_{j^{'}\in C_{i\setminus j}} r_{j^{'}i}(0)$$
$$q_{ij}(1) = K_{ij}P_i\prod_{j^{'}\in C_{i\setminus j}} r_{j^{'}i}(1) \tag{7}$$

Where the constants K_{ij} are chosen to ensure $q_{ij}(0)+q_{ij}(1)=1$.

The forth step: compute

$$Q_i(0) = K_i(1-P_i)\prod_{j\in C_i} r_{ji}(0)$$
$$Q_i(1) = K_iP_i\prod_{j\in C_i} r_{ji}(1) \tag{8}$$

Where the constants K_i are chosen to ensure $Q_i(0)+Q_i(1)=0$.

The fifth step: make decision according to Q_i

$$\hat{c}_i = \begin{cases} 1 & Q_i(1) > 0.5 \\ 0 & else \end{cases} \tag{9}$$

If $H\hat{c}^T = 0$ or the max-iterations is reached, the decoding process is ended, otherwise go to the step one.

2.2. Principle of UEP

The UEP is realized in three ways, besides the inherent UEP property of irregular LDPC codes mentioned above, the image can be divided into two parts with different significance, which are mapped to LDPC nodes with different degrees. Then in the modulation part after encoding, codewords can also be divided into two parts with different significance, which are mapped to different modulation constellations.

(1) Bit-based Image Division

With the explosive development of wireless applications, image transmission is becoming more and more important, which demand a high transmission quality. In photography and computing, a grayscale image is an image in which the value of each pixel is a single sample, that is, it carries only intensity information. This sort of images is composed exclusively of shades of gray, varying from black at the weakest intensity to white at the strongest. In computing, image pixels are stored in binary, quantized form. Grayscale images intended for visual display are commonly stored with 8 bits per sampled pixel, which allows 256 different intensities (*i.e.*, shades of gray) to be recorded. The binary representations assume that 0 is black and the maximum value (255 at 8 bpp) is white.

Bit-based image division is based on the observation that different bits in one byte (see Figure 2) have different visual effects on the image. Take b_0 and b_7 of a byte of 128 (10000000 in binary format) for example. If b_7 is wrongly transmitted to be “0” instead of “1”, the value of the transmitted byte will be 0 (00000000 in binary format) which denotes a blackest pixel in the 256-ary gray image instead of a gray pixel with the original value 128. On the other hand, if b_0 is wrongly transmitted to be “1” instead of “0”, the value of the transmitted byte will be 129 (10000001 in binary format) which denotes almost the same gray pixel as the original value 128, and there will be no difference in vision between the original image and the recovered image. Hence, bit b_7 is the most important bit in a byte and needs the best transmission protection while bit b_0 is the least important.

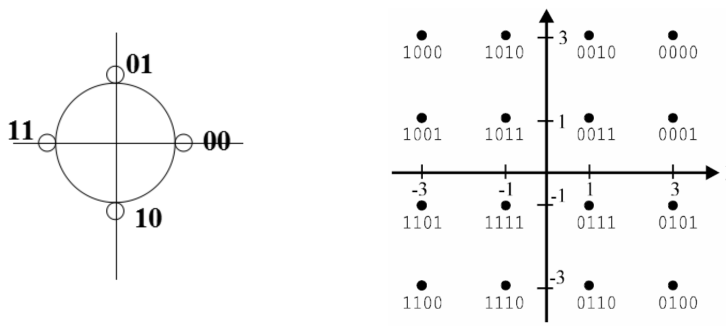
b_7	b_6	b_5	b_4	b_3	b_2	b_1	b_0

Figure 2. Eight Bits of a Byte

In bit-based image division, the whole image is divided into two parts: all b_7 of the bytes are mapped to the variable node with degree 15 in irregular LDPC codes, and other bits of the bytes (b_0 to b_6) are mapped to variable nodes with other degrees (3,4,5). In this way, the UEP of image transmission is achieved.

(2) Bit-based Mapping Strategy

In the LDPC codeword $w = [p, d]$, if we give d and p different protection, for example, give d a more powerful protection than p, that is, we protect the systematic part of the codeword more than the parity-check part, the whole performance of the LDPC code will be enhanced. We can get this unequal error protection by a new mapping strategy, that is, we map the information bits into a power efficient 4QAM constellation, and map the parity-check bits into a more spectral efficient 16QAM constellation, and for gray mapping, 4QAM constellation is a subset of 16QAM, so the new mapping strategy doesn't bring any more complexity than 16QAM [8].



(a) 4QAM mapping (b) 16QAM

Figure 3. Gray Mapping for 4QAM and 16QAM

3. Simulation Results

Through computer simulation, we get the performance of image transmission with UEP through AWGN channel. The irregular LDPC code is constructed by PEG method, the variable node degree distribution is

$$\lambda(x) = 0.47532x^2 + 0.279537x^3 + 0.0348572x^4 + 0.108891x^5 + 0.101285x^{15} \qquad (10)$$

the code length is 1008, and the code rate is 0.5.

Firstly, we examine the inherent UEP property of irregular LDPC codes, figure 4 gives the BER performance of different variable node degrees, we can see that the error-correcting ability for bits with higher degree is also stronger, which can then provide better protection to the important bits of the transmitted image. If we map the information bits to nodes with higher degrees and the parity-check bits to nodes with lower degrees, the method of UEP1 is achieved.

Secondly, we simulate an irregular LDPC code with the new mapping strategy, which we called UEP2, with n = 1008, m = 504, simulation results are presented over AWGN channels. With the code we chosen, the first 504 bits in a codeword will be the information bits and these bits will be 4QAM modulated, and the last 504 bits (parity-check bits) will be 16QAM modulated, which we called new mapping. Figure 5 gives the BER performance of different mapping strategies, it is clear that the BER performance of new mapping strategy is worse than 4QAM, but its spectral efficiency is

3bps/Hz, much higher than 4QAM (2bps/Hz). Compared with 16QAM, the BER performance of new mapping strategy is much better, but its spectral efficiency is lower than 16QAM. The advantage of our new mapping strategy is that when compared with 8PSK having the same spectral efficiency, it can provide a better BER performance. When BER=10^{-4}, the new mapping strategy has about 1.2dB performance gain than 8PSK.

Finally, considering the different importance of bits in image bytes, we combine UEP1 with UEP2 together to get UEP3. As analyzed in Section 2, in image transmission with UEP, image data are divided by unit of bit, the most important bits are mapped to variable nodes with highest degree, and the information bits are modulated with 4QAM.The simulation results are given in Figure 6, where 8PSK is used in UEP1.

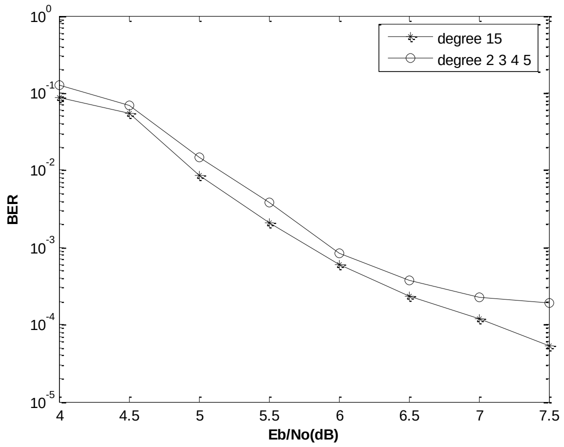


Figure 4. Performance of LDPC Nodes with Different Degrees

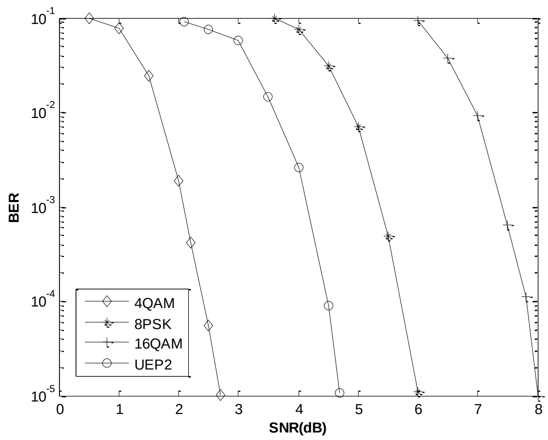


Figure 5. Performance of Irregular LDPC Codes with Different Mapping Strategy in AWGN Channel

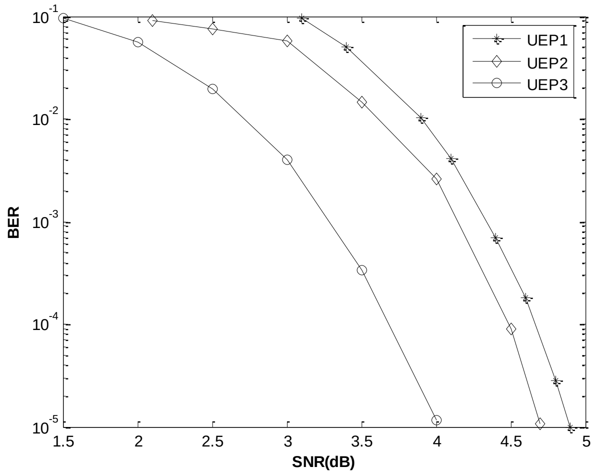


Figure 6. Performance of Irregular LDPC Codes with Different UEP Methods

In order to measure the transmission quality of the image, we compare the peak signal-to-noise ratio (PSNR) of original image and the reconstructed image.PSNR is an approximation to human perception of reconstruction quality. A higher PSNR generally indicates that the reconstruction is of higher quality, it is most easily defined via the mean squared error (MSE). Given a noise-free m×n monochrome image g and its noisy approximation $\hat{g}$, MSE is defined as[9]:

$$MSE = \frac{1}{mn}\sum_{Y}\sum_{X}\left[g(x,y) - \hat{g}(x,y)\right]^2 \tag{11}$$

Here *m*=256 and *n*=256. The PSNR (in dB) is defined as:

$$PSNR = 10\lg\frac{MAX_I^2}{MSE} \tag{12}$$

where MAX_I is the maximum possible pixel value of the image. When the pixels are represented using 8 bits per sample, MAX_I is 255.

The comparison of the PSNR values between image transmission with UEP and without UEP is shown in Figure 7. We can see that PSNR values of image transmission with UEP are much higher than that of without UEP. There's about 4dB gain of PSNR value at whole Eb/No range.

The advantage of image transmission with UEP can better be illustrated by the recovered images directly, as shown in Figure 8, the system is considered at Eb/N_0=4dB. It is clear that with UEP methods, the recovered image quality is better.

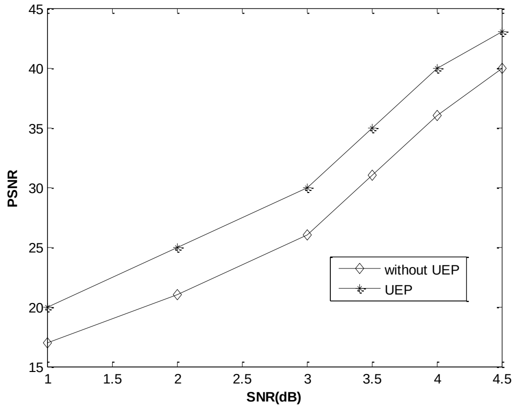
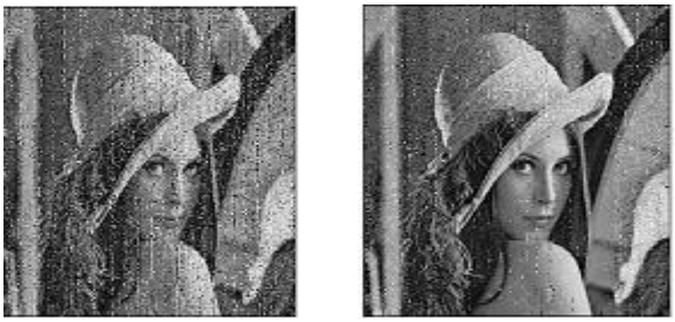


Figure 7. PSNR Comparison between Image Transmission with UEP3 and without UEP



without UEP UEP3

Figure 8. Recovered Images at Eb/N0=4dB

4. Conclusion

This paper proposes a method for image transmission with UEP implementation by irregular LDPC codes. Firstly, the image are divided into more important part and less important part according to different bits in bytes, then we explore the inherent UEP property of irregular LDPC codes and propose a new mapping strategy, the important bits are mapped to nodes with higher degrees in LDPC codes and modulated into more powerful modulation constellation. Through computer simulation, we give the numerical results, which we can see clearly that the transmission quality with UEP is better than that without UEP.

Acknowledgment

This work is supported by National Scientific Foundation of China (No. 61273152, No.61471185) and Scientific Foundation of Shandong Province (No. ZR2013FL007).

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