Performance Analysis of Raptor Codes in Mobile WiMax using FEC scheme

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Abstract- The physical layer of Mobile WiMAX (IEEE 802.1e-2005) is equipped with several Forward Error Correction (FEC) coding schemes, because to facilitate efficient and reliable delivery of information. Information may be any sequence of data or digital image. In this paper, we investigate the performance of raptor codes in the IEEE 802.16e-2005 physical layer for image transmission, employing different rate Low Density Parity Check (LDPC) code class described in the standard pre-codes. The simulation study is made with processing a black and white (monochrome) digital image under AWGN channel. The result obtained showed that the performance of raptor codes is better compared to LDPC codes over the Additive White Gaussian Noise (AWGN) channel.

Keywords- *WiMAX, Raptor codes, Low Density Parity Check (LDPC) Codes, Additive White Guassian Noise (AWGN), Belief Propagation (BP).*

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I. INTRODUCTION

The rapid growth of wireless internet causes a demand for high-speed access to the World Wide Web. To serve the demand for access to the internet "anywhere any time" and ensure quality of service, the broadband working group brought out a new broadband wireless access technology called WiMAX. WiMAX (Worldwide Interoperability for Microwave Access), or IEEE 802.16 is a communications standard that provides for the wireless transmission of information in a variety of ways, ranging from a point-to-point (P2P) link to full mobile cellular-type access. It enables the delivery of last mile broadband wireless access (BWA) as a replacement for wire-line broadband access technologies such as the traditional cable and Digital Subscriber Line (DSL) .The first version of the IEEE 802.16 standard operates in the 10-66 GHz frequency band and requires Line Of Sight (LOS) towers. This is otherwise known as fixed WiMAX or IEEE 802.16- 2004[1] . The incorporation of mobility support into the fixed WiMAX architecture evolved into mobile WiMAX or IEEE 802.16e-2005 enabling Non Line Of Sight (NLOS). Mobile WiMAX, which is considered in the current study, is based on Scalable Orthogonal Frequency Division Multiple Access (SOFDM) for optimum allocation of communication resources in both the time and frequency domains, and is designed to operate in 2-11 GHz frequency range [2]. Moreover, in order to facilitate efficient and reliable dissemination of information, the physical layer of mobile WiMAX is equipped with several forward error correction coding schemes. These include Convolution Codes (CC), Reed-Solomon codes (RS), Block Turbo Codes (BTC), Convolution Turbo Codes (CTC) and Low Density Parity Check (LDPC) codes.

Raptor codes are a significant theoretical and practical improvement over LT codes, which were the first practical class of fountain codes. Raptor codes combine the concatenated coding paradigm with that of iterative decoding to generate code with good asymptotic performance [3], Raptor codes are not part of the mobile WiMAX specification, but due to their attractive properties such as linear time encoding and decoding, excellent performance on channels with unknown statistics, and near-Shannon capacity approaching performance over the erasure channel model, we intend to investigate their performance in the mobile WiMAX physical layer over the AWGN channel. The variable rates raptor codes are achieved by employing the two different rates quasi-cyclic LDPC code categories specified in the mobile WiMAX profile as inner codes or pre-codes. These codes are sometimes called WiMAX LDPC codes. This paper extends the study to all the WiMAX LDPC code classes over the AWGN channel.

II. RAPTOR CODES CONSTRUCTION

Raptor codes are formed by concatenation of two codes, a pre-code or outer code and a inner code. Further, raptor codes can be viewed as a refinement of concatenated coding techniques in which a k-input vector $u = (u_1; u_2; : : : ; u_k)$ to be transmitted over a noisy channel is first pre-coded with a high rate traditional error correction code to generate $s = (s_1; s_2; : : : ; s_L)$ intermediate coded bits or code-words of length L. Thereafter, an appropriate Luby Transform (LT) code, the first practical realization of digital Fountain codes, is applied to generate a limitless stream of output symbols $z = z_1; z_2; : : : ;1$.The LT component code defines the rateless characteristic of the resulting raptor codes.

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A. The IEEE 802.16e Low Density Parity-Check Codes

Low density parity-check (LDPC) codes are linear block codes first discovered by Gallager [5]. They have been demonstrated to approach within a small fraction of a decibel from the capacity of most communications channels. As a result of their performance, LDPC codes have been adopted as a forward error correction (FEC) code in a number of emerging wireless technologies such as the IEEE 802.16e-2005, IEEE 802.16e standard defines six different LDPC code categories in its physical layer profile. LDPC codes are defined by a sparse parity-check matrix H, that is, a matrix with a low density of non-zero elements. Tanner graphs are often used to represent the parity-check matrix, and also illustrate the functionality of the decoding algorithm . A Tanner graph is a bipartite graph with two sets of nodes (variable and check nodes), in which undirected edges connect two nodes residing in different set.

LPDC codes are known to possess a high encoding complexity. However, the performance of these codes depends mostly on the structure of the parity-check matrix **H**. These codes are characterized with four rates ranging from 1/2 to 5/6. In general, the structure of the parity-check matrix H is quasi-cyclic. It consists of 24 columns and (1 □ R) _ 24 rows, where R represents the code rate. The first R_24 columns represent the systematic information while the remaining (1 □ R) _ 24 columns represent the redundancy or parity bits.

B. Luby Transform (LT) Encoder

A Luby transform encoder can be considered as a mapping of the L input vector (intermediate coded bits) s = (s_1; s_2; : : : ; s_L) into a limitless stream of encoded symbols z = (z_1; z_2; : : : ; z_W), where W = (1+_) _L, and _ is referred to as the code overhead. The code overhead determines the amount of redundancy needed for successful decoding of the input bits. The encoded symbols are generated by performing an exclusive-OR operation on a set of d distinct input bits, selected uniformly at random based on a redefined distribution. This distribution can either be the Robust Soliton distribution (RBS) [6] or the optimized degree distribution described in [4]. In this paper, we employ the optimized degree distribution defined as

Ω(x) =0:007969x + 0:493570x2 + 0:166220x3 + 0:072646x4
+ 0:082558x5 + 0:056058x8 + 0:037229x9
+ 0:055590x19 + 0:025023x65 + 0:0003135x66 (1)

Analogous to irregular low density generator matrix (LDGM) codes, the relationship between the input symbols and encoded symbols can be illustrated graphically with a factor graph or a Tanner graph, in which the input symbols and the encoded outputs represent the variable and check nodes, respectively the Tanner graph of the resulting LT codes is shown in Figure 1.

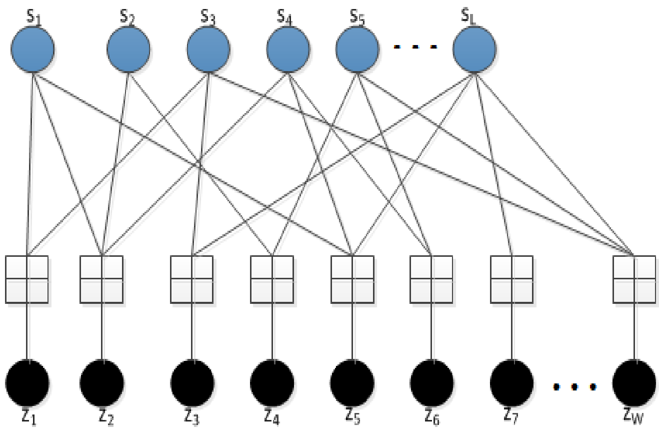

Figure 1. Tanner graph illustration of LT encoder

Additionally, the encoding relationship can be used to construct a generator matrix G, similar to the parity check matrix H of an irregular LDPC code, in which therows of G are associated with the encoded symbols. The nonzero elements of G represent the indices of the input bits that participated in the generation of the encoded symbols. The generator matrix G is a W _ L matrix, thus for the above illustration, G is defined as:

$$\mathbf{G} = \begin{bmatrix} 1 & 0 & 1 & 0 & 0 & \dots & 0 \\ 1 & 1 & 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & 1 & 0 & 0 & \dots & 1 \\ 0 & 1 & 0 & 0 & 1 & \dots & 0 \\ 1 & 0 & 0 & 1 & 0 & \dots & 1 \\ 0 & 0 & 0 & 1 & 1 & \dots & 0 \\ 0 & 0 & 0 & 0 & 0 & \dots & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 1 & 0 & 1 & \dots & 1 \end{bmatrix} \quad (2)$$

Therefore, the encoding operation can be obtained by matrix multiplication as follows:

$$z = \mathbf{G}.s \quad (3)$$

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C. Iterative Decoding of Raptor Codes

The algorithms employ in the decoding of raptor codes over a noisy channel are based on Belief Propagation (BP). BP operates iteratively by exchanging bidirectional real-valued messages among the nodes that constitute the decoding graph for each of the codes (i.e. variable and check nodes in LDPC, input and output nodes in LT codes). Since the BP decoding algorithms operate in a similar manner for both codes, here, for convenience, we concentrate on the description of the BP algorithm employed in the decoding of the LT component code of a raptor code. Prior to the decoding operation, the LT decoder is presented with the channel received information, which is obtained in the form of the log-likelihood ratio (LLR), the generator matrix that is utilized in the formation of the encoded symbols and its graphical representation (Tanner graph), and a termination criterion (such as convergence of the algorithm or a maximum number of iterations). Suppose $r^W = (r_1; r_2; : : : ;W)$ is the received sequence up to time W, where for every n € (1; 2; : : : ;W), r_n is the channel output for the encoded symbols z_n [7]. The channel LLR representing each of the encoded symbols z_n, denoted by λ_{ch}, can be defined as

$$\lambda_{ch} = \log\left(\frac{Pr(z_n = 0 \mid r_n)}{Pr(z_n = 1 \mid r_n)}\right) \tag{4}$$

For the AWGN channel, the channel LLR is expressed as

$$\lambda_{ch} = 2r_n/\sigma^2 \tag{5}$$

Where σ^2 is the channel variance. In each iteration of the algorithm, messages are exchanged between the input nodes and the output nodes. Let's represent the message sent from output node z_n to input node s_m in iteration ρ as $\Lambda^{\rho}_{n\to m}$, and $\Lambda^{\rho}_{m\to n}$ represent the message sent from input node s_m to output node z_n in ρ iteration. Also, let N(a) represent the set of adjacent nodes to a certain node a. At iteration 0 of the algorithm, all the output nodes pass 0 message value to all their adjacent input nodes. At subsequent iterations, the message sent from the output node z_n to input node s_m is updated using equation (6)

$$\Lambda^{\rho}_{n\to m} = 2\tanh\left(\tanh(\frac{\lambda_{ch}}{2}) \prod_{s_{m'}\in\mathcal{N}(z_n)\setminus\{s_m\}} \tanh(\Lambda^{(\rho-1)}_{m'\to n})\right) \tag{6}$$

(6)

The message sent from input node sm to output node zn is updated using equation (7):

$$\Lambda^{(\rho)}_{m\to n} = \sum_{z_{n'}\in\mathcal{N}(s_m)\setminus\{z_n\}} \Lambda^{\rho}_{n'\to m} \tag{7}$$

Hereafter, the summary messages at every input nodes are computed as (8), after a predefined criterion has been fulfilled:

$$\Lambda_m = \sum_{z_n\in\mathcal{N}(s_m)} \Lambda^{\rho}_{n\to m} \tag{8}$$

III. SYSTEM MODEL

The implementation model for IEEE 802.16e is as shown in figure 2. This corresponds to the physical layer of WiMAX, in which FEC coding is equipped. FEC techniques typically use error-correcting codes which can detect error location with high probability.

Figure 2 illustrates the physical layer architecture of a mobile WiMAX system. At the transmitter end of the model, the source information i.e. B/W image is first randomized to avoid long sequences of consecutive ones or zeros. Thereafter, the randomized information is passed through an LDPC encoder, which generates the intermediate sequence that is used by the LT encoder to generate the encoded symbols. An interleaver is not considered in this implementation, since doing so amount to permuting the columns of the LDPC parity-check matrix .Likewise, a de-interleaver is omitted between the two decoders. The resulting output of the raptor encoder is mapped into Quadrature Phase Shift Keying (QPSK) modulation constellations. Then, the output of the symbol mapper is passed into the OFDM modulator, which transforms the symbols from frequency domain to time domain through the Inverse Fast Fourier Transform (IFFT). In the initial part of the OFDM modulator, the resultant symbol stream from the mapper is first converted from serial to parallel prior to the application of N-point IFFT. A cyclic prefix is appended to the signal from the OFDM modulator before being transmitted over the channel.

At the receiver side, the ultimate goal is to be able to reconstruct the source information with minimum probability of error as a result of the channel imperfection. To achieve this goal, first the cyclic prefix is removed from the corrupted received signal, and then an N-point Fast Fourier Transform (FFT) is applied to transform the signal sample back to the frequency domain by the OFDM demodulator. Later the signal is de-mapped and the LT belief propagation decoding algorithm is applied to the resulting LLR form the de-mapper. Therafter, the second level of decoding is accomplished through the LDPC decoder, which is another version of the BP algorithm. In order to generate an estimate of the source information, the Raptor code utilizes the LLR information. Finally the performance of coding scheme is evaluated using the Bit Error Rate (BER) metric

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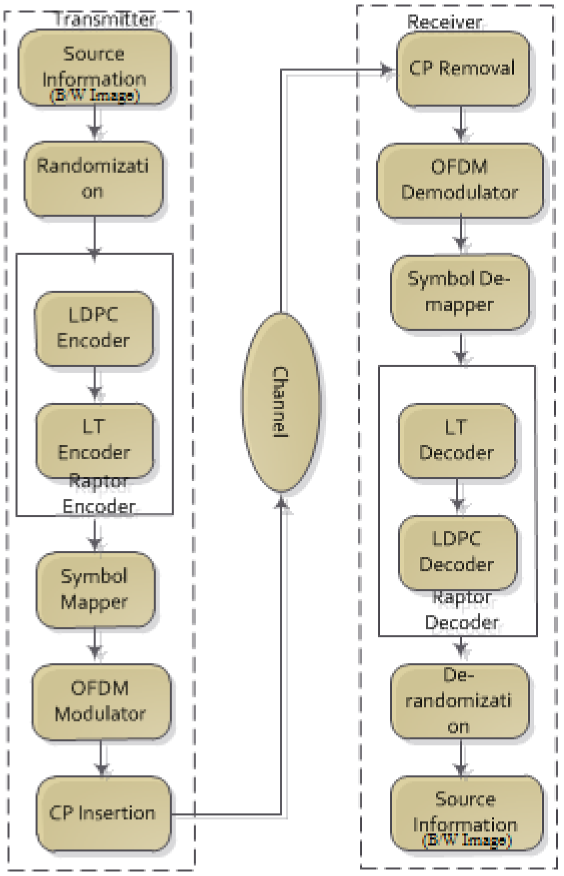

Figure 2. Implementation model for the IEEE 802.16e System [2]

IV. SIMULATION RESULTS

In this paper, we have simulated and compared the variable rates Raptor codes produced through the four different rates LDPC code classes specified in the mobile WiMAX PHY profile as forward error correcting scheme. Figure 3 shows the image which is used as source information to be transmitted and the image obtained at receiver. And the implementation is aimed at comparing the performance of each of the LDPC code rates with that of the raptor codes generated from them in mobile WiMAX with QPSK modulation over the AWGN channel. This section presents the results obtained from the implementation. The four different rates LDPC codes are characterized with rates 1/2, 2/3A, 3/4A and 5/6. The variable rates Raptor codes were achieved using the relation W = (1+_)N, in which _ is considered to be equal to 0.2. As a result, the code rates for the LT codes are held constant at approximately 5/6 while the varying rates of the Raptor codes were achieved through their pre-codes. Table I shows all the code rates together with the OFDM parameters utilized in carrying out the simulation. As explained earlier, both codes were decoded using the BP algorithms. All the LDPC codes considered were decoded within 10 iterations of the algorithm, whereas the decoding iterations in Raptor codes vary with the code rate as a result of the LT decoder complexity. As the rate decreases, the decoding complexity increases. For instance, the rate 5/12 code was decoded using 80 iterations while the rate 25/36 was decoded within 50 iterations of the algorithm.

TABLE I
SIMULATION PARAMETERS

Simulation Parameter	
WiMAX LDPC code Rates	1/2 2/3A 3/4B 5/6
Raptor Codes Rates	5/12 5/9 5/8 25/36
Modulation	QPSK
Channel Model	AWGN

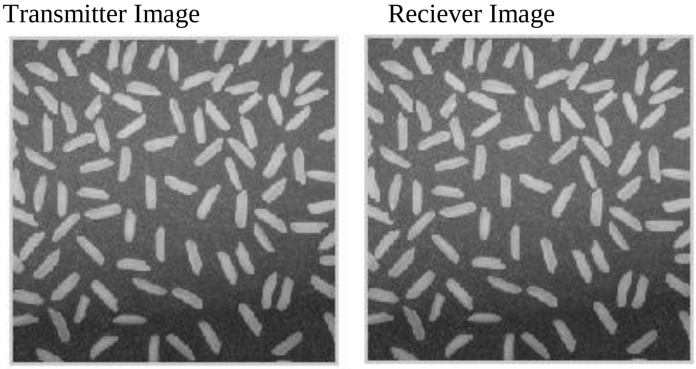

Figure 3. B/W Digital image

For each of the simulations, a Bit Error rate (BER) versus Energy per bit to noise power spectral density ratio (Eb/N0) curve was obtained using MATLAB. The BER versus Eb/N0 performance for the four LDPC code rates with QPSK modulation is depicted in Figure 4. As illustrated in the figure, at a BER of 10^{-4}, the coding gains of approximately 6.8 dB, 5.4 dB, 4.5 dB, and 3.5 dB can be achieved with each of the LDPC codes with respect to the uncoded mobile WiMAX with QPSK modulation. Moreover, Figure 5 demonstrates the BER versus Eb/N0 performance for the variable rates Raptor codes with QPSK modulation. Also, at a BER of $10^{\square 4}$, the approximate coding gains for the variable rates Raptor codes with respect to the uncoded mobile WiMAX are 7.4 dB, 6.4 dB, 5.4 dB, and 4.6 dB, respectively.

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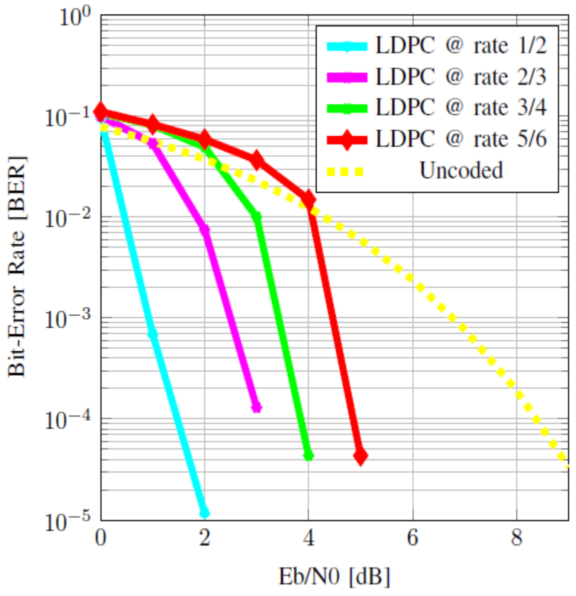

Figure 4. BER performance of the four LDPC code classes in mobile WiMAX with QPSK modulation

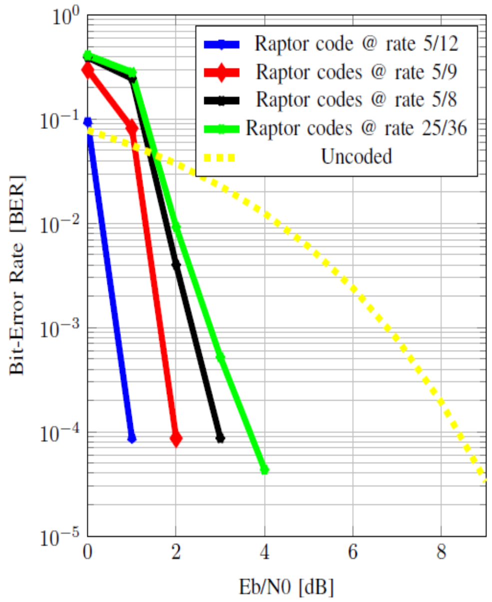

Figure 5. BER performance of the variable rates Raptor codes in mobile WiMAX with QPSK modulation

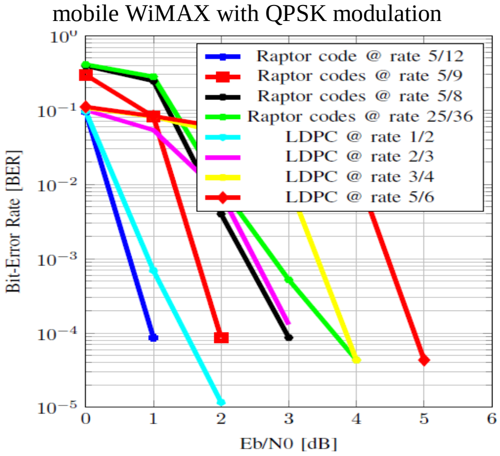

Figure 6. BER performance comparison of the four LDPC code rates with the variable rates Raptor codes in mobile WiMAX with QPSK modulation.

Figure 6 compares the error performance of the four LDPC code rates with that of the variable rates Raptor codes. From the figure, it is evident that Raptor codes generated from any of the WiMAX LDPC code classes show superior performance compared to the corresponding LDPC component code.

V. CONCLUSION

This paper has compared the performance of variable rates Raptor codes with that of the four different rates LDPC code categories specified in the mobile WiMAX PHY profile. Although the decoding complexity of Raptor codes is slightly higher than that of the LDPC codes, better performance can be achieved in terms of coding gains and proximity to the Shannon's capacity limit for an AWGN channel. As a result it may be concluded that Raptor codes can be used in digital image transmission over AWGN and due to their superior performance, raptor codes can potentially be incorporated into mobile WiMAX as a forward error correction code.

REFERENCES

[1]. IEEE Std 802.16-2004, *Standard for Local and Metropolitan area networks, Part 16: Air Interface Fixed* Broadband *Wireless Access Systems*, October 2004.

[2]. IEEE 802.16, *IEEE Standard for Local and Mertopolitan area networks, Part 16: Air Interface Fixed Broadband Wireless Access Systems*, May 2009.

[3]. A. Shokrollahi, "*Raptor codes*," IEEE Transactions on Information Theory, vol. 52, no. 6, pp. 2551–2567, Jun. 2006.

[4]. M. Luby, *"LT codes*," in Proceedings of the 43rd Symposium on Foundations of Computer Science, ser. FOCS '02. Washington, DC, USA: IEEE Computer Society, 2002, pp. 271–280.

[5]. R. Gallager, "*Low-density parity-check codes*," IRE Transaction on Information Theory, IT-8, pp. 21–28, 1962.

[6]. D. J. C. MacKay and R. M. Neal, "*Near shannon limit performance of low density parity check codes,"* Electronics Letters, vol. 32, no. 18, 1996.

[7]. Z. Cheng, J. Castura, and Y. Mao, *"On the design of raptor codes for binary-input gaussian channels,"* IEEE Trans. Commun., vol. 57, no. 11, pp. 3269–3277, 2009.