Comparing the BER Performance of WiMAX System by Using Different Concatenated Channel Coding Techniques under AWGN, Rayleigh and Rician Fading Channels

Rekha S.M, Manoj P.B

Abstract— WiMAX (Worldwide Interoperability for Microwave Access) has the capability to transmit the data to a greater extent with very high speed. Application of forward error correction codes (Reed-Solomon (RS), convolution codes (CC) and Low Density Parity Check codes (LDPC)) with WiMAX system ensures the reliability and efficiency of the system. Concatenated RS-LDPC and RS-CC codes will help to improve the performance of the WiMAX system. In this paper the system performance evaluation is performed by transmitting an image under different fading channels (Additive White Gaussian Noise (AWGN), Rayleigh and Rician). Comparison of two concatenated coding techniques is done by calculating the probability of Bit Error Rate (BER) for various values of Signal to Noise Ratio (SNR). The simulation results show that use of RS-LDPC with WiMAX gives better performance than RS-CC.

Index Terms: WiMAX, RS, CC, LDPC, AWGN, Rayleigh, Ricean.

I. INTRODUCTION

In recent year the need of wireless data transmission has grown tremendously with a high speed wireless data access i.e. in Mbps, with fewer errors to a very long distance. In order to fulfill the user needs WiMAX communication system is used. WiMAX is an upcoming 4G wireless data transmission technique cover a data range of up to 50Km, and provides a data rate of 70Mbps. Non Line of Sight (LOS) connection is also possible using WiMAX. High bit error rates of wireless communication system require employing forward error correction (FEC) methods on the data transferred in order to avoid burst errors that occur in physical channel. The FEC codes like RS, CC, LDPC can be applied independently or they can be concatenated together to provide a more efficient system with minimum bit error rate (BER). During transmission the noise (AWGN) may be added to the data or the data may suffer from fading (Rayleigh and Rician). The physical layer of WiMAX has been implemented in MATLAB.

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II. METHODOLOGY

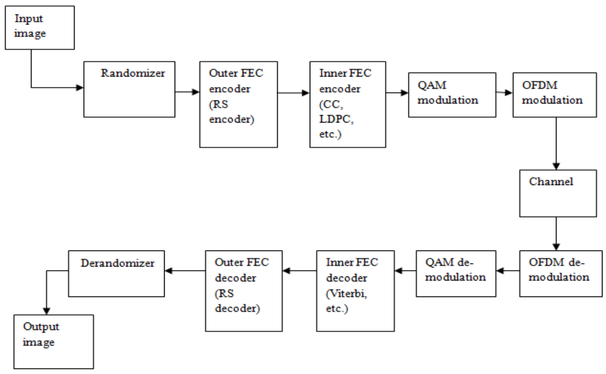

Fig. 1 Block diagram of WiMAX system

A 256 x 256 image is taken as input and applied to randomizer block. Output of the randomizer is encoded using the concatenated coding techniques before transmitting it through the channel. The output of the encoder is applied to the OFDM process as the physical layer of the WiMAX is made up of OFDM. In OFDM process the in phase and quadrature phase components of the symbols will undergo through the process of Inverse Fast Fourier Transform (IFFT) so that the requirement of effective bandwidth can be made approximately half without any Inter Symbol interference (ISI). The reverse operation is applied at the receiver side to reconstruct the image. BER values are compared for RS-LDPC and RS-CC codes.

III. IEEE 802.16/WIMAX TECHNOLOGY

WiMAX is wireless broadband solution based on the IEEE 802.16 standard. WiMAX offers rich features with a lot of flexibility in terms of deployment options and potential service offerings. Some of the salient features of WiMAX are:

- The physical layer is based on OFDM, which offers a good resistance to multipath, and allows WiMAX to operate in NLOS conditions.
- WiMAX supports a very high data rate up to 70Mbps.
- The data rate is scalable with the channel bandwidth in WiMAX physical layer architecture.
- WiMAX supports a number of modulations and forward error correction (FEC) coding schemes.
- Supports for Time Division Multiplexing (TDD) and frequency Division multiplexing (FDD).

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WiMAX is designed to supports a variety of applications, including voice and multimedia services.

IV. FADING CHANNELS

Fading is the result of multipath structure of the signal components, i.e. the signal components take different paths to reach towards the receiver. The actual received signal at the receiver is the vector sum of all the signals. In multipath, some signals add the direct path and some others subtract it. There are two types of fading; a) Large scale fading and b) small scale fading Rayleigh, Rician and AWGN are most widely used fading channels which come under the category of small scale fading.

A. Rayleigh Fading Channel

The multipath propagation of the signal will cause the Rayleigh fading [1], because of the infrequent availability of the line of sight path in between the transmitter and receiver in urban areas, Rayleigh channel modeling [2] is the best choice to model the WiMAX system. The probability density function (pdf) of Rayleigh model is given by:

$$f_{ray}(r) = \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right), r \geq 0$$

Where, r is a random variable. Here σ^2 is the variance of the in-phase and quadrature components. Theoretical considerations indicate that the sum of such signals will result in the amplitude having the Rayleigh distribution of the above equation. The phase of the complex envelope of the received signal is normally assumed to be uniformly distributed in $[0,2\pi]$.

B. Ricean fading model

In metropolitan areas where there would be a possibility of having at least one line of sight path along with multipath structure, the wireless channel can be modeled as the Ricean channel. Here the multipath variations of the signals are superimposed over the line of sight component which increases the overall strength of the whole information at the receiver. The pdf of such function is given by:

$$f_{ric}(r) = \frac{r}{\sigma^2} exp\left(\frac{-(r^2 + A^2)}{2\sigma^2}\right) I_0\left(\frac{Ar}{\sigma^2}\right), r \geq 0, A \geq 0$$

Where, σ_2 is the variance of the in-phase and quadrature components. A is the amplitude of the signal of the leading path and I_0 is the zero-order modified Bessel function. Normally the dominant path significantly reduces the depth of fading, and in terms of BER Rician fading provides superior performance to Rayleigh fading. If there is no dominant path then the Rician pdf reduces to Rayleigh pdf. When $A > \sigma$, the distribution is approximately Gaussian.

C. AWGN Channel

For the simulation purpose, the communication medium is considered to be suitable for long distance system wherein average fading is assumed to be constant throughout the path. To characterize the above system, the channel has been modeled as an additive white Gaussian noise (AWGN) channel. This is the simplest type of channel that is having the noise distribution with a constant power spectral density with Gaussian nature of (probability density function) PDF over the whole channel bandwidth. [3]

V. BER AND SNR

The BER, or quality of the system, is calculated from the number of bits received in error divided by the number of bits transmitted.

BER= (Bits in Error) / (Total bits transmitted).

BER is a unit less performance measure, often expressed as a percentage. BER performance is affected by noise and quantization errors. SNR is the ratio of the received signal strength over the noise strength in the frequency range of the operation. It is an important parameter of the physical layer of WiMAX. BER is inversely related to SNR, that is high BER causes low SNR. Signal to noise ratio (SNR) is an indicator commonly used to evaluate the quality of a communication link and measured in decibels and represented by equation.

SNR = 10 $\log_{10}$ (Signal Power / Noise Power) dB.

VI. CODING TECHNIQUES

A. Reed Solomon (RS) Code

Due to the fading nature of the wireless channel, the errors usually occur in busty manner. But, most of the existing channel codes are not good enough to correct the burst errors. As most of the errors in real time traffic in wireless environment are bust in nature and RS codes are found to be most efficient in correcting burst errors. RS codes are able to recover from errors more quickly. The use of RS codes will significantly reduce the number of retransmissions.

Reed-Solomon codes are block based error correcting codes with a wide range of applications in digital communications and storage. The fig.2 shows RS encoder and decoder system block diagram.

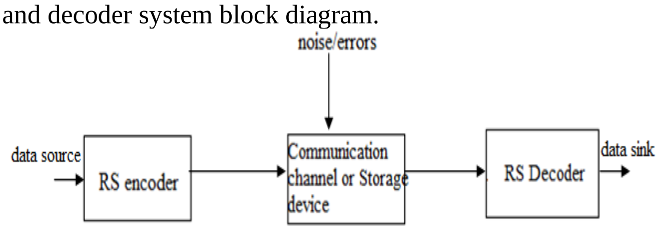

Fig. 2 RS encoder and decoder system

In RS encoder block the redundant bits are added to the block of data. Errors occur during transmission or storage for a number of reasons (for example noise, scratches on a CD, etc). The Reed-Solomon decoder processes each block and attempts to correct errors and recover the original data. The characteristics of the RS code affect the number and type of errors that can be corrected.

B. Convolutional Code

The convolutional coding technique is designed to reduce the probability of erroneous transmission over noisy communication channels. The most popular decoding algorithm for convolutional codes is perhaps the Viterbi algorithm. Although widely adopted in practice, the Viterbi algorithm suffers from a high decoding complexity for convolutional codes with long constraint lengths. While the attainable decoding failure probability of convolutional codes generally decays exponentially with the code constraint length, the high complexity of the Viterbi decoder for codes with a long constraint length to some extent limits the achievable system performance.

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C. LDPC Code

LDPC code is a kind of block codes that exhibit near Shannon limit performance. It was first introduced by Gallager in his thesis in 1960' and rediscovered by D. J. C. Mackay [4]. Iterative decoding method is adopted in this paper. Here are some notations in the algorithm: R_j= the set of column locations of 1's in the j^{th} row; Rj\i= the set of column locations of the 1's in the jth row excluding location i; C_i= the set of row locations of the 1's in the i^{th} column; Ci\j= the set of row locations of the 1's in the ith column excluding location j; $r_{ji}(b)$ = the probability of the jth check equation being satisfied given bit c_i= b and the other bits have distribution given by $\{q_{ij}\}j'\neq j$; $q_{ij}(b)$ = probability that c_i= b given extrinsic information from all check nodes except the jth node. The algorithm iterates back and forth between $\{q_{ij}\}$ and $\{r_{ji}\}$ using formulas given below.

$$r_{ij}(0) = \frac{1}{2} + \frac{1}{2}\prod_{i' \in j \backslash i}(1 - 2q_{i'j}(1))$$

$$r_{ij}(1) = r_{ij}(0)$$

$$q_{ij}(0) = K_{ij}(1 - P_i)\prod_{j' \in C_i \backslash j} r_{j'i}(0)$$

$$q_{ij}(1) = K_{ij}P_i\prod_{j' \in C_i \backslash j} r_{j'i}(1)$$

In equation shown below P_i is the probability that the i^{th} bit is 1. $Q(\{q_{ij}\})$ was initialized to $P(\{P_i\})$ to complete the iteration loop. In 16QAM modulation there is a different method to compute P_i. At first, we compute the received symbol probability conditioned on the transmitted symbol.

$$p(c_i = 1) = \sum_{x: x_i = 1} P(y|x)P(x)$$

$$p(y_k|x_k) = \frac{1}{\sqrt{2\pi}\sqrt{No/2}}$$

Where P (C_i=1) is the probability of the i^{th} bit in the symbol x is 1 and P(x) is a priori probability of symbol x for which the i^{th} bit is 1.

VII. CODE CONCATENATION

Code Concatenation [5] is used to avoid the decoding complexity (and hence cost) of long codes. In concatenation, two codes are combined together to achieve the performance level of a long code without the corresponding increase in hardware complexity normally expected of a code of that length [6]. Since RS, CC, LDPC codes have different error correcting capabilities, the combination of these codes can correct both random and burst errors. Thus in concatenation, the digital signal is subjected to two encoding operations before being transmitted over some channel. The first encoding is usually performed using a non-binary code and the result is then passed to a second encoder which encodes via a binary code.

VIII. RESULT

The simulation results are tabulated as shown in the Table. 1below. The table shows that RS-LDPC codes will give better results than RS-CC codes.

Table. 1 Tabulation of BER values for different values of SNR

SNR (dB)	AWGN(BER)		Rayleigh(BER)		Rician(BER)	
	RS-CC	RS-LDPC	RS-CC	RS-LDPC	RS-CC	RS-LDPC
1	0.46291	0	0.4858	0.18562	0.46683	0.015442
3	0.42939	0	0.48573	0.12933	0.43684	0.0026687
5	0.35902	0	0.4868	0.033791	0.3841	0
7	0.24347	0	0.48812	0	0.29622	0
10	0.015226	0	0.48728	0	0.1334	0
12	0	0	0.48934	0	0.003987 6	0
15	0	0	0.48821	0	0	0

A. Simulation results for AWGN Channel

BERs are calculated for different values of SNRs. The snapshots for various values of SNR are as shown in the Fig.3 to Fig.5. WiMAX system with RS-CC can recover the image at SNR= 15dB. But by replacing the RS-CC with RS-LDPC, the system recovers the image at SNR=1dB. Also the BER values are very high when RS-CC is used with WiMAX system. So for long distance communications the use of RS-LDPC codes with WiMAX gives better results.

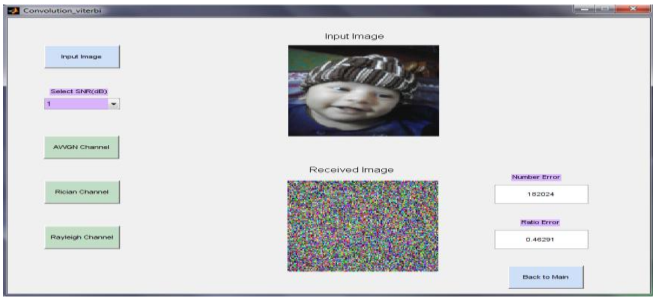

Fig. 3 Snapshot of simulation under an AWGN Channel for SNR=1dB for RS-CC code

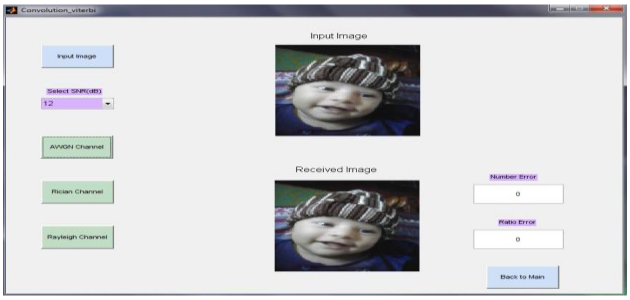

Fig. 4 Snapshot of simulation under an AWGN Channel for SNR=12dB for RS-CC code

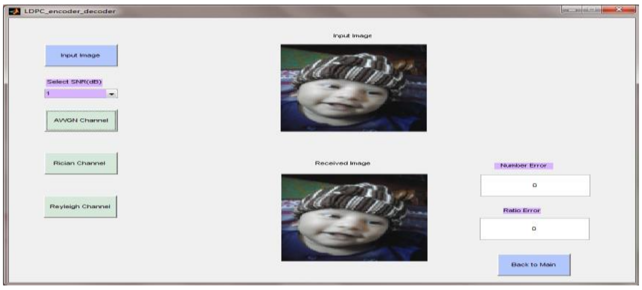

Fig. 5 Snapshot of simulation under an AWGN Channel for SNR=1dB for RS-LDPC code

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B. Simulation results for Rayleigh Channel

Rayleigh channel has the higher BER than AWGN and Rician channels. Fig.6 and Fig.7 shows the simulation results of WiMAX system under Rayleigh fading channel for different values of SNRs. Using RS-CC codes with WiMAX needs higher values of SNR to recover the image. But the application of RS-LDPC codes with WiMAX can recover the image at SNR=7dB with a BER=0.

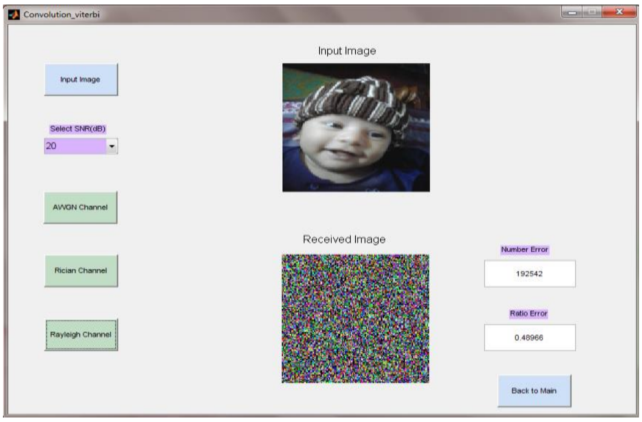

Fig. 6 Snapshot of simulation under Rayleigh Channel for SNR=10dB for RS-CC code

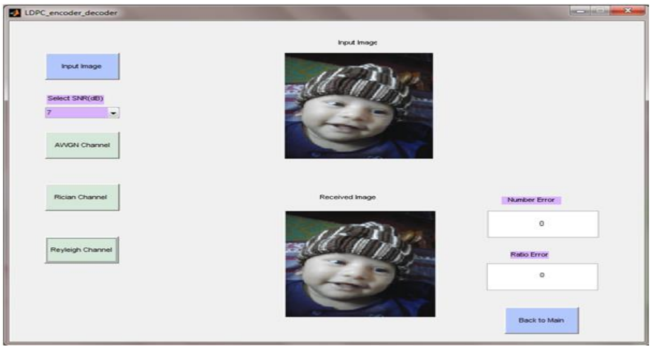

Fig. 7 Snapshot of simulation under Rayleigh Channel for SNR=7dB for RS-LDPC code

C. Simulation results for Rician Channel

Rician channel has a higher BER than AWGN, and has lower BER compared to Rayleigh fading channel. Fig.8 to Fig.10 shows the simulation results of WiMAX system under Rician fading channel for different values of SNRs. Using RS-CC with WiMAX recovers the image at SNR=15dB with a BER=0, while RS-LDPC with WiMAX system can recover the image at SNR=5dB with a BER=0.

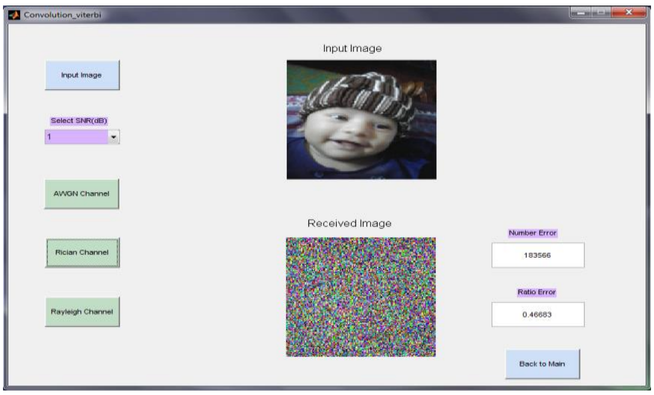

Fig. 8 Snapshot of simulation under Rician Channel for SNR=1dB for RS-CC code

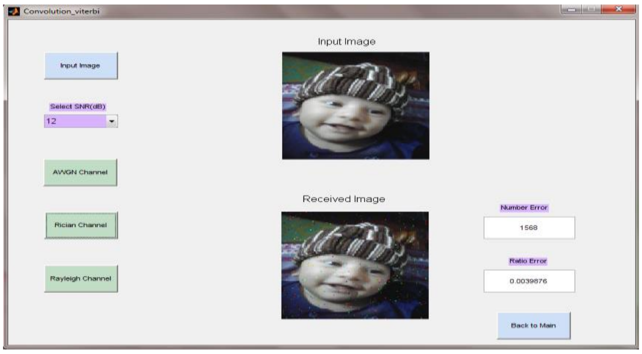

Fig. 9 Snapshot of simulation under Rician Channel for SNR=15dB for RS-CC code

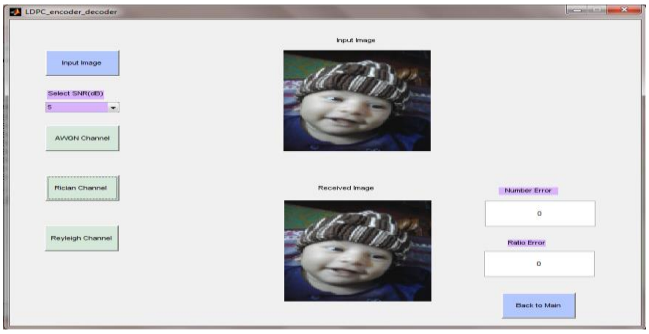

Fig. 10 Snapshot of simulation under Rician Channel for SNR=5dB for RS-LDPC code

IX. CONCLUSION

The simulation results shows that the use of RS-LDPC with WiMAX system gives better performance than using RS-CC with WiMAX system. The simulation results also shows that image can be recovered at the receiver even at very low SNR values.

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