1. Introduction

WiMAX is shortly used for World-wide Interoperability for Microwave Access and it refers to the inter-operable implementations of IEEE 802.16 of wireless standards given by the WiMAX forum. WiMAX technology is a rapidly growing broadband wireless technology, which makes use of both Line Of Sight (LOS) and Non-Line Of Sight (NLOS) transmissions. The operating bands of WiMAX system range between (2-11) GHz range for LOS and (10-66) GHz range for NLOS. The distance covered by LOS is (2-5) kms and NLOS is (5-50) kms. WiMAX can be either fixed - IEEE 802.16 or mobile – IEEE 802.16e. The key element of a WiMAX system is OFDM-Orthogonal Frequency Division Multiplexing scheme. What makes WiMAX system suitable for supporting a wide range of applications which include telecommunication services, backhaul broadband for cellular system and so much more is its large bandwidth, data rate and wide range\textsuperscript{1,2}. There is a pressing need of broadband wireless services. The conventional way out to obtain high-speed broadband is to use wired access technologies. The difficulty faced is that it is costly for carriers to make and look after wired networks, especially in hard to reach and rural areas. Broadband wireless access (BWA) technology is very flexible and intelligent solution to overcome these problems. WiMAX is the most popular BWA technologies used for wireless metropolitan area networks (WMANs).

As compared to the intricate wired network, WiMAX system consists of two main parts - Base Station (BS) and Customer Premise Equipment (CPE). Therefore, it can be built rapidly at a lesser cost. Finally, WiMAX is considered as advancement in the mobile technology’s hierarchical path. The patent combination of CDMA and WiMAX standards is what is known as 4G\textsuperscript{3}.

OFDM is an important part of WiMAX but has a
very poor performance in channels which are fading. With addition of coding, both frequency diversity and redundancy comes into picture but it reduces overall throughput by a factor of two. OFDM is finding acceptance very rapidly as a technique of efficient modulation because it often removes the need for the use of equalizers. OFDM using cyclic prefix eliminates ISI between consecutive OFDM symbols and allows easy frequency domain translation of effects of channel inside an OFDM symbol. WiMAX is a wireless technology developing rapidly. Exchange of ideas by manufactures, researchers, and technicians in realizing then designing, and then finally installing devices and equipment’s for it is done. The receivers strictly depend on a necessary down conversion of the radio frequencies which is input signal to the receiver or what we call a front end then other signal processing is to be suitably done to digitize the acquired samples. With evolving techniques nowadays no down conversion is required and we can make use of generally used measurement equipment’s like digital scopes and other acquisition systems. To improve the performance of a WiMAX system we must use different channel coding techniques which help in error detection and correction at receiver side by adding redundant bits on transmitter side. We should use bandwidth efficient higher order modulation systems like QAM and multiphase PSK plus Reed-Solomon codes as a channel coding technique to provide substantial gain in fading channels. Cyclic codes are considered to be an interesting class of channel codes due to their intelligent encoding and decoding procedures and algorithms. BCH codes come under the category of cyclic codes. They are very important in both hypothetically and in practically as they have enormous error correction capability and are used in communication systems like WiMAX and some storage devices. Recently LDPC codes have been used widely in various communication systems because they are considered as one of the best and fastest error correction schemes. When LDPC codes are used in a WiMAX system its performance is improved too. Before using LDPC codes concatenated RS-CC codes were used which have comparatively poor performance. LDPC codes are however difficult to implement and are complex. So lower complexity algorithms are being devised for LDPC codes so that the complexity of WiMAX system is improved in addition to the performance.

2. Model Description of WiMAX

WiMAX physical layer is a combination of certain blocks as shown in Figure 1. Each of these blocks have certain role to play and are important both from the construction and working point of view. The basic block diagram of WiMAX is given below. Some important blocks are briefly explained:

Figure 1. Block diagram of WiMAX physical layer.

Randomizer fulfills the objective of getting random data. It is implemented by the use of shift registers to produce a random sequence of bits. At the receiver side a de-randomizer does the inverse process of randomizer to undo the effect of randomizer. Channel encoder adds redundancy in a sequential manner at the transmitter end and channel decoder removes the redundancies added at the transmitter to get the actual information which was transmitted. The function of channel encoder and decoder is error detection and error correction plus it increases the reliability of the data transmission. In this paper we have used four types of channel coding techniques namely convolutional codes, BCH codes, RS codes and LDPC codes. Each coding technique has its own advantage and disadvantage.

Interleaver is basically a permuter which permutes the sequence. Its actual function is to get over burst errors which are difficult to correct otherwise. Its help in recovery of data during deep fades. On the receiver side we have a de-interleaver which does the opposite process of interleaver action. WiMAX has added benefit that we can use different orders of modulation schemes. When the channel is less likely to be corrupted by noise we can use higher modulation orders and when the channel is more likely to be corrupted by noise we use lower modulation orders. This change of modulation scheme with changing channel conditions is called adaptive modulation. In this paper we have used BPSK, QPSK, 16-PSK and 64-PSK.

OFDM multiplexer is an interface between the
modulator and the channel on the transmitter side. Its basic function is to make the signals to be transmitted orthogonal to each other that are converting a high-rate channel into many orthogonal low rate sub-channels. It is implemented by blocks like IFFT at the transmitter side and FFT at the receiver side. IFFT is the faster version of IDFT and FFT is the faster version of DFT. These are also called multi carrier schemes because they make use of multiple channels.

3. Channel Coding Schemes

The Channel coding techniques are widely used in wireless communication systems for the purpose of error detection and error correction. There are various channel coding techniques which have been developed from time to time which have varying efficiencies and error correcting capacities. The most primitive channel coding are codes like: hamming codes, block codes, cyclic codes, cyclic redundancy check and so on. But the channel coding techniques which are of prime importance to our study are:

3.1 BCH Codes

BCH stands for Bose Chaudhuri Hocquenghem codes after the names of the scientists who discovered this coding technique. This channel coding technique is one of the most popular and powerful coding techniques. It falls in the category of cyclic codes. Since they are a type of cyclic codes they can be encoded and decoded in the same way but that becomes little lengthy and troublesome, so we prefer some different easy encoding and decoding methods. These codes are different from earlier developed codes because in them we first used to construct the code and then find out its minimum distance to see how many errors it can detect and correct. In this coding technique we first figure out how many errors we want the code to detect and correct and then accordingly design a generator polynomial for it which can be used to create the codes.

BCH codes which are cyclic are amongst the most valued cyclic block codes, because they have a wide range of code rates, they have very high code gains, and are implementable at extremely high speeds. The block length that is the length of the codeword symbol in BCH codes:

\[ n = 2k - 1 \quad \text{for all } k > 3, \quad (1) \]

3.2 Convolutional Codes

These codes are used to correct the arbitrary errors in the transmission. These are represented by C (K, N, L), where each K-bit information symbol is encoded and transformed into an N-bit code word, K/N is defined as the code rate (N ≥ K) and the entire transformation is a dependent on the last L information bits. Also, L is known as the constraint length which means the number of memory elements used to store previous L bits. A combination of last L bits and current K bits gives rise to a code word which is N bit long. The code rates used in this paper is 1/2, 2/3 and 3/4. The decoding of convolutional is code is done by one of the very important algorithms called viterbi decoding algorithm. It is a maximum likelihood decoding algorithm abbreviated as ML decoding algorithm. The basic principle behind this is to find the path in the trellis diagram which was traced by the encoder to get the idea of the code word that was transmitted before being corrupted by noise. This algorithm was developed by a scientist names A. J. Viterbi. This decoding is applicable to soft decision decoding as well as hard decision decoding. Rate 1/2 convolutional encoder (2, 1, 7) is shown in Figure 2:

![Figure 2. Convolutional encoder.](image)

3.3 RS Codes

Reed-Solomon codes are derived from BCH codes. They are used in many digital communication applications like storage devices, digital television, mobile communication and can be used efficiently in WiMAX as well. In this coding rather than taking individual bits, bytes of data are taken which makes this coding scheme different from others. Since groups of bits are taken it can overcome burst errors which are difficult to remove otherwise. So, it can cope up with thousands of consecutive erroneous bits. For a code which can correct ‘t’ errors the generator polynomial is given by:
G(x) = LCM \left[ f_{1}(x), f_{2}(x), f_{3}(x), \ldots, f_{2t}(x) \right] \quad (2)

Where, \( f_{n}(x) \) is minimal polynomial. Reed-Solomon codes are actually non-binary codes. These are capable of correcting burst errors which appearing in data after long fading or deep fades and are mostly found in concatenation with other codes or with itself. The length of the codewords in RS codes is \( n = 2m-1 \). These codes can be extrapolated to \( 2m \) as well as \( 2m+1 \). The number of parity bits used to correct \( t \) no of errors is \( (n - k) / 2 \). The minimum distance represented as \( (d_{min}) = 2t + 1 \). RS codes are capable of achieving the highest possible \( d_{min} \) among all the linear codes.

### 3.4 LDPC Codes

LDPC stands for low density parity check codes and were first developed by R. G. Gallager in 1962. It is based on sparse parity check matrix which contains large number of zeros and very few number of ones. Due to the lack of information in fields like graph theory and signal processing it did not get the required amount of attention. It was later re-introduced by Mackay in mid 1990s and new decoding algorithms which are comparatively easy to implement are used since then. These codes mostly use iterative decoding which can achieve capacity close to Shannon’s limit. It is represented as \( C(n,p,q) \) where, \( n \) is the block length, \( p \) is the number of ones in each column and \( q \) is the number of ones in each row of the parity check matrix. The parity check matrix is represented by \( H \) and has size \( (n-k) \times n \), where \( k \) is the number of information bits. An example of parity check matrix is given below:

\[
H = \begin{bmatrix}
1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 \\
0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 \\
1 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\
0 & 1 & 0 & 1 & 0 & 1 & 1 & 0
\end{bmatrix}
\] (3)

Because the parity check matrix is sparse in nature, it can be represented as a bipartite graph which has two types of nodes i.e, bit nodes and check nodes and the graph is called as tanner graph. For parity check to be satisfied following equality should hold:

\[ H \times x^T = 0 \quad (4) \]

Where \( x \) is any code word.

### 4. Simulation Results

Firstly we have used AWGN channel to get BER versus SNR plots and then we have used Rayleigh channel to get BER versus SNR plots. Both channels use different modulation orders and channel coding techniques which are mentioned in Table-1 as simulation parameters. In Figure 3, we can see that to get a BER of \( 10^{-2} \), RS codes need an SNR of 4 dB, LDPC and BCH codes require almost the same SNR value of 4.8 dB whereas convolutional codes require an SNR of about 5.3 dB. So, from this we can say RS codes perform the best in this scenario with an improvement of about 0.8 dB compared to LDPC codes and BCH codes and improvement of over 1 dB in case of convolutional codes. Looking at Figure 4, when QPSK is used, we can see that RS codes again outperform the other codes. To get a BER of \( 10^{-2} \), RS codes require an SNR of 4.2 dB, LDPC and BCH codes require approximately same SNR of about 4.9 dB and convolutional codes require an SNR of 5.5 dB for code rate 1/2 and about 6 dB for a code rate of 3/4. Thus, RS codes perform the best in this case showing an improvement of about .7 dB from LDPC and BCH codes and an improvement of over 1 dB in case of convolutional codes. From Figure 5, when 16-PSK is used, BCH codes perform the best and convolutional codes with code rate 3/4 lag in performance. For a BER of \( 10^{-3} \), BCH codes require an SNR of about 11.5 dB, RS codes require an SNR of 12.9, convolutional code (1/2) require an SNR of 13.7 db, LDPC codes require an SNR of 14.9 db and convolutional code (3/4) require an SNR of 15.5 dB. Thus, BCH codes show an SNR improvement of over 1 dB in comparison to RS codes, over 2 dB when compared to convolutional code with code rate 1/2, over 3 dB when compared to LDPC codes and 4 dB improvement when compared to convolutional codes of code rate 3/4. From Figure 6, which uses 64-PSK, for the BER of \( 10^{-3} \), BCH codes require an SNR of 19 dB, RS codes require an SNR of 22 dB, LDPC codes require an SNR of 24.3 dB, convolutional codes (3/4) require an SNR of 25.8 dB and convolutional codes (1/2) require an SNR of 26.5 dB. Here again BCH codes perform very well compared to other codes showing an improvement of about 7.5 dB SNR for a BER of \( 10^{-3} \) compared to convolutional codes. In all the above, LDPC codes perform fairly well but cannot be
considered the best in any case. Also, another important thing to make note of is that with increasing order of modulation we require more value of SNR for same value of BER.

**Figure 3.** BER of WiMAX using BPSK over AWGN channel.

**Figure 4.** BER of WiMAX using QPSK over AWGN channel.

**Figure 5.** BER of WiMAX using 16-PSK over AWGN channel.

**Figure 6.** BER of WiMAX using 64-QPSK over AWGN channel.

**Figure 7.** BER of WiMAX using BPSK over Rayleigh channel.

**Figure 8.** BER of WiMAX using QPSK over Rayleigh channel.
Next we come to last four graphs which employ Rayleigh channel and different channel coding for WiMAX system. From Figure 7, which uses BPSK, for a BER of $10^{-3}$, BCH codes require an SNR of 6.8 dB, RS and LDPC codes require an SNR of about 9 dB and convolutional codes require an SNR of 11.5 dB. So, BCH codes have an outstanding performance giving an improvement of over 2 dB compared to RS and LDPC codes and over 4 dB compared to convolutional codes. Taking a look at Figure 8, which uses QPSK, for a BER of $10^{-3}$, RS codes require an SNR of 4 dB, BCH codes require an SNR of 7 dB, LDPC codes require an SNR of 10.2 dB, convolutional codes (1/2) require an SNR of 10.4 dB and convolutional codes (3/4) require an SNR of 15.7 dB. Hence, RS codes show an improvement of about 3 dB in SNR value compared to BCH codes, over 6 dB compared to LDPC and convolutional codes (1/2) and over 10 dB compared to convolutional codes (3/4). From Figure 9, which uses 16-PSK, for a BER of $10^{-3}$, RS codes require an SNR of 8 dB, BCH codes require an SNR of 12.5 dB, convolutional codes (3/4) require an SNR of 15 dB, LDPC codes require an SNR of 16 dB and convolutional codes (1/2) require an SNR of 17 dB. Hence, RS codes show an improvement of about 4.5 dB in SNR value compared to BCH codes, about 7 dB compared to convolutional codes (3/4), about 8 dB compared to LDPC codes and about 9 dB compared to convolutional codes (1/2). From Figure 10, which uses 64-PSK, for a BER of $10^{-3}$, BCH codes require an SNR of 12 dB, RS codes require an SNR of 16 dB, LDPC codes require an SNR of 22.5 dB, convolutional codes (1/2) require an SNR of 23.5 dB and convolutional codes (3/4) require an SNR of 35 dB. Hence, BCH codes show an improvement of about 4 dB in SNR value compared to RS codes, about 10.5 dB compared to LDPC codes, about 11.5 dB compared to convolutional codes (1/2) and more than 20 dB 9 dB compared to convolutional codes (3/4).

## 5. Conclusion

As we have used various modulation orders of PSK and channel coding schemes to our WiMAX system, we can deduce that for various modulations and channel coding schemes the results are different. The efficiency of codes in a WiMAX system also varies with different channels being applied to the system. Also, for a fact, there is requirement of higher SNR for higher modulation orders and for same BER value. This can be dealt with by using QAM which has a better performance compared to PSK. As of now, this paper gives us an idea that which code should be applied to a WiMAX system for a required performance. From the results discussion we come to the following conclusion that RS codes and BCH codes are a good competition to currently popular LDPC codes and conventional convolutional codes. By using a better channel coding technique, the performance of WiMAX system can be greatly improved which is our ultimate goal.

## 6. References

1. Benjangkaprasert C, Inchan T. Signal processing of Wi-


