# BER analysis of OFDM based WIMAX using Punctured Convolutional codes

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***Abstract*****--** In this paper, simulation model of OFDM based WIMAX system has been developed using punctured convolutional codes. The bit error rate performance of fixedWIMAX has been carried out for different modulation techniques like BPSK, QPSK, and QAM16 with different code rates 1/2, 2/3, 3/4 in each case of modulation technique. Puncturing is the process of deleting some parity bits from the code-word according to a puncturing matrix. Puncturing increases code rate without increasing complexity. The bandwidth efficiency decreases with increase in redundant bits in coding. By removing these redundant bits through puncturing improves the bandwidth efficiency.Puncturing is the trade-off between rate and performance. High-rate punctured codes have been derived from rate 1/2 specific convolutional codes. The performance evaluation is obtained by plotting graphs between BER and $E_b/N_0$ for different modulation techniques and comparing the results for different code rates. Obtained results indicate that the performance of punctured convolutional codes is worse than without puncturing convolutional code but coding scheme improve bandwidth efficiency and reduces the implementation complexity of the Viterbi decoder.

***Keywords*****—** BER v/s $E_b/N_{0,}$ BPSK, OFDM, Punctured Convolutional Codes, QPSK, QAM16, WIMAX

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## I. INTRODUCTION

After years of development and uncertainty, a standards-based interoperable solution is emerging for wireless broadband. WiMAX is a wireless broadband solution that offers a rich set of features with a lot of flexibility in terms of deployment options and potential service offerings[1]. The IEEE 802.16 group subsequently produced 802.16a, an amendment to the standard, to include NLOS applications in the 2GHz–11GHz band, using an orthogonal frequency division multiplexing (OFDM)-based physical layer. Further revisions resulted in a new standard in 2004, called IEEE 802.16-2004, which replaced all prior versions and formed the basis for the first WiMAX solution. These early WiMAX solutions based on IEEE 802.16-2004 targeted fixed applications, and we will refer to these as fixed WiMAX [2]. In December 2005, the IEEE group completed and approved IFEEE 802.16e-2005, an amendment to the IEEE 802.16-2004 standard that added mobility support. The IEEE 802.16e-2005 forms the basis for the WiMAX solution for nomadic and mobile applications and is often referred to as mobile WiMAX. [3] The WiMAX physical layer is based on orthogonal frequency division multiplexing. OFDM is the transmission scheme of choice to enable high-speed data, video, and multimedia communications and is used by a variety of commercial broadband systems, including DSL, Wi-Fi, Digital Video Broadcast-Handheld (DVB-H), and MediaFLO, besides WiMAX.

OFDM is an elegant and efficient scheme for high data rate transmission in a non-line-of-sight or multipath radio environment. The aim of OFDM is to divide the wide frequency selectivity of fading channels into multipleflat fading channels.The OFDM uses the spectrum more efficiently by making the entire sub carrier orthogonal to one another, preventing interference between the sub carriers.One of the main attractions of OFDM are handling the multi-path interference, and mitigate inter-symbol interference (ISI) causing bit error rates in frequency selective fading environments.

In recent years, there has been an increasing demand for efficient and reliable digital data transmission and storage systems. This demand has been accelerated by emergence of large-scale, high-speed data networks for the exchange, processing and storage of digital information in the commercial, governmental and military spheres. A merging of communications and computer technology is required in the design of these systems. A major concern of the system designer is the control of errors so that the data can be reliably reproduced.

By adding redundant information to the data to be transmitted, it is possible to detect and even correct the errors. This principle is called forward error control [4].It is clear that more redundant information will result in larger ability to detect and correct errors and therefore will result in a lower block error probability and lower bit error probability. By adjusting the amount of redundant information, the error protection given can be modified depending on the channel and/or source characteristics. In a mobile environment the system resources at the hand-held side are limited so the same decoder should be used independent of the amount of redundant information added. One of the variable rate convolutional encoding schemes is the punctured convolutional codes, where redundant information at the encoder output is deleted [5].

## II. WIMAX-OFDM TRANSRECEIVER

The OFDM based WIMAX system model is composed of a transmitter, AWGN communication channel and receiver.

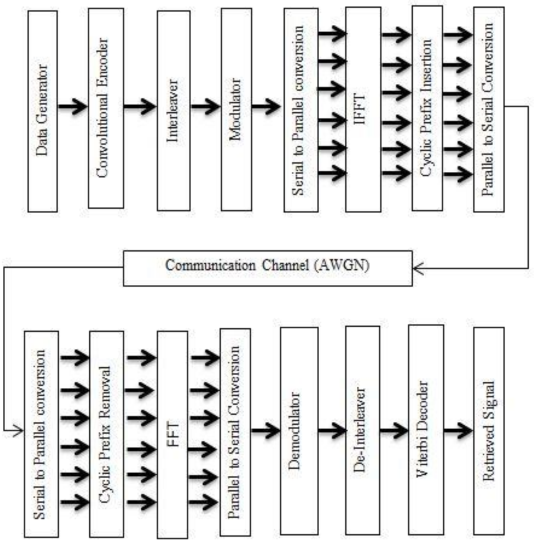

Fig. 1 WIMAX-OFDM Model

The basic principle of OFDM is to split a high data rate steam into a number of lower rate streams which are transmitted simultaneously over subcarrier[6]. In the transmitter path, binary input data is encoded by a rate 1/2 convolutional encoder. The rate may be increased to 2/3 or 3/4 by puncturing the coded output bits. After interleaving, the binary values are converted into modulated values. IFFT converts a number of complex data points, of length which is a power of 2, into the time domain signal of the same number of points. To make the system robust to multipath propagation, a cyclic prefix is added. The bit error rate (BER) performance at receiver side can be improved by utilizing convolutional coding, which provides vigorous improvement against channel impairments such as noise, interference and fading. At the receiver, Viterbi decoding is used to decode data in such a way as to minimize the probability of error.

### A. CONVOLUTIONALCODING

Convolutional codes are extensively used for real time error correction. Convolutional coding is done by combining the fixed number of input bits. The input bits are stored in fixed length shift register and they are combined with the help of mod-2 adders. An input sequence and contents of shift registers perform modulo-two addition after information sequence is sent to shift registers, so that an output sequence is obtained. This operation is equivalent to binary convolution and hence it is called convolutional coding.

Convolution codes are specified by three parameters (n, k, K), where n, k, K are length of the code word, number of input bits and constraint length respectively. The constraint length K, defines the past number of input bits in the memory register that affect the output code word. The relation R=k/n is The rate of Convolution code, which defined as the ratio of number of output bits to the number of input bits and is denoted by ‘R’.

In general, k data bits may be shifted into the register at once, and n code bits generated. In practice, it is often the case that *k*=1 and *n*=2, giving rise to a rate 1/2 code.

*Convolution encoder with K=7, R=1/2:* This convolutional encoder uses the industry-standard generator polynomials, G1 = 171 and G2 = 133 of rate R = ½.

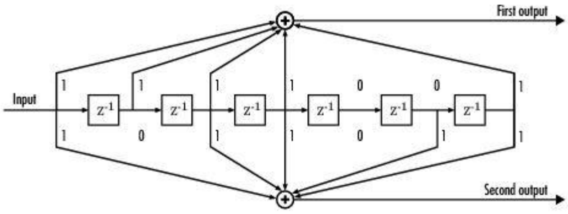

Fig. 2 Convolution encoder with K=7, R=1/2

Thus the generator polynomial matrix is [171 133]. Fig. 2 shows this type of convolution encoder employed in the implementation model of WIMAX. In this encoder two modulo-2 encoders are used to provide the corresponding outputs which are used as parameters of generator polynomial. Since different data rates are supported in WIMAX-OFDM, puncture is needed after Convolutional coding.

### B. PUNCTURED CONVOLUTIONAL CODES

A punctured convolutional code is a high-rate code obtained by the periodic elimination (i.e., puncturing) of specific code symbols from the output of a low-rate encoder. The resulting high-rate code depends on both the low-rate code, called the original code, and on both the number and specific positions of the punctured symbols. The pattern of punctured symbols is called the perforation pattern of the punctured code, and is conveniently described in a matrix form called the perforation matrix [7].

Puncturing has the effect of reducing the number of encoded digits corresponding to the information digits, i.e., of increasing the code rate. Thus, a low-rate encoder can be used to generate many high-rate codes by appropriately selecting the puncturing pattern. If a rate- 1/n original encoder is punctured by deleting some of the nP encoded bits corresponding to P information bits, then P is called the puncturing period. The puncturing pattern can be represented as an n × P matrix P whose elements are 1's and 0's, with a 1 indicating inclusion and a 0 indicating deletion

A puncture pattern is specified to create a rate 3/4 code from the previous rate 1/2 code using the puncture pattern vector [1 1 1 0 0 1]. The ones in the puncture pattern vector indicate that bits in positions 1, 2, 3, and 6 are transmitted, while the zeros indicate that bits in positions 4 and 5 are punctured or removed from the transmitted signal. The effect of puncturing is that now, for every 3 bits of input, the punctured code generates 4 bits of output (as opposed to the 6 bits produced before puncturing). This results in a rate 3/4 code.

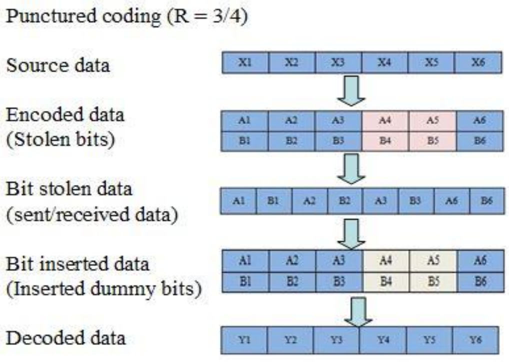

Fig. 3 Punctured Coding for rate 3/4

Similarly to create a rate 2/3 code from the previous rate 1/2 code puncture pattern vector [1 1 0 1] is used. The ones in the puncture pattern vector indicate that bits in positions 1, 2 and 4 are transmitted, while the zeros indicate that bits in positions 3 are punctured or removed from the transmitted signal. The effect of puncturing is that now, for every 2 bits of input, the punctured code generates 3 bits of output (as opposed to the 4 bits produced before puncturing). This results in a rate 2/3 code.

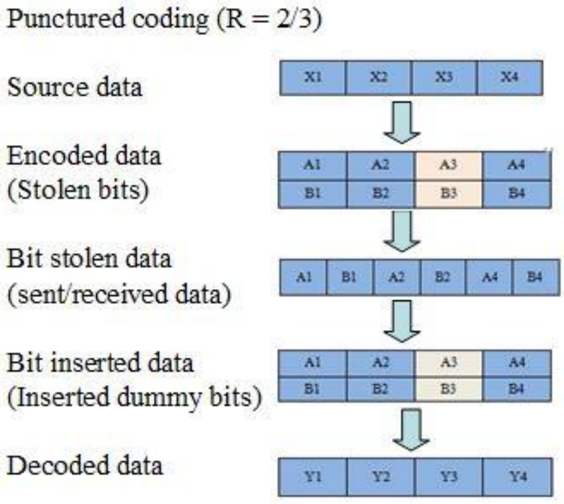

Fig. 3 Punctured Coding for rate 2/3

The advantage of using punctured codes is that a high rate punctured codes can be decoded using decoder for the low-rate original code, thereby requiring a smaller number of computations [8].Puncturing is the trade-off between rate and performance. Puncturing increases code rate without increasing complexity for code rate and at the same time provides bandwidth efficiency but the performance of system is comparatively degraded [9].

## III. SIMULATION

The WIMAX model used is simulated using BPSK, QPSK, and QAM16 modulation techniques with different punctured code rates. High-rate punctured codes have been derived from rate 1/2 specific convolutional codes. The punctured patterns used here are [1 1 0 1], for 2/3 rate, and [1 1 1 0 0 1], for 3/4 rate. The simulation results have been compared by plotting their BER versus $E_b/N_0$ through MATLAB.

TABLE 1

SIMULATION PARAMETERS

| **Parameters** | **Values** |
|---|---|
| FFT size | 256 |
| No. of data sub-carriers | 256 |
| OFDM symbols | 192 |
| Guard time | 64 |
| Modulation | BPSK, QPSK, 16QAM |
| Code Rates | 1/2, 2/3, 3/4 |
| Constraint Length | 7 |
| Code Generator | 171,133 |

The following section shows the simulated results of WIMAX based OFDM system. The simulation depicts the comparison of performance of system corresponding to different values of code rates for different modulation techniques.

A. *BPSK with code rates – 1/2, 2/3, and 3/4*: For BPSK, decrease the code rate the BER performance improves and the best result comes for rate 1/2, for this the absolute BER performance is approx. 3.5dB better than code rate 3/4 at BER of 10e-4. For BPSK, without puncturing; only 96 numbers of bits per OFDM symbol are sent over the channel, but as the puncturing rate increases more number of bits per symbol could be sent, which improves the bandwidth efficiency of the system.

TABLE 2

SIMULATION RESULTS for BPSK

| **$E_b/N_0$ (dB)** | Code Rate | | |
|---|---|---|---|
| | 1/2 | 2/3 | 3/4 |
| | BER | | |
| 1 | 7.2500e-04 | .0066 | 0.0573 |
| 2 | 7.2917e-05 | 5.6953e-04 | 0.0150 |

| | | | |
|---|---|---|---|
| 3 | 4.1667e-06 | 3.6719e-05 | 0.0030 |
| 4 | 0 | 2.3438e-06 | 4.3403e-04 |
| 5 | | 0 | 2.8472e-05 |

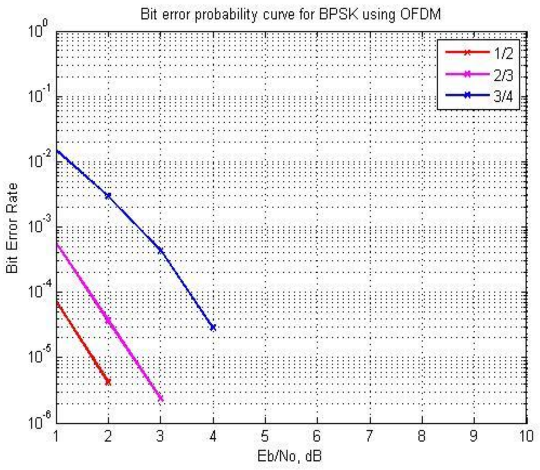

Fig. 5 BER vs $E_b/N_0$ curve for BPSK

B. *QPSK with code rates- 1/2, 2/3, 3/4*: Fig. 6 shows that in case of QPSK, for a fixed value of Eb/No (dB), the BER performance of the system is best when code rate is 1/2. The performance of the system goes on deteriorating as the value of code rate increases. But in case of good channel conditions, the BER performance of this system is better for higher order code rates. For example, on fixing BER between 10e-5 and 10e-6, the signal to noise ratio for code rate 3/4 is highest reaching value 8.

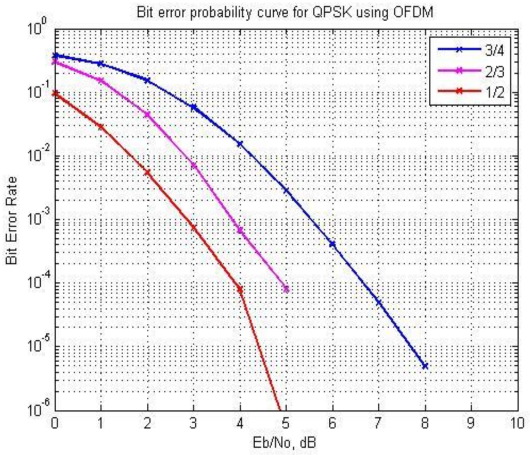

Fig. 6 BER vs $E_b/N_0$ curve for QPSK

TABLE 3

SIMULATION RESULTS for QPSK

| **$E_b/N_0$ (dB)** | Code Rate | | |
|---|---|---|---|
| | 1/2 | 2/3 | 3/4 |
| | BER | | |
| 1 | 0.0953 | 0.2999 | 0.3788 |
| 2 | 0.0280 | 0.1503 | 0.2763 |
| 3 | 0.0054 | 0.0442 | 0.1525 |
| 4 | 7.2604e-04 | 0.0071 | 0.0575 |
| 5 | 7.9167e-05 | 6.0662e-04 | 0.0151 |
| 6 | 5.2083e-07 | 8.0859e-05 | 0.0028 |
| 7 | 0 | 0 | 4.0521e-04 |
| 8 | | 0 | 4.8264e-05 |
| 9 | | | 4.8611e-06 |

C. *QAM16 with code rates- 1/2, 2/3, 3/4:* Fig. 7 shows that in case of QAM16,the performance of the system goes on deteriorating with increase in value of code rate. But the bandwidth efficiency of the system improves from 384 bits per symbol without puncturing to 576 bits per symbol with punctured code-rate 3/4.

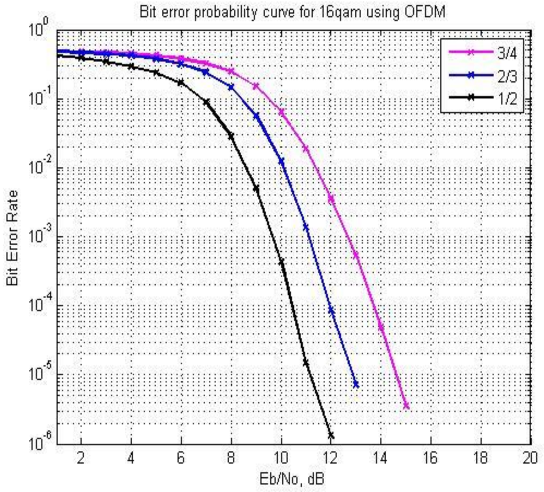

Fig. 7 BER vs $E_b/N_0$ curve for QAM16

TABLE 4

SIMULATION RESULTS for QAM16

| **$E_b/N_0$ (dB)** | Code Rate | | |
|---|---|---|---|
| | 1/2 | 2/3 | 3/4 |
| | BER | | |
| **1** | .4509 | .4870 | .4920 |
| **2** | .4231 | .4789 | .4862 |
| **3** | .3833 | .4645 | .4776 |
| **4** | .3414 | .4446 | .4650 |
| **5** | .2911 | .4162 | .4462 |
| **6** | .2357 | .3749 | .4198 |
| **7** | .1675 | .3172 | .3788 |
| **8** | .0887 | .2414 | .3234 |
| **9** | .0277 | .1462 | .2450 |
| **10** | .0050 | .0567 | .1484 |
| **11** | 4.3568e-04 | .0123 | .0635 |
| **12** | 1.4844e-05 | .0014 | .0189 |
| **13** | 1.3021e-06 | 8.5352e-05 | .0035 |
| **14** | 0 | 7.2266e-06 | 5.3056e-04 |
| **15** | | 0 | 4.8958e-05 |
| **16** | | | 3.4722e-06 |

D. *Comparing Code rate 3/4 for different modulation techniques*: For different modulation schemes at code rate

3/4, for a fixed value of Eb/No (dB); the BER performance of the system is best for BPSK and worst for QAM16. But in case of good channel conditions, the BER performance of this system is better for QPSK and QAM16 than BPSK. For example, on fixing BER between 10e-4 and 10e-5, the signal to noise ratio for QAM16 is highest reaching value 14.

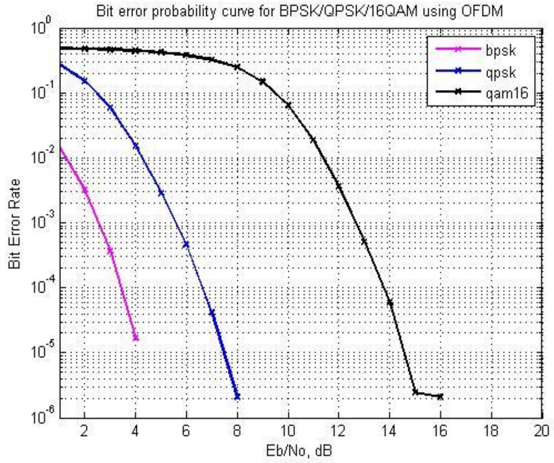

Fig. 8 BER vs $E_b/N_0$ curve for code rate 3/4

## IV. CONCLUSION

The redundant bits in coding decrease the bandwidth efficiency of the system.Puncturing is the process of deleting those redundant bits from the code-word resulting in improved bandwidth efficiency of the system.In this paper, the simulated results conclude that although the performance of the punctured code is worse than the performance of the mother code i.e. the BER performance is best for code rate 1/2, especially for noisy channel conditions.On the other hand, for punctured code rates, the system has better bandwidth efficiency and all punctured codes can be decoded by a decoder that is able todecode the mother code, so only one decoder is needed. The simulation results shows that, for BPSK without puncturing; only 96 numbers of bits per OFDM symbol are sent over the channel. However by using puncturing, 128 and 144 number of bits per OFDM symbol could be sent for punctured code rates 2/3 and 3/4 respectively, over the same channel bandwidth. For QPSK, for code rates 1/2, 2/3, 3/4; the numbers of bits per OFDM symbol that can be sent over the same channel bandwidth are 192, 256, and 288 respectively. On the other hand, for QAM16; 384 bits for 1/2, 512 bits for 2/3 and 576 numbers of bits per OFDM symbol for code rate 3/4 could be sent over the same channel bandwidth. Thus more data could be sent over the same channel bandwidth using puncturing although the performance of the mother code is better than the punctured codes.Using different puncturing schemes one canadapt to the channel, using the channel state information, send more redundancy, if the channel qualityis bad and send less redundancy/more information if the channel quality is better. This concludes that puncturing is a trade-off between bandwidth efficiency and performance.

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