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Bit Error Rate Performance Evaluation of Various Modulation Techniques with Forward Error Correction Coding of WiMAX

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Abstract: In this paper, a physical layer simulator for WiMAX corresponding to the IEEE 802.16e specification is simulated. The bit error rate performance evaluation of a WiMAX system using Reed-Solomon (RS) coding with Convolutional coding with 1/2, 2⁄3 and 3/4 rated codes in forward error correction channel coding and various digital modulation techniques (BPSK, QPSK, 4QAM and 16QAM) under communication channel AWGN is carried out.

Keywords: OFDM, WiMAX, Reed-Solomon coding, Convolution coding, Additive White Gaussian Noise, Bit error rate.

I. INTRODUCTION

The 802.16 family standard is called Wireless Metropolitan Area Network (MAN) commercially known as WiMAX (Worldwide interoperability for Microwave Access) which is launched in 1999. IEEE 802.16 is a solution of broadband wireless access (BWA) and recent wireless broadband standard that has promised high bandwidth over long-range transmission. The standard specifies the air interface, including the medium access control (MAC) and physical (PHY) layer. The important part in the PHY layer includes orthogonal frequency division multiplexing (OFDM), in which multiple access is achieved by assigning a subset of subcarriers to each individual user.[1]

In this paper the evaluation of the performance of WiMAX system using Bit Error Rate as performance parameter for data communication by the WiMAX Physical layer under different channel coding rates and digital modulation schemes under AWGN communication channel is carried out. Performance is investigated using the modulation schemes BPSK, QPSK and QAM with 1/2, 2/3 and 3/4 rated Convolutional coding using Reed Solomon coding as the forward error correction code.

II. WIMAX

WiMAX (Worldwide Interoperability for Microwave Access) is a telecommunications protocol that provides fixed and fully mobile internet access and comprises of fixed FFT size (256 carriers), variable subcarrier spacing to support multiple defined bandwidths and adaptive modulation with BPSK, QPSK, 16-QAM and 64-QAM. Channel coding in 802.16 uses an outer Reed-Solomon (RS) block code concatenated with an inner convolutional code. The inner convolution code has constraint length 7, and its rate varies between 1/2, 2/3 3/4. WiMax Forum specify the 256-carrier OFDM PHY. Of these 256 subcarriers, 192 are used for user data, with 56 nulled for a guard band and eight used as permanent pilot symbols. In order to provide robustness to multipath channels, 8, 16, 32, or 64 additional samples are prepended as the cyclic prefix, depending on the expected channel delay spread.[1,2]

TABLE I PARAMETERS OF WIMAX [10]

Parameters	**Values**
Number of FFT points	256
Number of null sub carriers	56
Number of data sub-carriers	192
Number of pilot sub-carriers	8
Subcarrier frequency spacing	0.3125 MHz
FFT symbol period	3.2µs
Cyclic prefix	0.8µs

III. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

OFDM is a combination of modulation and multiplexing. In OFDM, multiplexing is applied to the independent signals but these independent signals are a subset of the one main signal. In OFDM the signal itself is first split into independent channels, modulated by data and then multiplexed to create the OFDM carrier. OFDM is a special case of Frequency Division Multiplexing (FDM).

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission technique, which divides the available spectrum into many carriers, each one being modulated by a low rate data stream. OFDM is similar to FDMA in which the multiple user access is achieved by subdividing the available bandwidth into multiple channels, that are then allocated to users. OFDM uses the spectrum more efficiently by spacing the channels closer

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together. This is achieved by making all the carriers orthogonal to one another, preventing interference between the closely spaced carriers.[4]

Coded Orthogonal Frequency Division Multiplexing (COFDM) is the same as OFDM except that forward error correction is applied to the signal before transmission. This is to overcome errors in the transmission due to lost carriers from frequency selective fading, channel noise and other propagation effects

The attraction of OFDM is mainly because of its way of handling the multipath interference at the receiver. Multipath phenomenon generates two effects one is frequency selective fading and other is Inter symbol interference (ISI). The "flatness" perceived by a narrowband channel overcomes the frequency selective fading. On the other hand, modulating symbols at a very low rate makes the symbols much longer than channel impulse response and hence reduces the ISI. Use of suitable error correcting codes provides more robustness against frequency selective fading. The insertion of an extra guard interval between consecutive OFDM symbols can reduce the effects of ISI even more. [2]

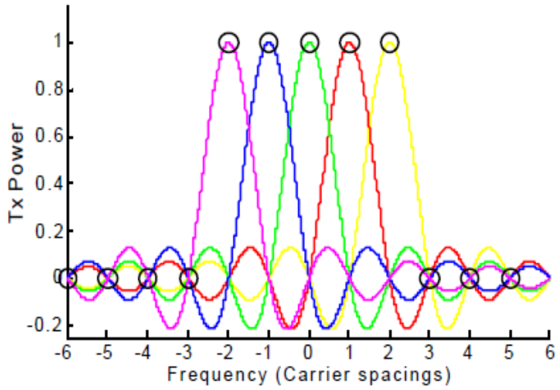

Fig.1. Frequency response of the subcarriers in 5 tone OFDM signal.

IV. CONVOLUTIONAL CODING

Convolutional code is a type of error Correcting code in which each m-bit information symbol (each m-bit string) to be encoded is transformed into an n-bit symbol, where m/n is the code rate (n ≥ m) and the transformation is a function of the last k information symbols, where k is the constraint length of the code. The binary numbers corresponding to the upper and lower adders in the fig 3.1 are 110 and 111, respectively. These binary numbers are equivalent to the octal numbers 6 and 7, respectively. G1 = 6 and G2 = 7 of rate R = 1/2. Thus generator polynomial matrix is [6 7].

This convolutional encoder uses the industry-standard generator polynomials, G1 = 171 and G2 = 133 of rate R = ½ having 64 states. Thus the generator polynomial matrix is [171 133]. Since different data rates are supported in WiMAX-OFDM, puncture is needed after Convolutional coding. 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.

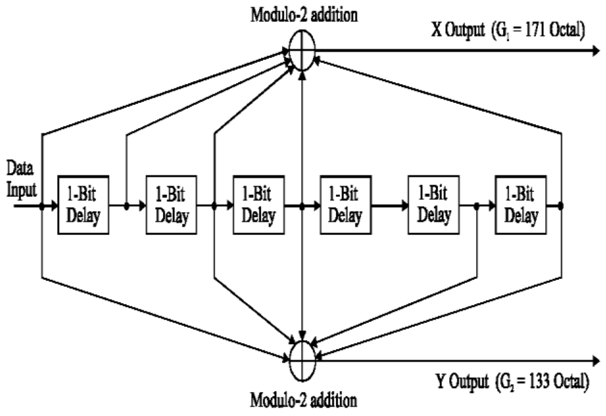

Fig. 2. Block diagram of convolutional code with k = 7 and rate 1/2 [9]

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.

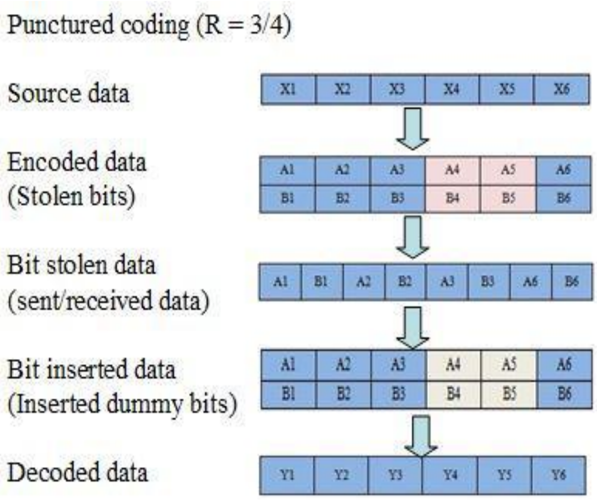

Fig. 3. Punctured Coding for rate 3/4 [13]

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.

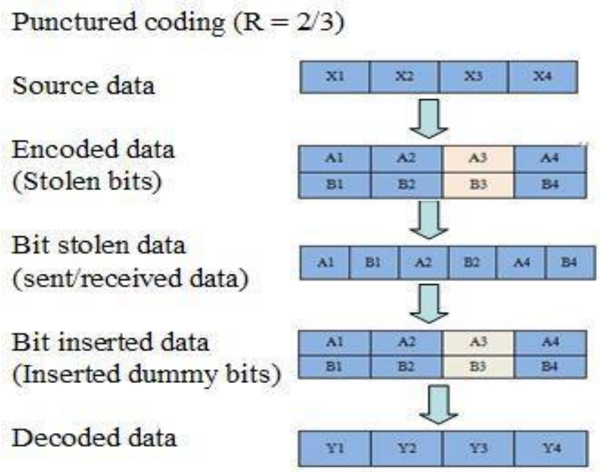

Fig. 4. Punctured Coding for rate 2/3 [13]

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].

V. REED SOLOMON CODING

Reed Solomon codes are a subset of BCH codes and are linear block codes. A Reed-Solomon code is specified as RS (n, k) with m-bit symbols. The encoder takes k data symbols of m bits each and adds parity symbols to make an n symbol codeword. There are $n - k$ parity symbols of m bits each. A Reed-Solomon decoder can correct up to e symbols that contain errors in a codeword, where $2e = n - k$. In this paper, all messages and codewords are over the finite field galois field GF (28), to make byte orientation simple.[11] The generator polynomial of reed Solomon code is given by

$$g(x) = (x - \propto)(x - \propto^2) \ldots . (x - \propto^{n-k}) \qquad (1)$$

where ∝ is the generator polynomial of GF (28). The IEEE 802.16 standard specifies Reed Solomon code (n, k) for QPSK 1/2 (32,24), QPSK 3/4 (40,36), 16QAM 1/2 (64,48), 16QAM 3/4 (80,72), 64QAM 2/3 (108,96) and 64QAM 3/4 (120,108).

VI. WIMAX SYSTEM

To implement the WiMAX system IEEE 802.16, the whole system is divided into three sections –transmitter, channel and receiver as shown in fig. 5.

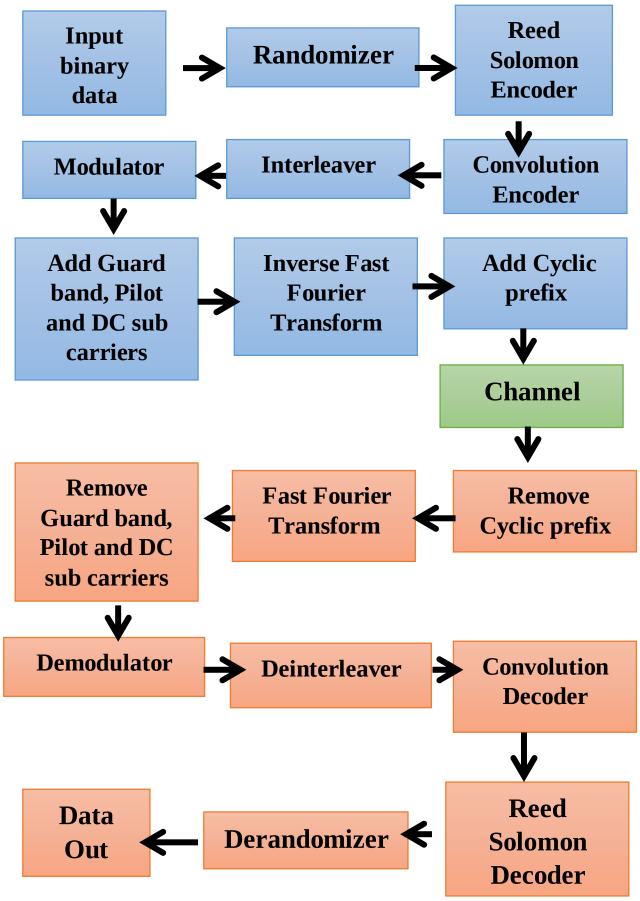

Fig. 5. Block Diagram of WiMAX system

In the transmitter, binary input data sequence is generated according to the using digital modulation technique as shown in table 2. The generation of data is one less byte than the uncoded block size because extra one byte of zeros is needed after randomization. The randomized information is then Forward error correction encoded and interleaved prior to modulation. The sequence is encoded by a Reed Solomon and Convolutional encoder. The information is converted to decimal prior to application of codes and then back to binary. The Reed Solomon encoder is realized according to the standard shown in table 2. The Galois field vector is generated and using that symbols are encode with Reed Solomon. Then the reed Solomon coded data is concatenated with punctured convolution encoder of rates 1/2, 2/3, 3/4 with Viterbi decoder.

Then interleaving is applied to randomize the occurrence of bit errors prior to increase performance. After interleaving, the binary values are converted to symbol values, on which digital modulation technique is applied. Previously, multi-carrier systems were implemented through the use of separate local oscillator. This was both inefficient and costly. The symbols are modulated onto subcarriers by applying the Inverse Fast Fourier Transform (IFFT) which keep tones to orthogonal with each other. The FFT is used to calculate the spectral content of the signal. It moves a signal from the time domain where it is expressed as a series of time events to the frequency domain where it is expressed as the amplitude and phase of a particular frequency. The output of this block is a sequence of logical indexes that gives a complete map of the subcarriers: subcarriers that will be modulated by data (192), pilot subcarriers (8), guard subcarriers (55) and the DC subcarrier (1) as shown in Table II.

The output is converted to serial and a cyclic extension is added to make the system robust to multipath propagation. The cyclic prefix (CP) consists in a copy of the last samples composing the OFDM symbol added in front of it. This function is built according to IEEE 802.16e specifications, which define 4 possible values for the ratio between the duration of the cyclic prefix and the duration of the useful OFDM symbol (1/4,1/8,1/16 and 1/32).
In channel, Additive White Gaussian Noise is taken. The receiver performs the reverse operations of the transmitter. After removing the cyclic extension, the signal can be applied to a Fast Fourier Transform to recover the modulated values of all subcarriers. The modulated values are then demapped into binary values, and finally deinterleaving and Reed Solomon and Viterbi decoder decodes the information bits. The system design parameters are derived according to the system IEEE 802.16 requirements. The design parameters for WiMAX system are shown in Table II.

TABLE II SIMULATION DESIGN PARAMETERS CONSIDER IN SYSTEM

Parameters	**Values**	
Number of OFDM symbols	1000	
Total data	BPSK 1/2	11*8,1
	QPSK 1/2	23*8,1
	QPSK 3/4	35*8,1
	16QAM 1/2	47*8,1
	16QAM 3/4	71*8,1
	64QAM 2/3	95*8,1
	64QAM 3/4	107*8,1
Number of data sub-carriers	192	
Number of FFT points	256	
Number of control sub-carriers	DC Sub carrier	1
	Guard band Sub carries	55
	Pilot Sub carriers	8
Cyclic prefix	16 (1/4), 32 (1/8), 48 (1/16), 64 (1/32)	
OFDM symbol	100	
Channel	AWGN	
Modulation scheme	BPSK, QPSK, 16QAM, 64QAM	
Reed Solomon coding m=8	BPSK 1/2	8 nulls
	QPSK 1/2	n=32, k=24
	QPSK 3/4	n=40, k=36
	16QAM 1/2	n=64, k=48
	16QAM 3/4	n=80, k=72
	64QAM 2/3	n=108, k=96
	64QAM 3/4	n=120, k=108
Convolutional Coding	Code rate 1/2, constraint length 7, generator polynomial [171, 133] with punctured codes having rate 2/3 and 3/4.	

VII. SIMULATION RESULTS

The Bit error rate curve for various digital modulation techniques with different code rates in WiMAX system with cyclic prefix 1/32 is shown in the Fig. 6.

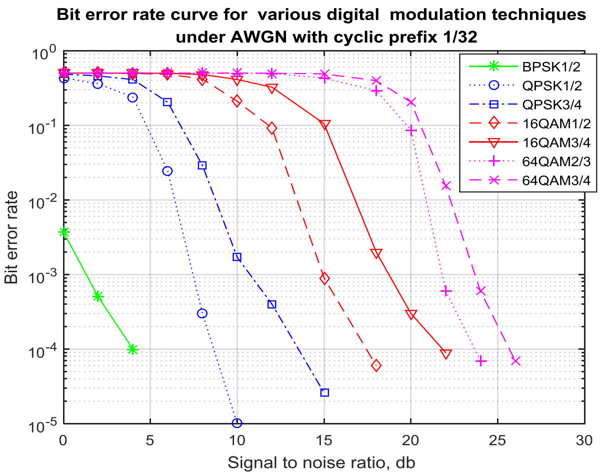

Fig. 6. Demonstrates plot of BER against SNR for various digital modulation techniques under AWGN

TABLE III REQUIRED SNR (DB) TO MAINTAIN A BER BELOW A GIVEN THRESHOLD FOR VARIOUS DIGITAL MODULATION TECHNIQUES UNDER AWGN WITH CYCLIC PREFIX 1/32

Modulation scheme	**BER < 10^{-2}**	**BER < 10^{-3}**	**BER < 10^{-4}**
BPSK 1/2	---	1	4
QPSK 1/2	4.9	6.5	8
QPSK 3/4	8.5	11	13
16 QAM 1/2	13	15	17.5
16 QAM 1/2	17	18.5	22
64 QAM 2/3	22	23	24
64 QAM 3/4	23	23.5	26

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Fig. 6 and Table III show that for various digital modulation techniques with different code rate, on fixing BER (Bit Error Rate), simulated SNR (db) values can be compared and depending on these values, adaptive modulation technique can be applied. At the permissible BER of the system, the modulation techniques can be selected for given SNR of channel.

BPSK digital modulation scheme works efficiently in worst SNR conditions. The Bit error rate curve for BPSK modulation technique in WiMAX system with different cyclic prefixes 1/4, 1/8, 1/16 and 1/32 is shown in the Fig. 7.

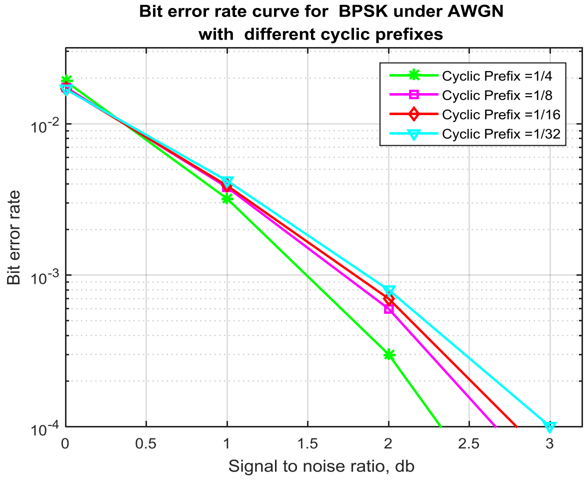

Fig. 7. Demonstrates plot of BER against SNR for BPSK under AWGN with different cyclic prefixes.

Fig. 7 shows that for BPSK, on fixing BER 10-4 the simulated SNR (db) is 2.3, 2.7, 2.8 and 3 for cyclic prefixes 1/4, 1/8, 1/16 and 1/32, which indicates the BER for system having 1/4 cyclic prefix is better than other cyclic prefixes variants.

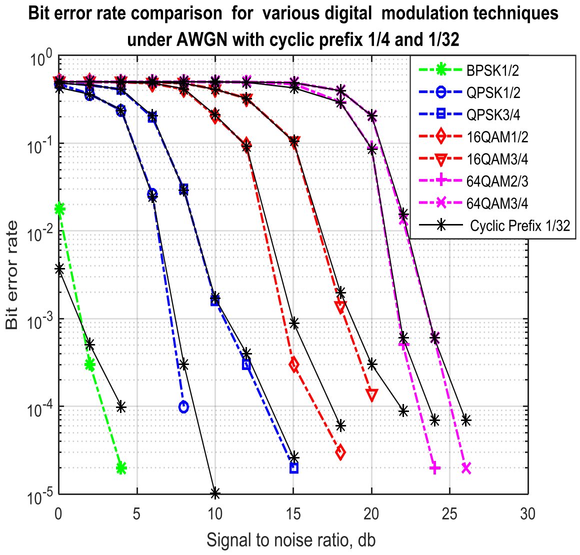

Fig. 8. Demonstrates plot of BER against SNR comparison for various digital modulation techniques under AWGN with cyclic prefix 1/4 and 1/32.

The Bit error rate comparison for various digital modulation techniques under AWGN with cyclic prefix 1/4 and 1/32 is shown in fig. 8. The coloured lines are various digital modulation techniques with cyclic prefix 1/4 and the black line are respectively digital modulation techniques with cyclic prefix 1/32 .

Fig. 8 shows that for BPSK, all digital modulation techniques under AWGN with cyclic prefix 1/4 are better than respective modulation technique with cyclic prefix 1/32. The BER of BPSK is far improved than other higher order modulation schemes for system having 1/4 cyclic prefix is better than other cyclic prefixes variants.

VIII. ADAPTIVE MODULATION

Adaptive modulation is a powerful technique for maximising the data throughput of subcarriers allocated to a user. Adaptive modulation involves measuring the SNR of each subcarrier in the transmission, then selecting a modulation scheme that will maximise the spectral efficiency, while maintaining an acceptable BER. The spectral efficiency can be maximised by choosing the highest modulation scheme that will give an acceptable Bit Error Rate (BER).

In systems that use a fixed modulation scheme the subcarrier modulation must be designed to provide an acceptable BER under the worst channel conditions. This results in most systems using BPSK or QPSK. But these modulation schemes give a poor spectral efficiency (1 - 2 b/s/Hz) and result in an excess link margin most of the time. Using adaptive modulation, the remote stations can use a much higher modulation scheme when the radio channel is good which increases the spectral efficiency of the system.

IX. CONCLUSION

The simulation results of estimated Bit Error Rate (BER) displays that the implementation of interleaved RS code (120,108,8) with 2/3 rated Convolutional code of 64 QAM modulation technique gives less error as compared to other techniques. The modulation scheme is set based on the SNR (dB) of the channel. The SNR (dB) must be greater than the threshold chosen from Table 3 to maintain a maximum BER.

In systems that use a fixed modulation scheme the subcarrier modulation must be designed to provide an acceptable BER under the worst channel conditions. This results in most systems using BPSK or QPSK. But these modulation schemes give a poor spectral efficiency (1 - 2 b/s/Hz).

Using adaptive modulation, the remote stations can use a much higher modulation scheme when the radio channel is good. Thus as a remote station approaches the base station the modulation can be increased from 1 -2 b/s/Hz (BPSK-QPSK) up to 3 - 9 b/s/Hz (8-QAM – 512-QAM), significantly increasing the spectral efficiency of the overall system.

Use of adaptive modulation can effectively control the BER of the transmission, as subcarriers that have a poor Eb/No (db) can be allocated a low modulation scheme such as BPSK rather than causing large amounts of errors with a fixed modulation scheme. For good Eb/No (db), the high modulation scheme giving priority to spectral efficiency can be considered. Eb/No of the channel is estimated before the transmission. The modulation scheme is set based on the SNR of the channel.

The conclusion is that on fixing BER and under good channel conditions QAM with higher mode value gives best spectral efficiency and under worst channel conditions, we can use QPSK, BPSK. Thus, adaptive modulation should be adopted depending upon channel conditions.

Adaptive modulation has not been used extensively in wireless applications due to the difficulty in tracking the radio channel. Work will be done in analysing the SNR (db) of the channel before transmission.

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