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Performance of COFDM Technology for the Fourth Generation (4G) of Mobile System with Convolutional Coding and Viterbi Decoding

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Abstract

The fourth generation (4G) of mobile cellular system network is growing very fast and new services come-up, so intelligent way of visualization and managing the 4G network and service states are required. In this paper, coded orthogonal frequency division multiplexing (COFDM) scheme using convolutional coding with different code rates and Viterbi decoding is used to analyze its performance with respect to un-coded OFDM over both defined categories (A and B) of the 4G system. The bit error rate (BER) is deeply studied taking into account additive white Gaussian noise (AWGN) channel. Hard decision and soft decision of Viterbi decoding are compared through BER. In order to reach high data rate a higher order of modulation schemes M-QAM (M=16, 64 and 256) are employed. Obtained results show that a significant improvement of BER is due to using forward error correcting (FEC) or channel coding compared to un-coded OFDM strategy. The using of two categories of COFDM in 4G parameters gives a good opportunity to make a multiple choices for best selecting the 4G category which make it useful in wide range of environments.

Key-words: 4G, COFDM, convolutional coding, Viterbi algorithm, soft decision, hard decision.

1. Introduction

Due the nowadays huge amount of information to be exchanged via the different wireless communication networks and its predicted traffic increase in near future. The third generation (3G) of cellular mobile network will reach its limits in responding to users' high data rate demand. So, the future 4G mobile communication system deployment comes to solve in part the limitations and remaining problems of 3G systems and to provide a wide variety of new services such as; high quality voice, high-definition video, high speed internet access, and high data rate connections to both wired and wireless channels. Technically, 4G stands for one integrated, IP-baseband environment for all telecommunications requirements including voice, video, broadcasting media and internet that uses both fixed and wireless networks [1]. A concise statement explaining what 4G is meant to be is given as follows:

"4G will be a fully IP-based integrated system of systems and network of networks, achieved after the convergence of wired and wireless networks as well as computer, consumer electronics, communication technology and several other convergences that will be capable of providing 100 Mbps and 1Gbps in outdoor and indoor environments respectively with end-to-end quality of service, high security anytime, anywhere, at affordable cost and one billing" [2].

The coded orthogonal frequency division multiplexing (COFDM) is a modified version of the orthogonal frequency division multiplexing (OFDM). COFDM is used with forward error correction (FEC) or channel coding and gives powerful results in the high data transmission systems over the multipath environments. COFDM has been proposed to be used in the adopted European telecommunications standards institute (ETSI) through terrestrial channels with severe delay spread [3]. Several experimental research works and simulations has been carried out during the last few years on the performance of the COFDM by using different kind of forward error correction (FEC) schemes [4,5,6 and 7]. Research works mentioned in the references [4]-[7] are carried out based on the following standards: IEEE802.11a, fiber optics, DVB-T, and the IEEE802.11a respectively. In this paper, COFDM scheme with channel coding using convolutional coding with code rates ½, 2/3, ¾ and 4/5 is used in the fourth generation (4G) of communication mobile transmitter and Viterbi decoding with hard and soft decisions at the receiver over AWGN channel. A high order modulation schemes such as 16-QAM, 64-QAM and 256-QAM are employed in order to see system behavior using high modulation orders. This paper is structured as follows: Section 2 explains the COFDM system structure. Section 3, describes the channel coding and decoding procedures. Simulation results and discussions are provided in Section 4. Finally, the paper is concluded in Section 5.

2. COFDM system structure

2.1 A qualitative description of COFDM simulation model

In COFDM, the data rate is divided between a large numbers of closely-spaced carriers. This accounts for ‘the frequency division multiplexing’ part of the name COFDM. Only a small amount of the data is carried on each carrier, therefore this significantly reduces the influence of inter symbol interference. The ‘orthogonal’ part of the COFDM name indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system. A forward correcting error (FEC) or channel coding is incorporated in the COFDM system. By using FEC which adds extra data bits at the transmitter, it is possible to correct many of the bits that were incorrectly received. In principal, many modulation schemes can be used to modulate the data at a low bit-rate onto each carrier. In our simulated model of COFDM-4G as shown in the figure 1, quadrature amplitude modulation (M-QAM) which is indicated by data mapper in the COFDM structure is used. OFDM modulation and demodulation are executed by IFFT and FFT respectively. A cyclic prefix (CP) or a guard interval (GI) is added to the start of each time domain COFDM symbol before transmission. In other words a number of samples from the end of the symbol are appended to the start of the symbol. Although the CP introduces some redundancy, and reduces the overall data rate but the CP eliminates both Inter Symbol Interference (ISI) and inter carrier interference (ICI) from the received signal. Finally, a digital to analogue converter (D/A) is used.

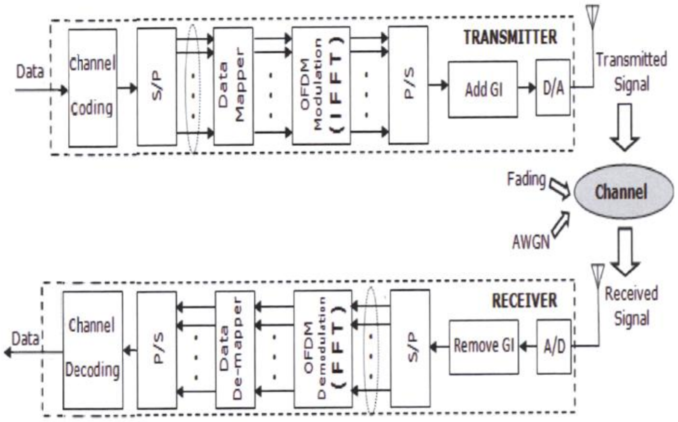

Fig.1. Block structure of COFDM-4G simulation model

In COFDM, the data rate is divided between a large numbers of closely-spaced carriers. This accounts for ‘the frequency division multiplexing’ part of the name COFDM. Only a small amount of the data is carried on each carrier, therefore this significantly reduces the influence.

2.2-Mathematical development of COFDM Scheme

As mentioned above, COFDM transmits over a large number of narrowband carriers, closely spaced in the frequency domain. In order to avoid a large number of modulators and filters at the transmitter, complementary filters and demodulators at the receiver, it is desirable to be able to use modern digital signal processing techniques.

Each carrier can be described as a complex wave as the following

$$x_c(t) = X_c(t).\, e^{j(2\pi f_c t + \varphi_c(t))} \quad (1)$$

Where $X_c(t)$and φ_c(t) are the amplitude and phase of the carrier respectively and can vary on a symbol by symbol basis. The value f_c means the carrier wave frequency, and $x_c(t)$ is the complex time signal of the complex wave of a single carrier. A total of *N* sub-carriers are used in COFDM system. Therefore, the total complex signal $x_s(t)$can be represented by

$$x_s(t) = \sum_{k=0}^{N-1} X_k\,(t).\, e^{j(2\pi f_k t + \varphi_k(t))} \quad (2)$$

Where $X_k(t)$means the COFDM symbol (COFDM frame or block period of COFDM) generated by M-QAM modulation and carried by k^{th}sub-carrier (*k*={0,1,..,*N*-1), f_k is the carrier frequency and $\varphi_k(t)$ is the phase of the sub-carrier. The frequency space between each sub- carrier is defined as:

$$f_k = f_c + k.\Delta f \quad (3)$$

Where Δfrepresent the frequency bandwidth between two successive sub-carriers.

If the signal is sampled using a sampling frequency factor of $\frac{1}{T}$, then the resulting signal is

$$x_s(nT) = \sum_{k=0}^{N-1} X_k\, .\, e^{j[2\pi(f_c + k\Delta f)nT + \varphi_k]}. \quad (4)$$

At this stage, the time over which the signal to *N* samples is analyzed has been restricted. It is convenient to sample over the period of one data sample. Thus, the relationship between the sampling time and the carrier frequency spacing is

$$\tau = NT = \frac{1}{\Delta f} \quad (5)$$

If (4) is now simplified without loss of generality, by letting f_c =0 and also $\varphi_k = 0$ (which means free offset), then the signal becomes as,

$$x_n = \sum_{k=0}^{N-1} X_k\, e^{j(\frac{2\pi nk}{N})} \quad (6)$$

Where x_n is used instead $x_s(nT)$ which represents a discrete time signal in time domain. Now the value in (6) can be compared with general form of the inverse fast Fourier transform (IFFT) as

$$x_n = \frac{1}{N}\sum_{k=0}^{N-1} X_k\, e^{(\frac{j2\pi kn}{N})} \text{ for } 0< n < N-1 \quad (7)$$

And the forward fast Fourier transform (FFT) corresponding to (7) is,

$$X_k = \frac{1}{N}\sum_{k=0}^{N-1} x_n\, e^{(\frac{j2\pi kn}{N})} \text{ for } 0< k < N-1 \quad (8)$$

It should be noted that X_k represents the data to be carried on the k^{th} carrier. Usually M-QAM (M=16, 64 and 256) modulation scheme is used in COFDM, so each of the elements of X_k is a complex number representing a particular M-QAM constellation point. At the receiver side the FFT performs a forward transform on the input sampled data of each symbol [8]:

$$Y_k = \frac{1}{N}\sum_{k=0}^{N-1} y_n\, e^{-(\frac{j2\pi kn}{N})} \text{ for } 0< k < N-1 \quad (9)$$

Where $y = [y_0 y_1 y_2 \ldots\ldots y_{N-1}]^T$ is the vector representing the sampled time domaine signal at the input of FFT at the receiver, and $y = [Y_0 Y_1 Y_2 \ldots\ldots Y_{N-1}]^T$ is the discrete frequency domain vector at the output of the FFT block (see figure 1). In case having additive white Gaussian noise (AWGN) at the receiver, obtained signal is

$$y_n = x_n + w_n \quad (10)$$

Where w_n means the AWGN noise at the *n*-th sample. By substituting (10) into (9), received signal in frequency domain is

$$Y_k = \frac{1}{N}\sum_{k=0}^{N-1}(x_n + w_n)\, e^{-(\frac{j2\pi kn}{N})} = X_k + W_k \quad (11)$$

Where

$$W_k = \frac{1}{N}\sum_{k=0}^{N-1} w_n\, e^{-(\frac{j2\pi kn}{N})} \text{ for } 0< k < N-1 \quad (12)$$

W_k is the noise component at the k^{th}sub-carrier in frequency domain. As each value of W_k is the summation of *N* independent white Gaussian noise processes, its combination with the use of FEC means that usually the performance of COFDM systems depends on the average of the noise power.

3- Channel coding and decoding

The distribution of the data over the many carriers means that selective fading effect will cause some bits to be received with errors. By using channel coding or forward error correcting (FEC), occurrence of errors in communication channel can be avoided. The purpose of FEC is to improve the capacity of a channel by adding some carefully designed redundant information to the data being transmitted through the channel. The process of adding this redundancy is known as channel coding. In this paper a convolutional encoder and Viterbi algorithm of decoding are used for channel coding and decoding respectively.

3.1 Convolutional coding

Convolutional codes are widely used in wireless communication. They are specified by three parameters; (n, k, m), n: is the number of output bits, k: is the number of input bits and m: is the number of memory registers. The quantity R= k/n is called code rate. The parameters k and n range from 1 to 8, and m from 2 to 8 and the code rate from 1/8 to 7/8 except space applications where code rates as low as 1/100 or even longer have been employed [9]. Often the constraint length L= k(m-1) represents the number of bits in the encoder memory that affect the generation of the n output bits.

Conventional encoding is accomplished using several linear shift registers and occurred to add redundant bits to data flow. An input sequence k and contents of shift registers perform modulo-two addition after information sequence is sent to shift registers, so that an output sequence ¨c¨ is obtained. Shift registers store the state information of convolutional encoder, and constraint length ¨L¨ relates the number of bits upon which the output depends. The trellis representation is an adapted diagram for decoding of convolutional codes especially once using Viterbi decoding algorithm.

3.2 Decoding of conventional codes: the Viterbi decoding algorithm

The decoding procedure of Viterbi algorithm consists of calculating the Hamming distance between the receive sequence at an instant ti at a given state of the trellis, and each of all the code sequences that arrive at that state at that instant t_i. This calculation is done for all states of the trellis, and for successive time instants, in order to look for the sequence with the minimum hamming distance. Viterbi algorithm can be used for both hard decision (HD) and soft decision (SD).

4- Simulation results and discussions

The simulation process is carried out on the simulation COFDM-4G model as shown in figure1. Convolutional encoder based on trellis algorithm with different code rates: ¼, 1/3, 1/2 and 2/3 are employed. Higher order modulation schemes M-QAM (M=16, 64 and 256) are used in order to obtain high data rate. Prefix cyclic (CP) is used to prevent both inter symbol interference ISI and inter carrier interference (ICI) from the received signal. AWGN channel is considered. Viterbi based on the trellis algorithm for both hard decision (HD) and soft decision (SD) is used in the channel decoding process. Since 4G systems will be used in wide range of environments, a fixed set of parameters is not capable of achieving high performance in all causes. Consequently 4G systems will be very capable of dynamically adapting one or more of the following design parameters may offer superior performance. So, the parameters shown in table 1 are used in our simulation [10].

Table 1: COFDM design parameters for 4G system

Parameter	Values “A”	Values “B”
Operating Frequency	2GHz	2GHz
Bandwidth ($\boldsymbol{B}$)	4096kHz	4096kHz
Useful Symbol Duration ($\boldsymbol{T}$)	62.5 $\boldsymbol{\mu s}$	125 $\boldsymbol{\mu s}$
Guard Interval Duration ($\boldsymbol{T_g}$)	15.625 $\boldsymbol{\mu s}$ ($\boldsymbol{T/4}$)	31.25 $\boldsymbol{\mu s}$ ($\boldsymbol{T/4}$)
Total Symbol Duration ($\boldsymbol{T_{symbol}}$)	78.125 $\boldsymbol{\mu s}$ (with GI=$\boldsymbol{T/4}$)	156.25 $\boldsymbol{\mu s}$ (with GI=$\boldsymbol{T/4}$)
Inner Channel Coding	Punctured ½ rate convolution code, Constraint length 7.$\boldsymbol{\{133, 171\}_{octal}}$	Punctured ½ rate convolution code, Constraint length 7.$\boldsymbol{\{133, 171\}_{octal}}$
FFT Size	256	512
Number of data Sub-carriers ($\boldsymbol{N_D}$)	216	432
Sub-carrier spacing(Δ_f)	16 kHz	8 kHz

The obtained results referred to technical values “A” of 4G (see depicted values “A” in Table 1) are shown in the figures 2, 3, 4, and 5. Figure 2 represents BER versus SNR for different higher order modulation schemes such as16-QAM, 64-QAM and 256 QAM for hard decision of Viterbi algorithm with ½ of code rate. From the figure 2 we can see that for M=256, SNR =25 dB, for this we got a bit error rate (BER) of 10^{-4} which is fine for digital transmission. So we can conclude that, since the data rate$(D_r = n \log_2 (M)$where n is the number of bits) is directly proportional to M, M increases high data rate increases. A comparison among hard decision, soft decision and un-coded OFDM strategy based on BER versus the signal to noise ratio (SNR) and BER versus energy per bit over average noise power (E_b/N_0) are shown in the figures 3 and 4 respectively. A significant improvement regarding soft decision can be distinguished in both figures. Here, we should note that BER converges toward 10^{-6}. Figure 5depicts the BER performances versus SNR for different code rates ¼, 1/3, ½ and 2/3. It can be observed that as the code rates decreases as better BER is for each SNR value.

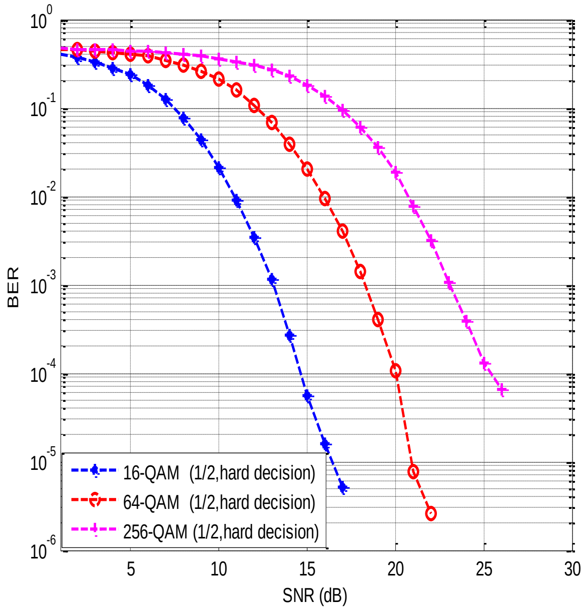

Fig. 2 BER versus SNR for 4G values A for R=1/2 for hard decision

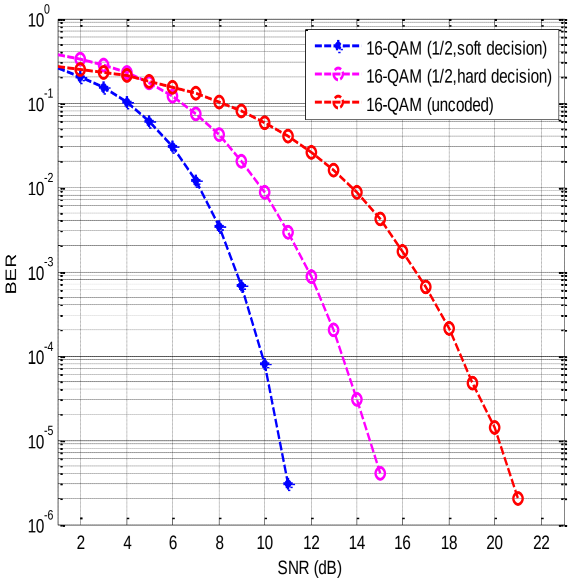

Fig.3 BER versus SNR for 4G values A for R=1/2

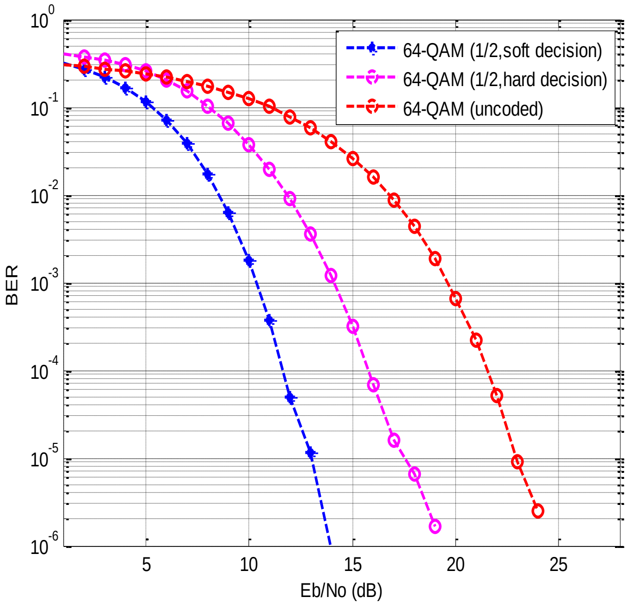

Fig.4 BER versus Eb/No for 4G category A for R=1/2

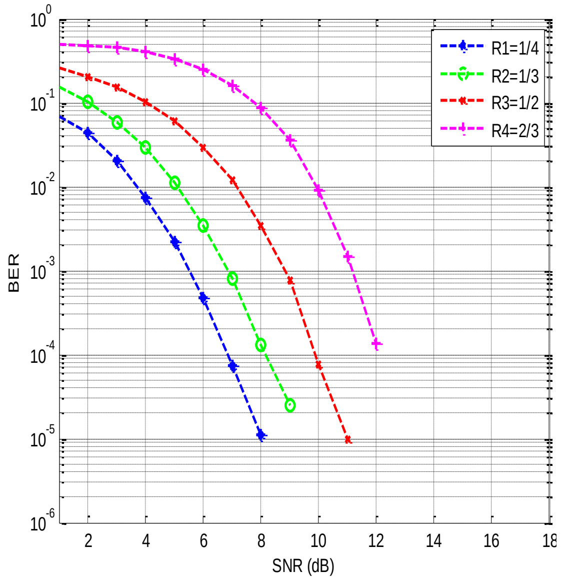

Fig.5 BER versus SNR for different cod rates

(1/4, 1/3, ½ and 2/3) for 4G values A

The obtained performance results of COFDM using technical parameter **"B"** of 4G systems (see "B" values in Table 1) are shown in the figures 6-8. Figure 6 represents BER versus SNR for higher modulation schemes for hard decision; the results in this case are more accurate than category A. Figure 7 makes a comparison among hard decision soft decision and un-coded OFDM strategy. Here, also soft decision is more accurate than hard decision. Figure 8 represents a comparison based on BER versus E_b/N_0 for hard decision, soft decision and un-coded OFDM where soft decision is much accurate with respect to others. From figure 8 we can note that for E_b/N_0 = 9 dB, the corresponding BER is 10^{-6} for the soft decision, however for the same value of E_b/N_0 the corresponding value of BER is 10^{-3} for hard decision and a difference of 4 dB between them. So, we can conclude that our developed COFDM-4G system for soft decision can be hardly implemented with great accuracy.

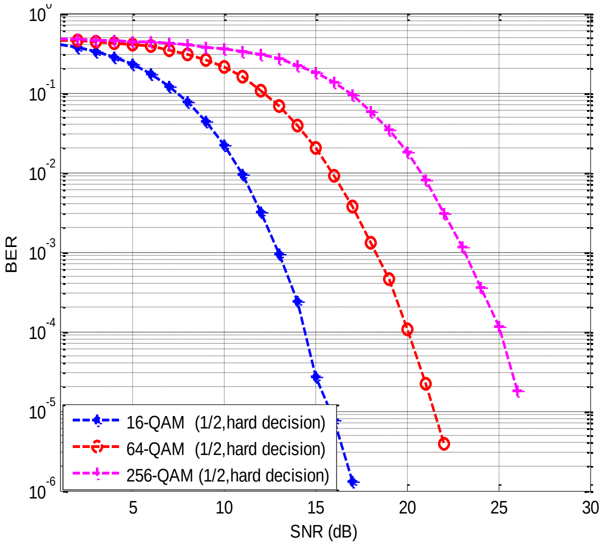

Fig.6 BER versus SNR for 4G values B for R=1/2

for hard decision

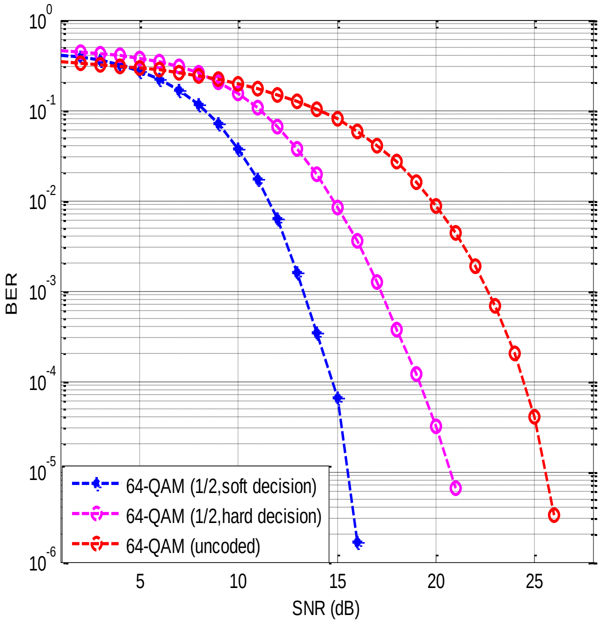

Fig.7 BER versus SNR for 4G values B for R=1/2

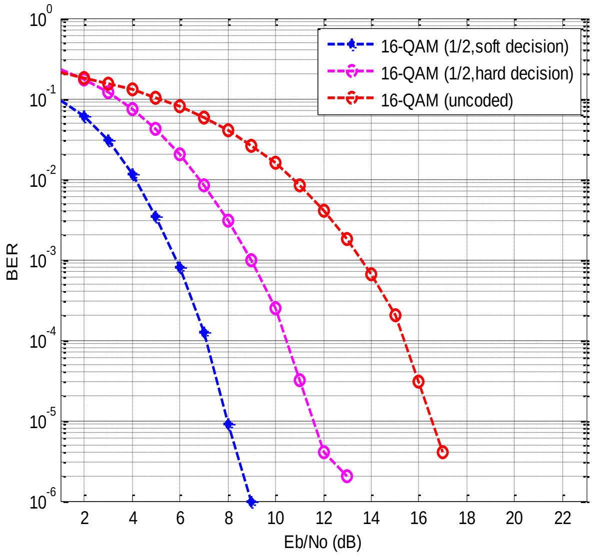

Fig.8 BER versus E_b/N_0 for 4G values B for R=1/2

5. Conclusion

Accurate results are obtained through COFDM-4G model simulation where BER attends almost $10^{-6}$for the most the cases especially for soft decision of Viterbi decoder. This paper provides a clear map for kind of parameters of COFDM-4G that can be adopted since 4G systems will be used in wide range of environments. The obtained results are compared to the results published in references [10] and [11] and they are in good agreement which strengthen the actual work.

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