Afr. J. Comp. & ICT
Vol. 1, No. 1, 2008, pp. 11 -21
ISSN 2006-1781

PERFORMANCE OF A TURBO CODED DIGITAL COMMUNICATION SYSTEM ON WIRELESS COMMUNICATION CHANNELS

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Received 20 June,2006

Communicated by Dele Oluwade

ABSTRACT

In modern digital communication systems, error-free transmission is often required. And the issue of wireless communications is becoming increasingly important. However, due to the hostile nature of wireless communication channels, it is necessary to develop a very powerful coding scheme. In this paper, we design a low complexity iterative decoding algorithm with interleaver, and also we develop an efficient method for its implementation in hardware. We investigate the performance of turbo codes on a wireless communication channel by varying some turbo codes parameters using an Error Correction Coding (ECC) technique to achieve high coding gain. This investigation is important because of the challenges of 3G/4G wireless generation and the fact that wireless communication systems has the potential of making the idea of communication everywhere a reality. We use a turbo-coded digital communication system to compare the performance of wireless channels for future wireless communication systems.

Keywords: Wireless communication channels, turbo codes, digital communication systems

I. INTRODUCTION

Wireless transmission is radio transmission via the airwaves. It is a generic term that refers to numerous forms of non-wired transmissions, including AM and FM radio, TV, cell phones, portable phones and wireless LANs. Various techniques are used to provide wireless transmissions, including infrared line of sight, cellular, microwave, satellite, packet radio and spread spectrum. The challenges of 3rd generation (3G) and 4th generation (4G) wireless communications have made wireless systems gain enormous attention. These challenges such as high data rate transmissions and Quality of Service (QoS) management have made researchers focus attention on the wireless domain. Presently, wireless systems are considered an integral part of the information superhighway [1]-[3]. Also, because of the high data rate, turbo codes have been adopted in the 3rd generation mobile systems [4]. In order to achieve high rates of data and low Bit Error Rate (BERs), turbo codes are explored. They were first introduced by [5] in 1993. The original turbo codes offer near-capacity performance for deep space and wireless channels [5], [6]. Turbo codes and iterative decoding techniques based on the Maximum A Posteriori (MAP) algorithm with Soft-In Soft-Out (SISO) decoders are methods for obtaining high error control decoder performance with moderate decoder complexity at very low signal to noise ratio (SNR). They combine recursive systematic convolutional (RSC) codes along with a pseudo-random internal interleaver and (MAP) iterative decoding algorithm to achieve performance, which is close to the Shannon limit [5],[8]. Because of these features, turbo codes have been proposed for communication systems such as wireless communication links [7].

On many links such as wireless communication channels, transmission errors are usually caused by variations in the received signal strength and this is referred to as fading[9],[10]. This degrades the transmission performance. Error Correction Coding (ECC) techniques are required to reduce the effect in signal-to-noise ratio (SNR)[10],[11]. ECC is a system of error control for data transmission wherein the receiving device has the capability to detect and correct some bits or symbols corrupted by transmission errors. This is accomplished by adding redundancy to the transmitted information using a predetermined algorithm.

It is not easy to achieve high data rates over wireless channels because of these characteristics [7]. Further, unlike bounded systems, wireless communication systems are susceptible to time-varying impairments, such as multi-path fading [10],[11]. Multi-path fading refers to radio signals that take two or more paths because the signal is reflected off buildings or other obstructions. Multi-path is a problem with all kinds of radio transmission. The effects of multi-path include constructive and destructive interference, and phase shifting of the signal. The standard statistical model of this gives a distribution known as the Rayleigh distribution as shown in Figure 1. Rayleigh fading with strong line of sight content is said to have a Rician distribution as shown in Figure 2. In digital radio communications multi-path can cause errors and affect the quality of communications. The degree of distortion of the received signal varies in time and this is classified as large-scale variations and small-scale variations [12]. Large-scale fading represents the average signal power attenuation due to the motion over a large area while Small-scale fading (e.g Rayleigh/Rician distribution) refers to the changes in signal amplitude and phase that occur as a result of small changes in the distance between the transmitter and the receiver [10],[12].

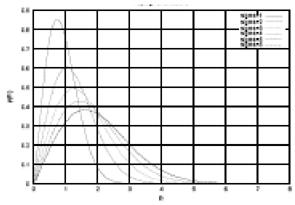

Fig.1. Rayleigh Channel

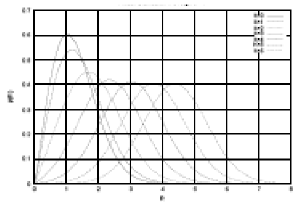

Fig.2. Rician Channel

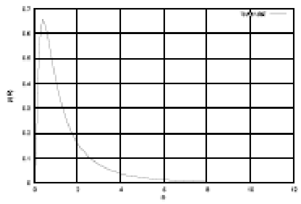

Fig.3. Lognormal Channel

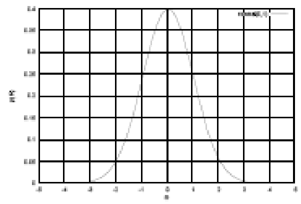

Fig.4. Gaussian Channel

The log-normal distribution as shown in Figure 3 is used to model environment where power-controlled fading is required [6],[11]. AWGN shown in Figure 4 represents the model of thermal noise in all electronic circuitry, and it is always added to a simulation channel model, irrespective of what other channel effects are taken into account. This paper focuses on the performance of turbo codes over AWGN and flat wireless communication channels. We investigate the iterative power of turbo codes on wireless channels. We varied the frame length of the input bits and the state of encoder to exploit the performance limit of turbo iterative decoding.

The remainder of this paper is organised as follows: Section II presents general transmission of information. In Section III, wireless channel characteristics are discussed. Section IV presents some common fading channel models. Section V describes the components of turbo codes. In Section

VI, the system model and simulation results are presented. Conclusions are drawn in Section VII.

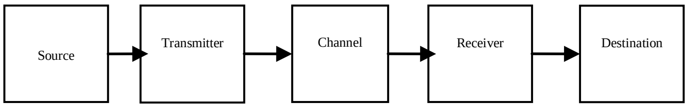

Fig.5. Block Diagram of Digital Communication System

II. THE TRANSMISSION OF INFORMATION

Since the development of equations to describe electromagnetism medium by James Clerk Maxwell, and the subsequent invention of radio communications, the Electromagnetic spectrum has been widely used for various applications since the development of equations that describe electromagnetism medium. As a result radio communications was invented. A lot of work has been carried out that analysed the communication between two entities and characterised the information received. This was performed to optimise the rate of communication and bit error rate (BER) between the two communication entities. A communication system can be described as a link between a source and a destination. In this system the information is usually sent from the source and received at the destination as shown in Figure 5. The transmitter takes the information from the source and encodes it in a form suitable for transmission over the channel in such a way that the cost of transmission is reduced. The cost of transmission is a function of the bandwidth, the time taken to transfer information and the bit error rate. The channel describes how the communications medium alters the communication signal by introducing some kind of random errors. The receiver at the other end decodes the signals, which have been distorted by the channel, and attempts to recover the information that was sent by the source. Eventually, the estimate of this information is passed to the destination as the received information from the source. The task of improving the performance of communication system is the goal of coding techniques and it is the focus in this paper.

Technically, for a radio communication system, the channel can be expressed in terms of an impulse response. In an environment where there are numbers of distinct propagation paths from the transmitter to the receiver, the complex baseband discrete representation of the channel impulse response is:

$$h(t) = \sum_j A_j e^{i\phi_j} \delta(t - \tau_j) \tag{1}$$

where A_j represents the magnitude of the impulse response at the delay τ_j with associated phase, angle ϕ_j , and $\delta(.)$ is the Dirac delta function. In a mobile wireless communication system, the channel is affected by the motion communicating entities and environments such as terrain features. The performance here depends on time-varying and delay due to changing environment. This channel impulse responds can be represented as

$$h(t,\tau) = \sum_j A_j(t) e^{i\phi_j(t)} \delta(t - \tau_j) \tag{2}$$

where $A_j(t)$ and $\phi_j(t)$ depend on the distance from the transmitter to the receiver and are described statistically in many channel models 21]. In a communication system the received signal is generally described in terms of the transmitted signal and the channel impulse as:

$$\tilde{r}(t) = \tilde{s}(t) \otimes h(t,\tau) + \tilde{n}(t) \tag{3}$$

Using equation (2 and 3) we obtain

$$\tilde{r}(t) = \sum_j A_j(t) e^{i\phi_j(t)} \tilde{s}(t - \tau_j) + \tilde{n}(t) \tag{4}$$

where $\otimes$ represents the convolution operation and $\tilde{n}(t)$ represent the noise function, which is the equivalent complex baseband AWGN with the single receiver for the j^{th} channel with single-sided power spectral density 2N W/Hz. N_k; k = 1, 2,… x [20],[22].

III. WIRELESS CHANNEL CHARACTERISTICS

The communication channel is the path for data transmission between the source and the destination. In this work the radio frequency spectrum is considered as the transmitting channels. This Section explains the mode of electromagnetic propagation and the losses experienced in line-of-sight (LOS) link wireless communication.

A. Mode of Electromagnetic Propagation

The largest obstacle facing designers of wireless communications systems is the nature of the propagation channel. Wireless channels are characterised by fading and interference. However, the performance of wireless channel depends on the mode of propagation of radio waves. Electromagnetic waves travel through the Earth's atmosphere in different modes: The Ground Wave propagation is a mode whereby the wave propagating frequencies are below 30Mhz and the propagate along the Earth's curvature guided by the surface. The guided wave has two components, the direct wave, and the reflected component. Ionospheric waves propagation with frequencies between 30Mhz and 300Mhz. These frequencies are reflected by the ionosphere and travel much further than ground waves.

In Tropospheric Scattering, the propagating wave's frequencies are above 300 MHz and less than 3 GHz. Here, the signal cannot cross the troposphere but is scattered by it. The scattered waves, which are much weaker, can be received and demodulated. LOS is a kind of wireless communication with frequencies above 3Ghz and to about 12Ghz. However, frequencies above 12Ghz suffer from oxygen and water vapour absorption and this could cause a degradation in the transmission [6]- [27].

B. Losses Experienced in LOS links

The loss experienced by the transmission signal are classified as free space loss (FSL), loss due to rain, loss due to antenna misalignment and loss because of gaseous absorption. FSL is the largest signal energy attenuation and it is a function of the distance travelled. Signal attenuation as a result of rain is the second most significant after FSL. Frequencies in the Ku and Ka bands are affected most by the attenuation effects. The effects are depending on location of the transmitting system. This problem is mostly address by ground diversity such as having another ground station located a few miles away in rainy seasons. The effect of antenna misalignment is noticed if the received power is off the bore sight. The gaseous absorption is the attenuation caused by clouds and fog [6]-[27].

IV. THE CHANNEL MODELS

The link between the transmitter and the receiver varies from purely LOS to one that is scattered through obstruction by buildings, mountains etc. There are several factors which determine the behaviour of such a channel, for instance, the terrain features between the transmitter and receiver, the speed of transmitter and receiver, and weather conditions. Over the years several studies and measurements have been undertaken in different locations for such channels. Various models have been proposed. Frameworks and simulation results of the wireless channels along with the time variations have been extensively reported in the literature. Based on the nature of the radio propagation environment, different mathematical models exist to describe the statistical behaviour of the fading channel [22]:

A. Gaussian Fading Distribution

In a fixed wireless channel, the signal envelopes and phase can be modelled as a Gaussian distribution given by [1]

$$p_1(r) = \frac{1}{\sqrt{2\pi}\sigma_1} exp\left(-\frac{(r-\mu_1)^2}{2\sigma_1^2}\right) \qquad (5)$$

and

$$p_2(\phi) = \frac{1}{\sqrt{2\pi}\sigma_2} exp\left(-\frac{(\phi-\mu_2)^2}{2\sigma_2^2}\right) \qquad (6)$$

where μ_1 σ_1 and μ_1 σ_2 represent the mean and variance of the of the envelope and phase respectively.

B. The Rayleigh Fading Distribution

The Rayleigh distribution model assumes that all the components that make up the resultant received signal are reflected or scattered and there is no direct path (i.e LOS) from the transmitter to the receiver. The Rayleigh distribution is a model used to describe the diffuse component. The diffuse component can be expressed as a sum of a number of scattering point sources.

$$R_{diffuse} = \sum_j A_j.e^{i\theta_j} \qquad (7)$$

where θ_j is the phase of the j^{th} diffuse component, A_j is the random amplitude of j^{th} scattered wave. The probability density function (pdf) of the Rayleigh model is given as [22]

$$p(r) = \frac{r}{\sigma^2} exp\left(\frac{-r^2}{2\sigma^2}\right), \quad r \geq 0 \qquad (8)$$

where r is the received signal envelope and σ is the variance of the distribution.

C. Rice Fading Distribution

The Rice distribution is used to model the propagation environment in which LOS propagation is dominant. In such case the resultant signal amplitude follows the Rician distribution with the ratio between the LOS and diffused components denoted by the Rice factor K. The model is usually used to describe the unshadowed component. It can be expressed as

$$R_{unshadowed} = C + \sum_{j=1}^{n} A_j . \exp^{i\theta_j}, \qquad (9)$$

where C is a constant coherent signal with clear LOS and the rest of the symbols are as defined above. The model, in terms of probability distribution of the received signal envelope, r, is given as [6],[24]

$$p(r) = \frac{2r}{2\sigma^2} exp\left(-\frac{r^2 + C^2}{2\sigma^2}\right) I_o\left(\frac{2rC}{\sigma^2}\right), \qquad r \geq 0 \, (10)$$

where I_o is the modified Bessel function of order zero. The phase distribution is no longer uniform like a Rayleigh distribution. Also, with C = 0, its pdf tends to Rayleigh fading process.

V. **DESCRIPTION OF TURBO CODES**

It has been proved that the reliable communication is possible over a noisy channel as long as the transmission rate is less than the channel capacity [16]. Also it has been proved that the channel capacity can be achieved by using linear codes. This has lead to report work on turbo codes. Turbo codes are the concatenation of two recursive systematic convolutional linear codes separated by an interleaver [6]. Turbo codes have been shown to perform near the Shannon limit on AWGN channels with a relatively simple iterative decoding technique [5].

A convolutional code can be made systematic without affecting its minimum distance properties by feeding back one of the outputs to the input. Such a code is called a Recursive Systematic Convolutional (RSC) code, and is the bases for turbo codes. A systematic code is one for which each n symbol codeword contains the k data bits. The remaining n − k bits are called parity bits. A Recursive Systematic Convolutional codes with two components is shown in Figure 6 [25],[26],[27].

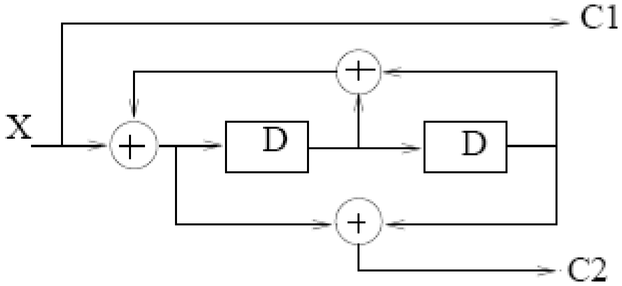

Fig.6. The RSC Encoder

A. Turbo Code Encoder

A configuration of turbo code is shown in Figure 7. It represent the turbo code encoder with r = 1/3. The first RSC encoder outputs the systematic c1 and recursive convolutional c2 sequences while the second RSC encoder describes its systematic sequence and only outputs the recursive convolutional c3. x denotes the information source [25]-[27].

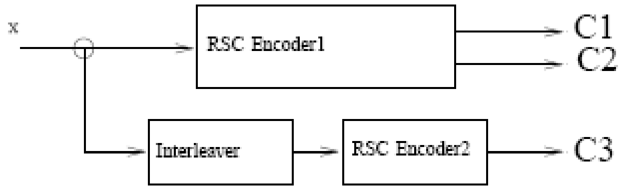

Fig.7. Block Diagram of Turbo Encoder with rate = 1/3

B. Turbo Decoding - MAP Decoding

The optimum decoding procedure for turbo codes is the maximum a posteriori (MAP) algorithm. It is an algorithm that estimates random parameters with prior distributions. With reference to decoding of noisy coded sequences, the MAP algorithm is used to estimate the most likely information bit to have been transmitted in a coded sequence. This algorithm is suited for iterative decoding because it provides better performance. In solving the codeword decoding problem, the MAP codeword decoding identifies the most probable codeword x given the received signal r. In general this can be represented as

$$P(x|r) = \frac{P(r|x)P(x)}{P(r)}$$

The second factor in the numerator defines the prior probability of the codeword, P(x), which is usually assumed to be uniform over all valid codewords. The first factor in the numerator, P(r|x), defines the likelihood of he codeword, which is a separate function and is given as

$$p(r|x) = \prod_{n=1}^{N} P(y_n|x_n). \qquad (11)$$

If we consider a Gaussian channel with transmissions $-\mu$

or $+\mu$ and additive noise of standard deviation σ, then the probability density of the received signal r_n in the two cases $x_n = 0, 1$ and is given as

$$p(r_n|x_n = 1) = \frac{1}{\sqrt{2\pi}\sigma} exp\left(-\frac{(r-\mu)^2}{2\sigma^2}\right) \qquad (12)$$

and

$$p(r_n|x_n = 0) = \frac{1}{\sqrt{2\pi}\sigma} exp\left(-\frac{(r+\mu)^2}{2\sigma^2}\right) \qquad (13)$$

For decoding part of the transmitting system, the likelihood ratio is always considered. Also, if Gaussian channel is considered, the equation becomes

$$\frac{p(r_n|x_n = 1)}{p(r_n|x_n = 0)} = exp\left(\frac{2\mu r_n}{\sigma^2}\right) \qquad (14)$$

For instance, if the likelihoods are given as (0.2, 0.4, 0.9, 0.1, 0.7), then the ratios of likelihoods resulted from this are

$$\frac{p(r_n|x_n = 1)}{p(r_n|x_n = 0)} = \frac{0.2}{0.8}, \quad \frac{0.4}{0.6}, \quad \frac{0.9}{0.1}, \quad \frac{0.1}{0.9}, \quad \frac{0.7}{0.3}. \quad (15)$$

Finally, if the threshold of the he likelihoods is considered at 0.5 then r = (0, 0, 1, 0,1)

VI. **THE SYSTEM MODEL AND RESULTS**

A. The System Model

A turbo coded system signalling through AWGN and fading channels is considered. This is modulated by a Binary Phase Shift Keying (BPSK) spread-spectrum. The block diagram for the implementation of the system is presented in Figure 8.

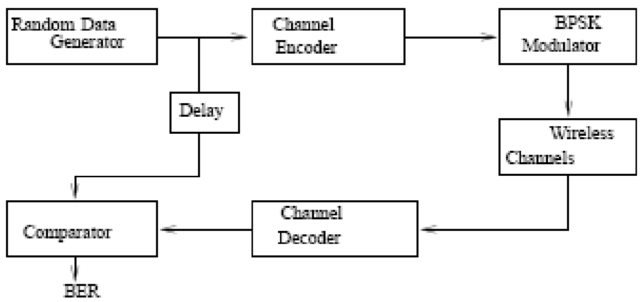

Fig.8. Block Diagram of System Model

In the transmission system, The binary information bit stream $d_x(i') \in (0,1)$ where $i' = 1,2,\ldots E$ is encoded by a rate 1/3 turbo encoder. The output of the turbo encoder is the code bit stream $b(i) \in (-1,+1)$ where $i = 1,2,\ldots D$. Interleaver may be is used to reduce the influence of the error burst at the input of each channel decoder. The BPSK is applied and each interleaved code bit is modulated and mapped as -1 and +1. The spread spectrum signal is then transmitted through the a channel and the transmitted signal generated is given by

$$y_x(t) = A\sum_{i=1}^{M} b^k(i)s_i(t) \qquad (16)$$

Where M denotes the number of code bits per frame. A and $s_i(t)$ denote respectively the amplitude and normalised signature waveform of the i^{th} code bit, and The interleaved bit is denoted by b^k. It is assumed that $s_i(t)$ is the unit energy. A periodic spreading sequence is also assumed. In the turbo encoder the frame of input binary information bits, denoted by d_x , where x = 1,2, … I and I represents the size of information bit frame. The output bit frame is denoted by b_x , where x = 1,2, … M and M represents the size in bits of the encoded frame.

A time varying, asynchronous channel model is considered but the mobility of the users is assumed to be constant in the implementation. However, a signal y(t) assumed to be transmitted through a channel with impulse response

$$h(t) = \sum_{l=1}^{x} A_l'(t)\delta(t-\tau_l) \qquad (17)$$

where $A_l'(t)$ are complex fading processes, and τ_l is the delay of the path signal. It is assumed that the fading processes are known to the receiver and do not vary during one coded interval, but may vary from symbol to symbol. Using equations (16) and (17), the received faded signal is resolve to

$$r(t) = y_x(t) \otimes h(t) = A\sum_{i=1}^{M} b^k(i)\sum_{l=1}^{x} A_l(t)s_i(t-\tau_l) \qquad (18)$$

The total received signal is then given summarised as

$$\tilde{r}(t) = r(t) + n(t) \qquad (19)$$

where n(t) is zero-mean, complex white Gaussian noise
of power spectral density σ^2.

B. Input Parameters
The following parameters shown in table below are considered for this system.

Parameters	Value Considered
Frame-Length	256 and 1024 bits
Encoder State	4, 8, and 16 States
Iterations	1, 2, and 8
Rate	1/3
Channels	AWGN, Rayleigh and Rician
Seeds	987654321
Information	1000000 bits

C. Simulation Results
Computer simulations were carried for the evaluation of our system to determine the performance of turbo codes of varying complexity in the AWGN and frequency non-selective wireless channels. The average BER of the coding schemes in an ideal situation is determined. The performance of turbo codes was found to depend on the number and position of errors within the received sequence. In particular, the performance of turbo code over MAP algorithm is performed on AWGN with frame length 256 and 1024 bits. The state 4, 8 and 16 were considered and the simulation results are presented in Figure 9 and 10 respectively. In both cases the coding gain is obtained when the number of iterations is increased. Figure 11 shows the performance of state 4, 8 and 16 when the frame length was kept constant. It is found that the state 4 has the worst performance while the state 16 has the best performance with coding gain of about 1.9 decibels at BER = 10^{-6}. The performance comparisons of frame-length 1024 and 256 were also investigated at different state of encoder but with a fixed number of iteration. This simulation result is presented in Figure 12. It can be seen from the curves that in all the states of encoder, the frame length 1024 bits outperform 256 bits. For instance, 1024 bits have an average coding gain of about 0.5 decibel at BER = 10^{-6} over 256 bits. Finally, Figure 13 shows the performance result of turbo codes for some wireless channel distribution models. This includes AWGN, Rician and Rayleigh channels models. In the Figure, the performance of turbo codes over AWGN is found to be the best follow by the Rician channel.

VII. **CONCLUSION**

In this paper, the performance of turbo codes of rate 1/3, frame-length 256 and 1024 bits, and encoder states of size 2, 4 and 16 are investigated over

AWGN and fading wireless channel. The performance among these parameters is varied and compared using turbo error correcting codes. It has been shown that a substantial coding gain can be obtained when the number of iterations is increased. Similar coding gain is obtained for the increase in frame-length and state of encoder. The performance comparison among AWGN, Rayleigh and Rician channels is investigated in an ideal condition.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the African Institute for Mathematical Sciences (AIMS) for providing the facilities, which he uses to prepare this paper and Dr. Dele Oluwade for his academic support and encouragement. He would also like to thank Professor A.F. Beardon of Cambridge University, Professor Wesley Kotźe, Dr. Mike Pickles and Adze Emmanuel Teba for carefully reading this paper and providing useful suggestions. Special thanks go to my wife, Olajumoke Olufemi Ajibesin, for her contributions and love.

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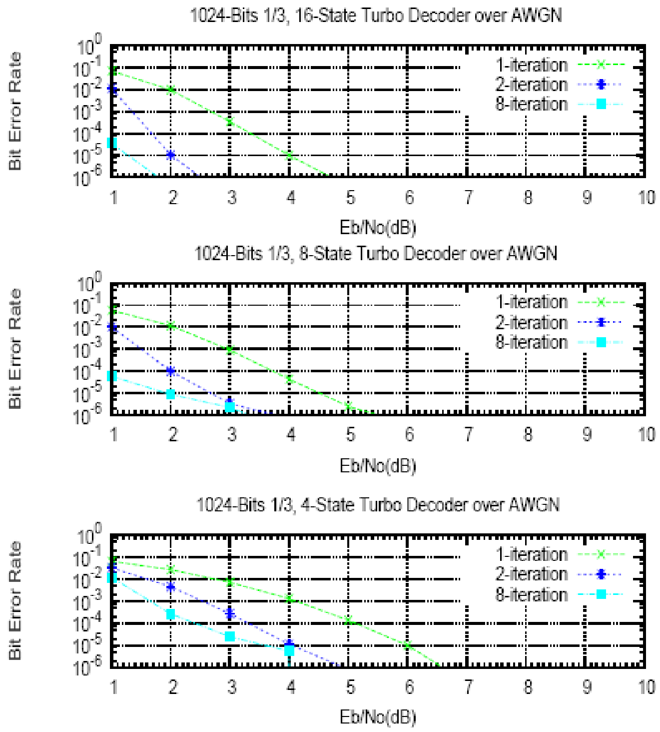


Fig. 9. Determine the performance of turbo codes by varying the number of iteration and encoder state for transmission bits = 1024

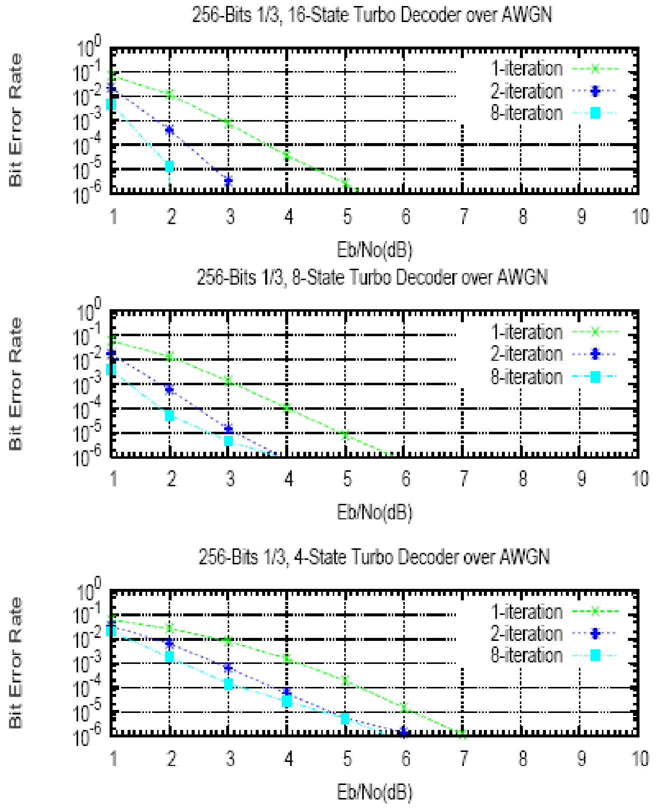


Fig. 10. Determine the performance of turbo codes by varying the number of iteration and encoder state for transmission bits = 256

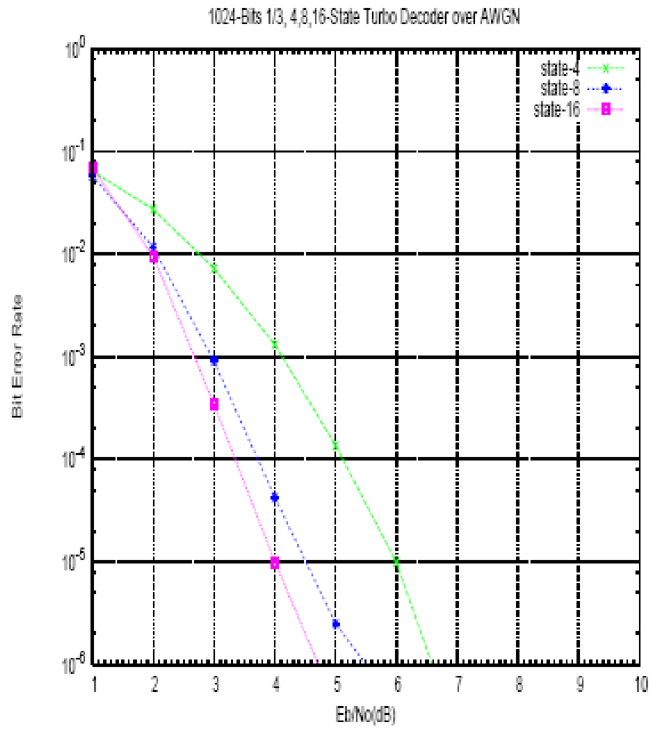


Fig. 11. Determination of the performance of turbo codes by Comparing the state of encoder at a fixed frame length = 1024

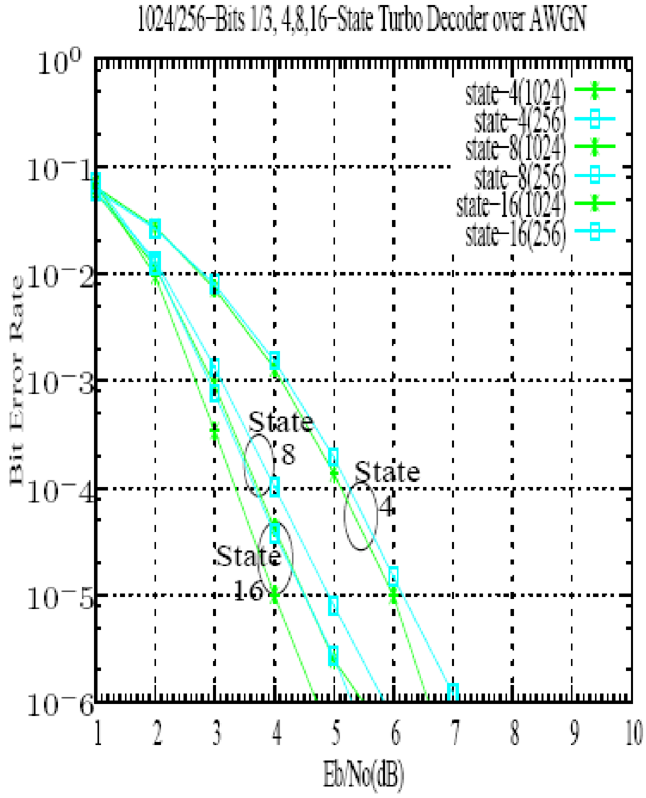
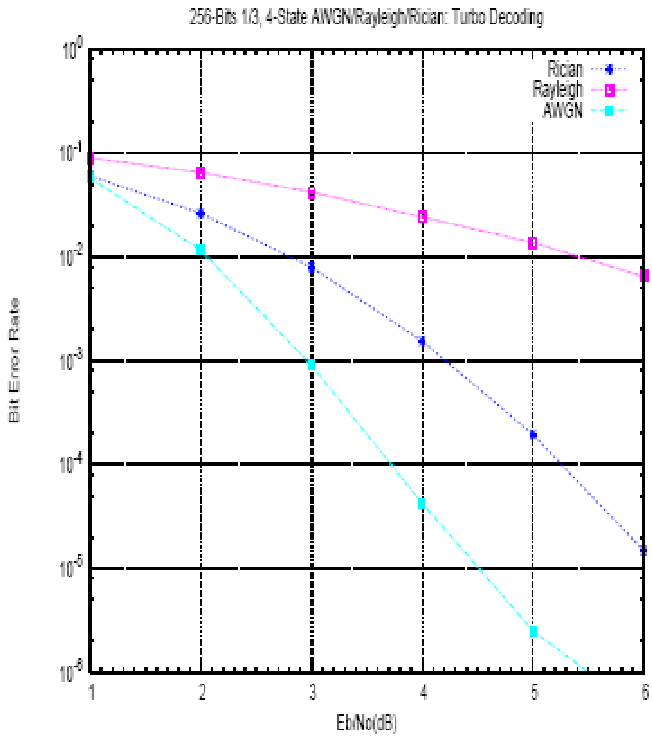


Fig. 12. Determination of the performance of turbo codes by comparing the state of encoder at different frame length at a fixed number of iteration.



The performance comparison of AWGN, Rayleigh and Rician channels in ideal situation at a fixed number of iteration, state of encoder and frame lenght