Enancement The Reverse Link Capacity of Third Generation Mobile Radio System

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Abstract

The paper investigates the effect of including the turbo coding in the 3G system. The bit error rate performance of the system with AWGN channel is investigated to study the effect of number of iteration, frame size, code rate and memory size of the symmetrical convolutional code. It then assess the performance of the system over mobile fading channel that exhibits Rayleigh multipath. The assessment also compares the performance with and without diversity. This paper also investigates the effect of turbo code with diversity on reverse link capacity to find the maximal number of simultaneous users per cell.

The results of computer simulation clearly demonstrate the magnificent enhancement gained by the use of turbo coding on the performance of the system (bit error rate). Furthermore, it has been found that as the iteration number and frame size increase the advantages in tolerance to additive white Gaussian noise will also increases.

Keywords: Turbo coding, Diversity, CDMA and Mobile Radio Receiver

ألخلاصة

يعرض البحث تأثير إضافة المر مز التربوي في نظام الجيل الثالث. تم بحث أداء معدل الخطأ للبت للنظام في القناة نوع AWGN لغرض دراسة تأثير عدد المحاولات وطول الأطر ومعدل الترميز ومقياس الذاكرة للمر مز الالتفافي المتناظر كما تم تقييم الأداء للنظام عبر القناة الرديوية المتنقلة ذات المسارات المتعددة نوع رايلي. في تقييم ألأداء تم فحص معدل الخطأ لبت لسرع نقال مختلفة وأطر مختلفة وحالات ترميز مختلفة في المر مز وكذلك عدد محاولات مختلفة في فك الترميز. إن التقييم يقارن ألأداء مع وبدون استلام متعدد. إن البحث هنا يدرس تأثير المر مز مع ألاستلام المتعدد في سعة الوصلة العكسية لغرض إيجاد أقصى عدد من المستخدمين في آن واحد لكل خلية.

إن نتائج المحاكاة الحاسبية أوضحت قدر التحسين بالأداء بعد استخدام المر مز التربوي وأوضحت أيضا انة كلما ازدادت عدد المحاولات وحجم الإطار في المر مز كلما ازدادت الفائدة في السماحة للضوضاء المضافة نوع كاوسين.

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I- Introduction

The proposed third generation wireless system have to support variable data rate from (348 kbps) for business to up 2 Mbps for local high bit rate. Some of the data services require highly reliable communication having bit error rates less than (10^{-5})[1]. Spread spectrum techniques have been long established for antijam and multipath rejection application. Recently, one form of spread spectrum techniques, CDMA capacity is only interference limited (unlike FDMA and TDMA capacities which are primarily bandwidth limited). Thus it is efficine in recent application where there is a great demand on bandwidth. Furthermore, human voice activity cycle is 35 percent. Thus when users assigned to cell are not talking VAD (voice activity detection). This will allow all other users to benefit due to reduced mutual interference. CDMA is only technology that takes advantage of this phenomenon.[2,3]

Parallel concatenated interleaved codes popularly known as " turbo codes " have shown to perform near Shannon limit on the (AWGN) channel. This powerful channel coding technique has also been studied for digital communication system over more problematic wireless fading channels, but mainly for flat fading channel and short form speech transmission with narrow band (DS – CDMA) system. [4, 5]

Diversity is a well-known technique for improving performance in mobile radio communications at relatively low cost. Furthermore, there are wide ranges of diversity implementations, many which are very practical and provide significant link improvement. There are different techniques for generating diversity paths one of which is antenna diversity. In antenna diversity, antennas can be separated vertically or horizontally in the base station. Separations between antennas on the order of several tens of wave lengths are required [4, 5] .

In this paper, the performance of a turbo code in a Rayleigh Multipath Channel is studied through simulation. Set of simulation parameters is chosen to closely match the 3rd generation UMTS requirements. The effects on bit error performance with AWGN and multipath fading is investigated by high and low mobile speed with and without diversity under different sizes of frame length, memory of systematic convolutional code (RSC) to evaluate the number of users per cell.

II- CDMA Capacity

The system to be considered consists of numerous mobile (or personal) subscribers communication with one or multiple cell site (or base stations) which are interconnected with mobile telephony switching office (MTSO). We begin by considering a single cell system. Each user of CDMA system occupies the single entire allocated spectrum, employing a direct sequence spread spectrum waveform. We assume a CDMA system at subscriber units with digital baseband processing units as shown in Fig. (1).

It can be noted that for a single cell site with power control all reverse link signal are received at the same power level. For N users, each cell site demodulator processes a composite received waveform containing the desired signal having power S and (N-1) interfering signal each also of power S. thus the signal-to-noise (interference) power is.

$$SNR = \frac{S}{(N-1)S} = \frac{1}{(N-1)} \quad (1)$$

It is interesting to note that the number of users is limited by the by the user SNR. Furthermore, the energy per bit to noise density ratio is

$$\frac{Eb}{No} = \frac{S/R}{(N-1)S/W} = \frac{W/R}{(N-1)} \quad (2)$$

where R is the information bit rate, W is the total spread bandwidth, and W/R is the processing gain of CDMA system. If background noise due to spurious interference and thermal noise is also considered equ. 2 becomes

$$\frac{Eb}{No} = \frac{W/R}{(N-1)+(\eta/S)} \quad (3)$$

This implies that the capacity in terms of the number of users is given by:

$$N = 1 + \frac{W/R}{Eb/No} - \frac{\eta}{S} \quad (4)$$

Here Eb/No is the value required for adequate performance. Any spatial isolation of users in a CDMA system will be translated directly into an increase in the system capacity.

Let there are three directional antennas having 120 degree beamwidths. Now the interference source can be seen by any of the omni-directional antenna. This reduces the interference term in denominator of equ. (3) by a factor 3 and the number of users (N) is approximatily by the same factor. Let N_s be the number of users per sector. The interference received by the antenna in that particular sector is proportional to N_s and the number of users per cell is approximately dive by $N=3N_s$.

Voice activity monitoring is a feature present in most digital vocoders where the transmission is suppressed for that user when no voice is present. Let the term α denotes the voice activity factor which has been set to 3/8 (corresponding to the human voice activity cycle of 35-40 present). The interference term in the denominator of equ. (3) is thus reduced from (N-1) to (N-1)α. Thus with VAD and sectorization, the Eb/No becomes

$$\frac{Eb}{No} = \frac{W/R}{(Ns-1)\alpha + (\eta/S)} \quad (5)$$

and the number of users per cell worked out to be [2]

$$N = 3Ns = 3\{1 + \frac{1}{\alpha}\{\frac{W/R}{Eb/No} - \frac{\eta}{S}\}\} (6)$$

III-<u>Turbo Coding</u>

A special types of convolutional codes, called Recursive Systematic Convolutional Codes (RSC), are used as the building blocks of the turbo code encoder as shown in Fig. (2).

The encoder ENC_1 and ENC_2 of the two component RSC, encode the same input information bits (U_k) but in different order, because of the interleaver before the ENC_2 Appropriate puncturing of parity bits from two encoders can produce a turbo code of desired rate. A fired Peseudo Random Interleaver is used. It has been selected a many randomly generated interleaver based on frequency of low-weight output code words for weight-two sequence [8,9].

Fig. (3) shows the structure of turbo code decoder. The two decoders DEC_1 and DEC_2 corresponding to encoders ENC_1 and ENC_2 are serially connected through the sum interleaver that used in the encoder. In Fig (3) an interleaving is denoted by (π) whereas (π^{-1}) denotes the inverse permutation (deinterleaving).

In this paper iterative turbo decoding is implemented using Log-MAP algorithm Soft Input Soft Output (SISO) decoders. Appropriate soft outputs from the demodulator $C_{soft,ch}$ are used as distution for information bits. $I_{Apriori}$ are initialized for the first iteration by assuming information bits to be equally probable. However after the first decoding step, $I_{Apriori}$ will be a available from soft outputs of information bits I_{ext} computed in the previous decoding stage. The SISO decoder can be used to compute extrinsic information corresponding to both information bits I_{ext} and coded bits C_{ext} in general.

For iterative decoding of a turbo code only I_{ext} is required and it is passed to next decoder after each decoding step to improve the correction capacity of decoding. Detection is made after final iteration by adding the a posteriori probability values of information bits I_{App} from the output of the last decoding stage to the values of a priori distributions $I_{Apriori}$ [10, 11, 12].

IV- Diversity Combiner

There are two main issues in reviewing the properties of alternative diversity combiners. The first is related to where the combining process takes place in the system and the second is how to combine the diversity path [13]. In practical application, a linear combiner is most often used. The output of a linear combiner for (L) diversity paths can be expressed as:

$$r(t) = \sum_{K=1}^{L} a_k r_k(t) \qquad (7)$$

where a_k is the weight assigned to the signal component in the kth diversity path respectively. In the *Selection Diversity Combiner* (SDC) the diversity path having the strongest signal is selected, so the output of combiner is the same as that of strongest diversity path. In this case only one $a_k = 1$ at any time is chosen, others are all zero . as shown in Fig. (4). The inputs to branches in Fig. (4) are the Rayleigh signal $S_1$and S_2. The signals S_1 and S_2 are received with amplitude r_1 and r_2 with phases θ_1 and θ_2, respectively. Both branches are corrupted by additive noise sources n_1 and n_2 which are identically distributed white Gaussian noise sources. The statistics for n_1 and n_2 are executed to be equivalent with zero mean and a variance of (Nv). The signal to noise ratio after selection combining is simply the maximum of both branches or equivalently

$$SNR = Max[r_1/\sqrt{Nv}, r_2/\sqrt{Nv}]$$
$$= 1/\sqrt{Nv} Max(r_1, r_2) \qquad (8)$$

Since the noise power , Nv , is assumed to be constant, Nv=1, eq. (9) becomes

$$SNR = Max(r_1, r_2) \qquad (9)$$

V-Data Communication System Modeling

The low pass-equivalent simulation models for synchronous transmission used in this paper is shown in Fig. (5). The transmitter section consists of turbo code encoder , followed by BPSK modulation specified by UMTS. The data bits for each frame are generated by random data generator and passed to turbo code encoder. Since ideal time synchronization is assumed; band limiting transmitter and receiver filter are omitted in the simulation models.

Rayleigh fading channels are considered for a typical urban flat fade. Complex Gaussian samples are filtered by a classical Doppler filter (5th order Bessel filter) to introduce correlated fading typical high and low (50,100 and 150) mile/km mobile speeds are considerd. Hence maximum Doppler frequency shifts for high and low mobile speeds are calculated by using :

$$Fd = |v / \lambda| \qquad (10)$$

where (v) is the speed of the mobile and (λ) is the wavelength of the carrier .

Another channel parameter called the Channel Coherence Time (T_{coh}) which can be defined as

$$Tcoh = 1 / B_d \qquad (11)$$

where B_d is the Doppler spread of the channel. Thus a slowly fading channel has large coherence time and fast fading channel has small coherence time. In a similar manner the channel coherence bandwidth (B_{coh}) can be defined as the reciprocal of multipath spread i.e,

$$B_{coh} = 1 / T_m \qquad (12)$$

The product (T_m B_d) is called the spread factors of the channel.

Two antennas are used for diversity to select best paths by using selection diversity. The best signal passed to BPSK demodulator specified by UMTS, The E_b/N_o is calculated from the exact variance used in noise source of the simulation model. The soft outputs are then passed to the turbo decoder. Iterative turbo decoding is implemented using the Log-MAP algorithm in the SISO decoders as described in the previous section.

VI- Simulation Results and Assessments

This simulation attempts to find the followings:

1. The performance, in terms of advantages in tolerance to additive white Gaussian noise, of turbo code and its relation to memory size, frame length, number of iterations.
2. The effect of mobile speed and fading rate on turbo code performance.
3. The performance of turbo code with different diversity techniques.
4. Evaluating the number of users per cell with and without turbo code and diversity.

The simulation uses the turbo recursive systematic convolutional encoder with generator matrices $[1,7,5]_2$ and shift register memory 3,4. The frame size either 5000 or 10000 bits/frame.

To investigate the effect of number of iteration in turbo decoder with frame length 5000 bits/frame the results shown in Fig.(6) with different number of iteration 2, 4, 6, and 8 with transfer function [1,7,5] over AWGN has been obtained. Its clear that the BER decrease when number of iteration increase. The advantage gained in performance between 8 iteration and 6 iteration is low compared with 4 iteration and 2 iteration. To evaluate the effect of frame length on the performance of turbo code over AWGN channel, another frame length have been chosen, 10000 bits/frame. The performance at different iteration 2, 4, 6, and 8 with transfer function $[1,7,5]_2$ over AWGN have been evaluated as shown in Fig. (7). These results show that significant improvement in performance can be observed with the increase in frame length and number of decoding iteration. Furthermore, the performance of turbo code with different frame length at 8 iteration decoder on AWGN with transfer function $[1,7,5]_2$ have shown that an advantage 0.2 dB at BER 10^{-4} have been gained when frame length varies from 10000 bits to 5000 bits as shown in Fig. (8). The above assessment have been investigated but with different transfer function $[1,11,15]_2$. The results of such test are as shown in Fig. (9) and Fig. (10) for different frame length 5000 bits/frame and 10000 bits/frame, respectively.

Fig (11) shows the performance of turbo code with rate 1/3, same frame length 10000 bits and different transfer function [1,7,5] and $[1,11,15]_2$. The performance shows an advantages of 0.2dB can be gained.

The performance turbo code on correlated fading channel with 10000 bits/frame, 2 iteration and different mobile speed have evaluated. The correlated fading channel uses jake fading simulation model. Fig. (12) shows the performance corresponding to speed 50, 100, and 150 mile/h with Channel Coherence Time (T_{coh}) 0.0045, 0.0022, and 0.0015 sec. when carrier frequency is 2 GHz. The results show that low coherence time gives less correlation of fading processes. Hence the better the performance. Furthermore, the performance of turbo code on correlated Rayligh multipath fading channel with rate 1/3 and transfer function $[1,7,5]_2$ having memory size equal 3 and frame length equal to 10000 bits without diversity and different number of iteration 2, 4, 6, and 8, the effect of increase number of iteration are observed in shown in Fig. (13). It is clear that more advantage can be gained at mobile speed of 50 mile/h.

The performance of turbo code in Rayleigh fading channel with channel coherence time (T_{coh}) 0.0045 sec. Can be increased further with antenna diversity as shown in Fig (14) and Fig (15). Two antenna diversity combiner with different number iteration 2,4,6, and 8 and frame length 5000 bits/frame and 10000 bits/frame respectively have been assumed.

The effect of memory size on the performance of turbo code is shown in fig. (16) with memory size 4 and transfer function $[1,11,15]_2$ with different number of iteration and diversity. To compare between performance of turbo code in Rayeigh fading channel with channel coherence time (T_{coh}) 0.0045 sec. with two antenna diversity combiner and without diversity. The results show the diversity gave advantage (4 dB) at BER equal 10^{-4} with 8 iteration and 10000 bits/frame as show in Fig.(17).

Fig. (18) shows the effect of transfer function on the performance over Rayeigh fading channel with channel coherence time (T_{coh}) 0.0045 sec. with two antenna diversity combiner the gain advantage equal 0.8 db at BER 10^{-4} when the memory size increase from 3 to 4.

The capacity calculation for CDMA reserve link depended on the following parameter :

- The spread bandwidth W is chosen to be 1.25 MHz.
- The bite rate is 8 Kbps for a nearly acceptable toll-quality vocoder.
- A voice activity factor α of 3/8 and sectorization 3

Fig. (19) shows the relation between the number of user per cell to BER when a turbo code applied at Rayleigh multipath channel at different channel coherence time. The figure shows that the number of user increases when the channel coherent time decreases as shown in Table 1.

Table 1 Number of user per cell for different BER at different channel coherence time with rate 1/3 ,transfer function [1,7,5]2, frame length 10000 bits and 2 iteration

CCT. / BER	0.0045 sec.	0.0022 sec.	0.0015 sec.
10^{-2}	409	467	501
10^{-3}	277	345	380
10^{-4}	214	287	231

The effect of number of iteration on the capacity per cell can be seen in Fig, (20) which shows that at number of iteration increases as the number of user increases. At low BER increase number of user but at height BER the effect of the number of iteration does not affect of number of user. Diversity techniques have performance reduce the interference and also increase number of user per cell as shown in Fig. (21) and Fig, (22) at different number of bit per frame, whereas the number of user respect to BER are shown in Tables 3-4. Finally, the effect of memory on number of user can be shown in Fig. (23).

Table 2 Number of user per cell for different BER at channel coherence time 0.0045 sec. with rate 1/3, transfer function [1,7,5]2, frame length 10000 bits

No. of itration. BER	2	4	6	8
10^{-2}	409	489	479	492
10^{-3}	383	370	407	441
10^{-4}	229	317	364	412

Table 3 Number of user per cell for different BER with two antenna diversity at channel coherence time 0.0045 sec. and frame length 5000 bits.

No. of itration BER	2	4	6	8
10^{-2}	990	1075	1145	1180
10^{-3}	780	903	993	1115
10^{-4}	607	800	852	918

Table 4 Number of user per cell for different BER and two antenna diversity at channel coherence time 0.0045 sec. with rate 1/3, transfer function [1,15,11]2, frame length 5000 bits.

No. of itration BER	2	4	6	8
10^{-2}	919	1109	1150	1181
10^{-3}	722	966	1063	1089
10^{-4}	610	883	997	1035

VII- Conclusions

The paper has presented the computer simulation of 3rd generation mobile communication system that show the effect of inclusion of turbo coding and diversity in the system. Furthermore it studies the effect of turbo coding and diversity parameter on the BER performance of the system together with change in the channel condition from AWGN to Rayleigh multipath fading mobile channel.

The simulation results show that the turbo code achieves a significant advantage in tolerance to AWGN over system without turbo coding. Number of user increases when using turbo code with diversity. The most important conclusion points that have be drawn from there test results are:

1- The more number of iteration will get low BER but the delay in the decoding becomes longer. The large frame length will give better performance but the delay in decoding also longer.
2- Large memory size of encoder get low BER but the disadvantage is long delay.
3- Diversity with turbo code give better performance and compact the multipath fading effect.
4- Number of users depend on BER , when BER height give large number of user but the

quality of service poor, when BER low give small number of user with high quality of service.

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Fig.1 Cellular System Reverse Link Subcarrier

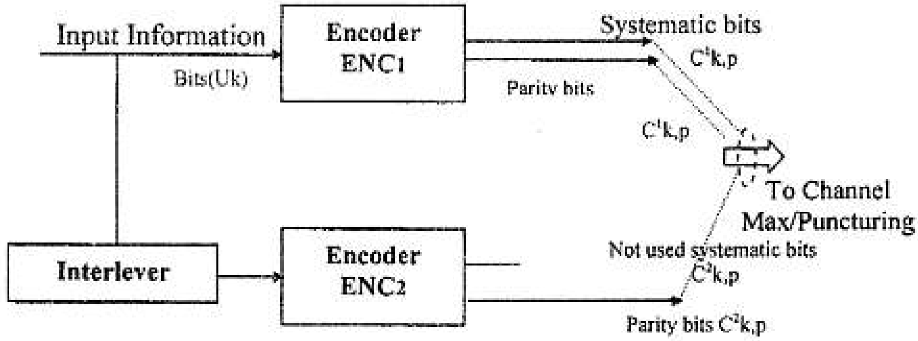

Fig.2 Structure of turbo encoder

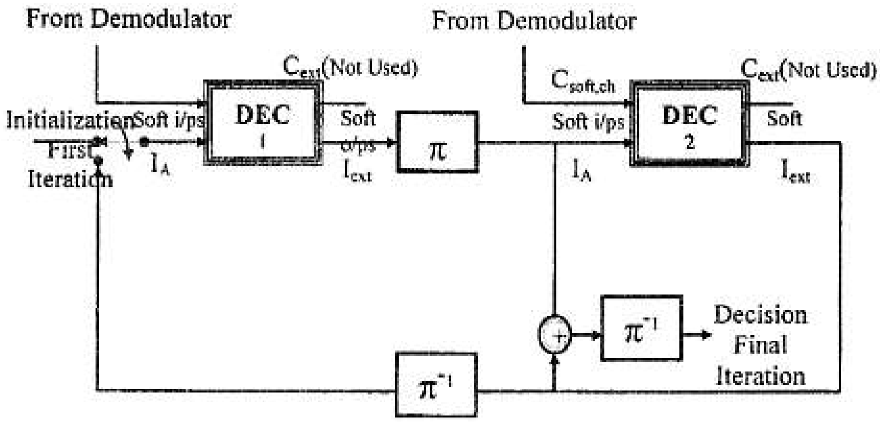

Fig.3 Structure of turbo code

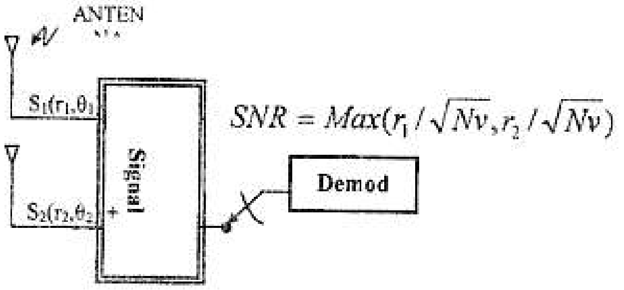

Fig.4 Block diagram of two – branches selection diversity system
for equal noise power in both branches

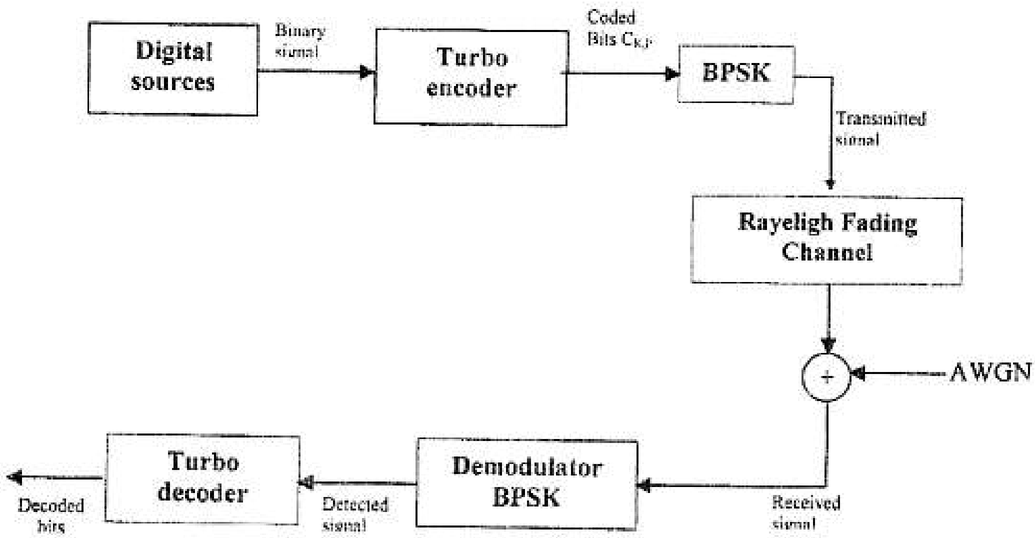

Fig.5 System model for simulation turbo code for
Rayligh fading channel

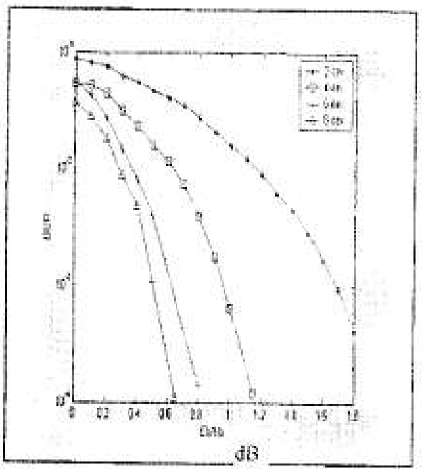

Fig.6 Performance of turbo code with rate 1/3 ,transfer function $[1,7,5]_2$, frame length 5000 bits on AWGN Channel

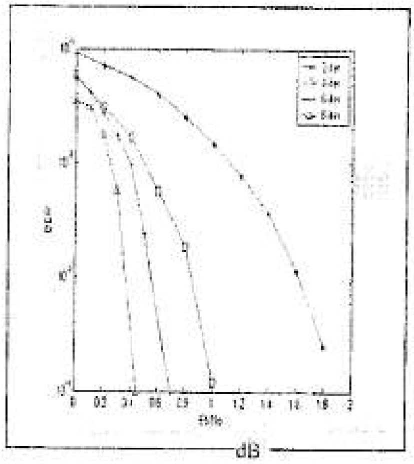

Fig.7 Performance of turbo code with rate 1/3 ,transfer function $[1,7,5]_2$, frame length 10000 bits on AWGN Channel

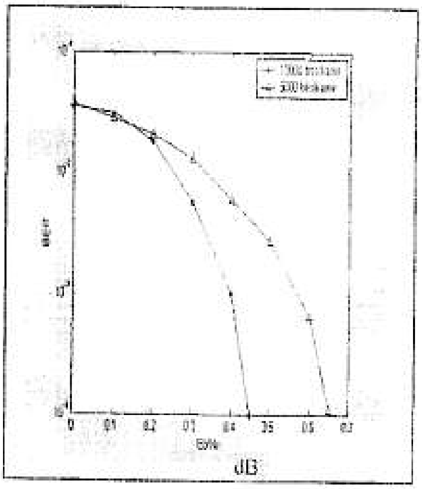

Fig.8 Performance of turbo code with rate ,transfer function $[1,7,5]_2$, 8 iteration AWGN Channel

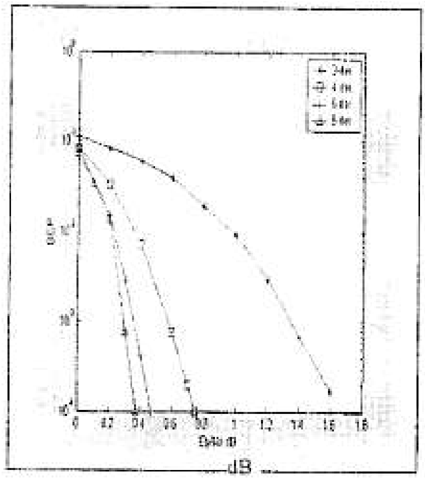

Fig.9 Performance of turbo code with rate 1/3 ,transfer function [1,11,15]2, frame length 5000 bits on AWGN Channel

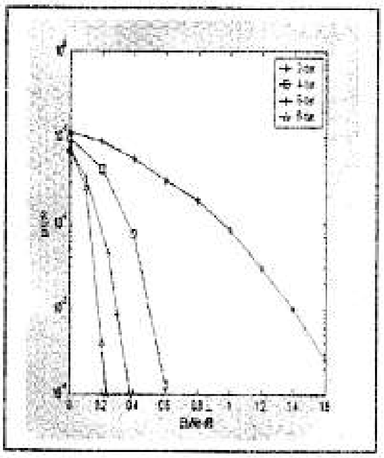

Fig.10 Performance of turbo code with rate 1/3, transfer function $[1,11,15]_2$, frame length 10000 bits on AWGN Channel

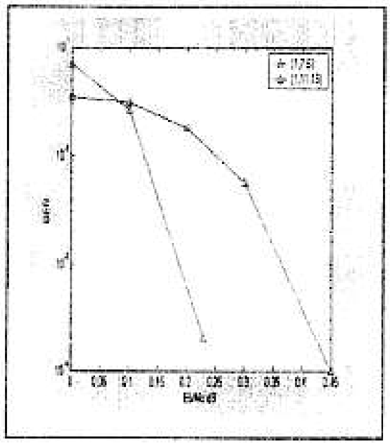

Fig.11 Performance of turbo code with rate 1/3, 8 iteration , 10000 bits/ frame on AWGN Channel

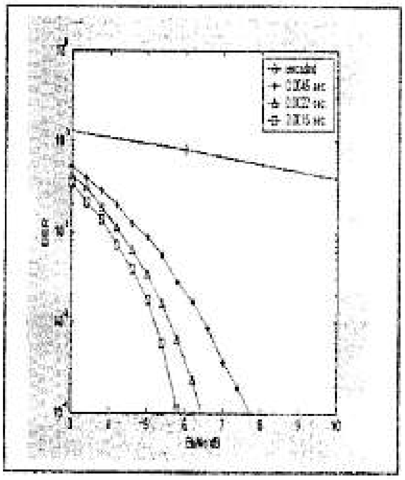

Fig.12 Performance of turbo code in Rayleigh multipathfading channel at different channel coherencetime with rate 1/3 ,transfer function $[1,7,5]_2$, frame length 10000 bits and 2 iteration

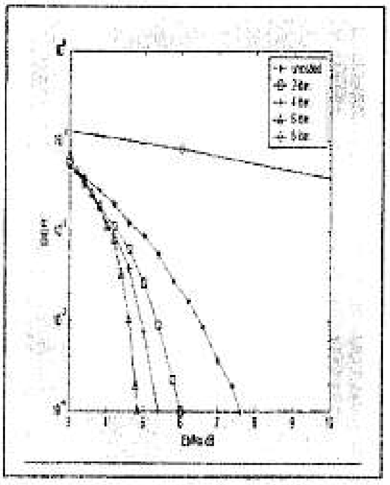

Fig.13 Performance of turbo code in Rayleigh multipath fading channel with rate 1/3 ,transfer function $[1,7,5]_2$, framelength 10000 bits

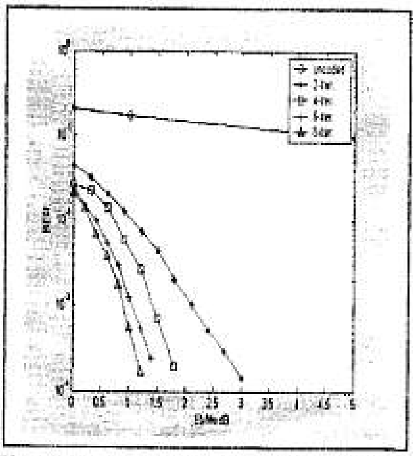

Fig.14 Performance of two antenna diversity with turbocode in Rayleigh multipath fading channel at channel coherence time 0.0045 sec. with rate 1/3 .transfer function

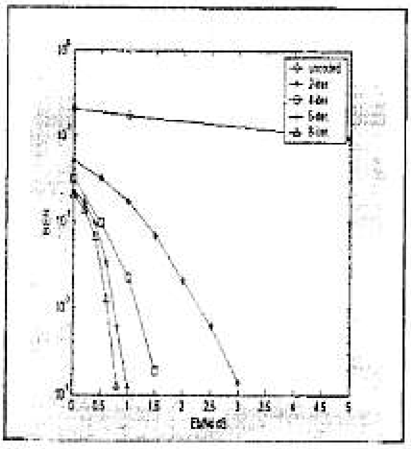

Fig.15 Performance of two antenna diversity with turbo code in Rayleigh multipath fading channel at channel coherence time 0.0045 sec. with rate 1/3 ,transfer function $[1,7,5]_2$, frame length 10000 bits.

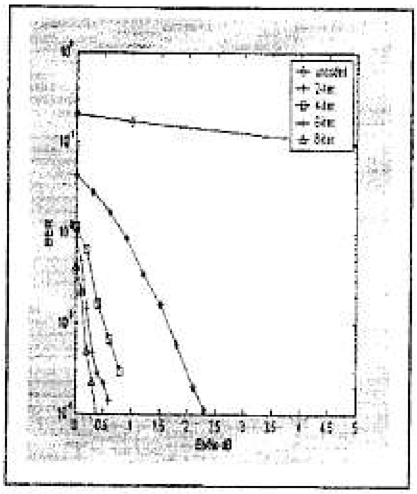

Fig.16 Performance of two antenna diversity with turbo code in Rayleigh multipath fading channel at channel coherence time 0.0045 sec. with rate 1/3 ,transfer function $[1,11,15]_2$, frame length 5000 bits

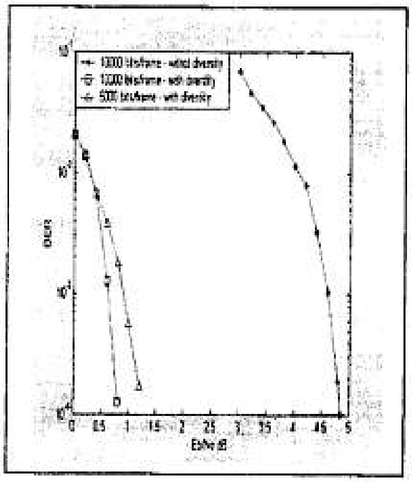

Fig.17 Performance turbo code in Rayleigh multipath fading channel at channel coherence time 0.0045 sec. with rate 1/3 ,transfer function $[1,7,5]_2$.

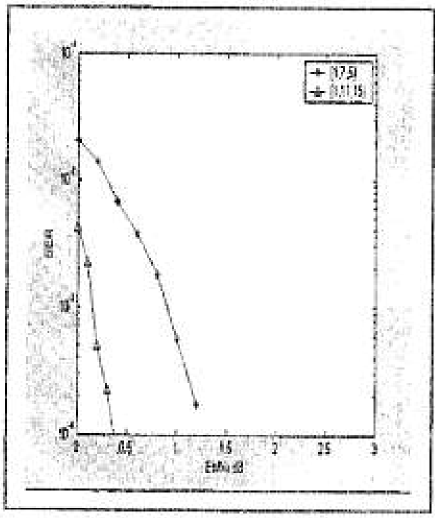

Fig.18 Performance turbo code in,Rayleigh multipath fading channel at channel coherence time 0.0045 sec. with rate 1/3, frame length 5000 bits

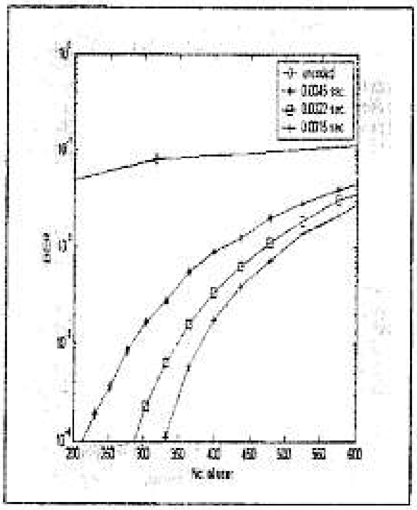

Fig.19 The relations between number of user and BER per cell with turbo code in Rayleigh multipath fading channel at different channel coherence time with rate 1/3 ,transfer function $[1,7,5]_2$, frame length 10000 bits and 2 iteration.

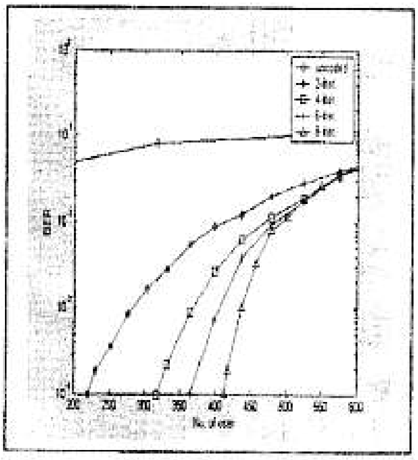

Fig.20 The relations between number of user per cell and BER with turbo code Rayleigh multipath fading channel at channel coherence time 0.0045 sec. with rate 1/3, transfer function $[1,7,5]_2$, frame length 10000 bits.

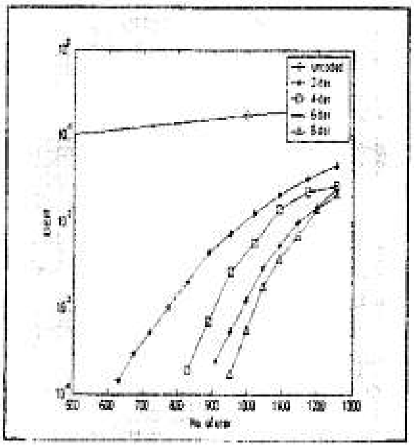

Fig.21 The relations between number of user per cell and BER of two antenna diversity with turbo code in Rayleigh multipath fading channel at channelcoherence time 0.0045 sec. with rate 1/3 ,transferr function [1,7,5]2, frame length 5000 bits.

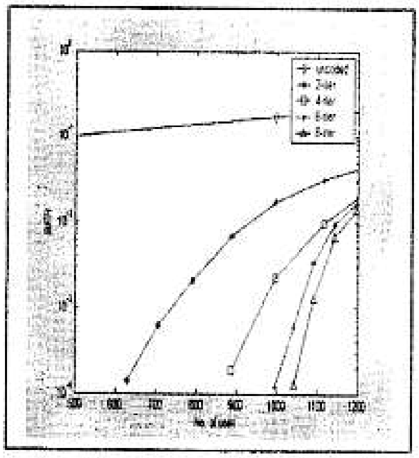

Fig. 22 The relations between number of user per cell and BER of two antenna diversity with turbo code in Rayleigh multipath fading channel at channel coherence time 0.0045 sec. with rate 1/3 ,transfer function [1,7,5]2, frame length 10000 bits.

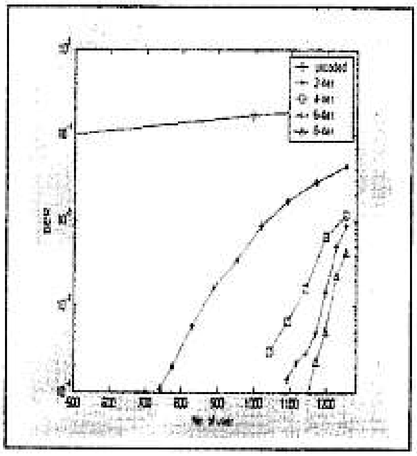

Fig.23 The relations between number of user per cell and BER of two antenna diversity with turbo code in Rayleigh multipath fading channel at channel coherence time 0.0045 sec. with rate 1/3, transfer function [1,15,11]2, frame length 5000 bits.