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Efficient Selection of Circular and Random Interleaver for Turbo Codes Multiuser CDMA System with Hadamard Spreading code in AWGN and Rayleigh Fading Channels

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Abstract

Recently, turbo codes have attracted many researchers because of the codes astonishing performance at low signal to noise ratio SNR. The interleaver types and lengths is an important part in the design of a turbo code. In this paper, the performance of turbo codes with efficient selection length for random and circular interleaver is studied with various issues related to the turbo code performance are investigated. These include the effect of number of decoding iteration used in iterative decoding algorithm, the effect of number of states used in a convolutional code, the effect of interchanges the interleaver type and the effect of the interleaver length for Multiuser-CDMA system. Simulation results show that the BER performance of random interleavers is better than circular interleavers for all SNR and the efficient performance gained for turbo coded 16 user CDMA system in AWGN or Rayleigh fading channels when using Random interleaver of length 512 or Circular interleaver of length 1024. The BER performances are evaluated using MATLAB R2009a computer simulation software.

Keywords: Efficient selection, Circular interleaver, Random Interleaver, Turbo Codes, Multiuser CDMA, Hadamard Spreading code, AWGN, Rayleigh Fading Channels.

الملخص

لقد استحوذت شيفرات التربو مؤخراً على اهتمام الكثير من الباحثين بسبب أدائها الباهر عند القيم المنخفضة لنسبة الاشارة الى الضوضاء (SNR) . ويعتبر نوع وطول المبعثر جزءاً هاماً في تصميم شيفرات التربو. في هذا البحث تمت دراسة أداء شيفرات التربو لأكفى اختيار لطول المبعثرات العشوائية و المبعثرات الدائرية والعديد من العوامل المتعلقة بأداء شيفرات التربو مثل تأثير عدد دورات فك التشفير وتأثير عدد الحالات States المكون لل convolutional code وتأثير تغير المبعثر وطول المبعثر لنظام متعدد المستخدمين لمتعدد النفاذ بالتقسيم المشفر Multiuser-CDMA . وتظهر نتائج المحاكاة ان أداء احتمالية خطأ البت للمبعثرات العشوائية أفضل من أداء المبعثرات الدائرية لكافة قيم نسبة الاشار الى الضوضاء (SNR) وكذلك أظهرت النتائج أن أكفى أداء يمكن الحصول عليه لنظام 16user CDMA لقناتي ضوضاء كاوسي أو قناة خفوت رايلي عندما نستخدم مبعثر عشوائي بطول 512 اومبعثر دائري بطول 1024. لقد تمت عملية المحاكاة باستخدام الحاسبة عن طريق (MATLAB R2009a computer software).

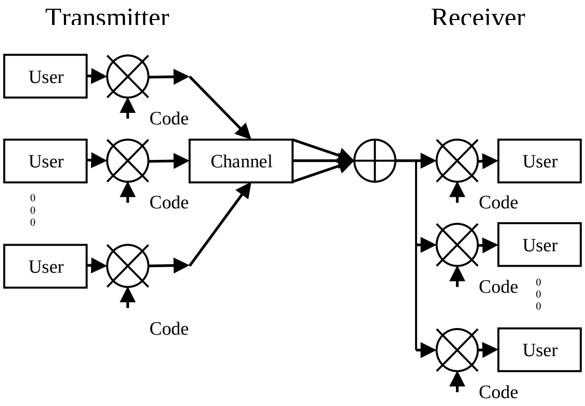
1- Introduction

Fading is the term used to describe the rapid fluctuations in the amplitude of the received radio signal over a short period of time. Fading is a common phenomenon in Mobile Communication Channels, where it is caused due to the interference between two or more versions of the transmitted signals which arrive at the receiver at slightly different times. The resultant received signal can vary widely in amplitude and phase, depending on various factors such as the intensity, relative propagation time of the waves, bandwidth of the transmitted signal etc.,[1]

2- Multiuser Code Division Multiple Access (Multiuser CDMA)

CDMA is the code division multiple access technique in wireless communications that allows a number of users to simultaneously access a channel by modulating and spreading the information signals with code sequences. [1,2,3,4] The conventional CDMA receiver is composed of a bank of single user detectors, each with a correlator matched to a specific spreading signal. This is the simplest receiver for the CDMA system and is optimum only if the received signals are orthogonal.[3,5]

A Multiuser code division multiple access (Multiuser-CDMA) technique is performed by multiplying a radio frequency (RF) carrier and spreading code generator signal. Fig(1) shows a basic Multiuser - CDMA system for both the transmitter and the receiver. First the spreading code is modulated onto the data signal, using one of several modulation techniques (e.g BPSK, DPSK and QPSK, etc). Then the spreading modulated data signal and the RF carrier are multiplied. This process causes that the RF signal to be replaced with a very wide bandwidth signal with the spectral equivalent of a noise signal. In the reception of the signal, the receiver must not only know the code sequence to despread the signal but also it requires to be synchronized with the code generator in the transmitter.[2,3,4,6]



Fig(1) : Multiuser - CDMA system.

The multiplication in the time domain of the data signal by the spreading code sequence results in a signal with a frequency spectrum similar to the spectrum of the spreading code signal (due to the fact that $T_c<T_b$, where T_c and T_b represent the duration of one chip in the spreading code and one symbol in the data signal respectively). Therefore, the effects of increasing the data rate from R_S(symbol level) to R_c (chip level) are a reduction in the amplitude spectrum (from T_b to T_c) and an expansion of the signal in the frequency domain. Since the wide bandwidth of the spreading codes BW_{SS} allows us to reduce the amplitude spectrum to noise levels (without loss information), the generated signals appears as background noise in the frequency domain. From another perspective, the bandwidth of the data signal BW_{info} is basically spread by a factor $N=T_b/T_c$ which corresponds to the processing gain (GP)in the Multiuser- CDMA system. In this type of systems the length of the code is the same as the processing gain.

$$G_p = \frac{\mathrm{BW}_{\mathrm{ss}}}{\mathrm{BW}_{\mathrm{info}}} = \frac{R_c}{R_s} = \frac{T_b}{T_c} = N_c \qquad (1)$$

Where T_b is called the bit duration, T_c is the chip duration and N_c is the number of chips per information bit. The receiver correlates the received signal with a synchronously generated replica of the spreading code to recover the original information-bearing signal. This implies that the receiver must know the code used to modulate the data.**[2,3,4,7]**

Hence, the large channel bandwidth Rc(chip rate) instead of R_s (symbol rate)increase the received noise power with G_p (processing gain) .**[1,3,7]**

$$N_{\inf o} = N_o.BW_{\inf o} \qquad (2)$$

$$N_{ss} = N_o.BW_{ss} = N_{\inf o}.G_p \qquad (3)$$

Where, N_{info} = information noise, N_{ss}=spread spectrum noise and N_o = noise power

Therefore, the increase in received noise power degrades the BER (Bit Error Rate) when increasing number of users.

3. Turbo Codes

Parallel concatenation of at least two component codes with interleaver in between them forms a parallel concatenated interleaved code, also known as a turbo code. A turbo code encoder with two component codes is shown in the Fig(2). Special types of convolutional codes, called recursive systematic convolutional codes (RSC), are used as the building blocks of a turbo code encoder.

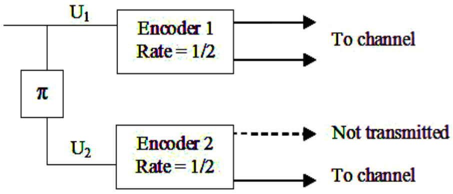


Fig. (2) Parallel concatenation convolutional code (PCCC) of rate 1/3

The encoders Encoder1 and Encoder2 of the two component RSCs (normally equal rate R = k/n) encode the same input information bits U_k but in a different order, because of the interleaver before the Encoder2 **[8,9]**. i.e, The k information sequences are transmitted together with the check sequences(n-k) of the first encoder and the same information sequences are interleaved and enter to the second encoder; the (n-k) check sequences generated by the second encoder are also transmitted. The rate of parallel turbo code is then Ro = k/(2n-k). **[9,10]**The output of the turbo encoder is formed by multiplexing the data bits and the parity bits of the two RSC encoders. In this study, two memory-2 recursive systematic convolutional codes of rate 1/2 and a generator of $(5, 7)_{\text{octal}}$ are used as component codes **[8,9,10]** and the overall code rate of the parallel turbo code is then Ro = 1/3 .**[6,9]** The important characteristics of turbo codes are the small BER achieved even at low Signal to noise ratio (SNR) and the flattening of the error rate curve ,i.e. the error floor at moderate and high values of SNR. **[9,11]** In turbo codes **R**ecursive **S**ystematic **C**onvolutional (RSC) codes are proved to perform better than the non-recursive ones **[8,10]** The recursive systematic convolutional (RSC) encoder is obtained from the nonrecursive nonsystematic (conventional) convolutional encoder by feeding back one of its encoded outputs to its input.**[10,11]**A recursive convolutional encoder tends to produce code words with increased weight relative to a nonrecursive encoder and this leads the BER for a recursive convolutional code is lower than that of the corresponding nonrecursive convolutional code at low signal to noise ratios Eb/No.**[11]**

After the final encoded message is computed, it is transmitted across a (noisy) channel. Once received, the intended recipient attempts to decode the message. The received sequence from demodulator denote by $\lambda(C_1,I)$ and $\lambda(C_2,I)$ are fed to the input port of $SISO_1$(Soft input soft output) and $SISO_2$ respectively at the same time. Here, the number 1 and, 2 is referred to the first and second encoders (or decoders) respectively. At the first iteration, $\lambda(U_1,I)$, and $\lambda(U_2,I)$ are zero (there is no prior information available on the input information bits of each encoders). $\lambda(U_1,O)$ are passed through interleaver π that rearranges the ordering of sequence of symbols in a deterministic manner to obtain $\lambda(U_2,I)$, while $\lambda(U_2,O)$ are deinterleaved the received sequence using deinterleaver π^{-1} that applies the inverse permutation to restore the original sequence to obtain $\lambda(U_1,I)$ and start the second iteration. At a final iteration, $\lambda(U_2,O)$ out from the SISO2 will be summed with $\lambda(U_1,O)$ after out from interleaver π to give the estimated information bits $\hat{U}$ **[5,6,8,9,12]**.as shown in Fig(3).

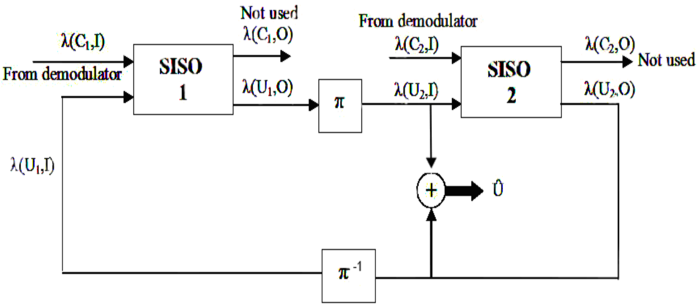


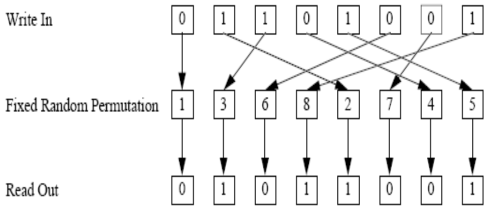
Fig. (3) Iterative decoder of Parallel concatenation convolutional code (PCCC)

4. Interleavers

Interleaving is a widely used technique in digital communication and storage systems. An interleaver takes a given sequence of symbols and permutes their positions, arranging them in a different temporal order. The basic goal of an interleaver is to randomize the data sequence. When used against burst errors, interleavers are designed to convert error patterns that contain long sequences of serial erroneous data into a more random error pattern, thus distributing errors among many code vectors[13] . in another word, The role of the interleaver is to break low weight input sequences, and hence increase the code free Hamming distance or reduce the number of code words with small distances in the code distance spectrum.[14] Burst errors are characteristic of some channels, like the wireless channel.[13] The two main issues in the interleaver design are the interleaver size and the interleaver map. The size of the interleaver plays an important rule in the trade off between performance and time (delay) since both of them are directly proportional to the size. On the other hand, the map of the interleaver plays an important role in setting the code performance.[10,14] For this reason, efficient length of Random and circular interleaver can be implemented in this paper

4.1. Random Interleaver

The random interleaver uses a fixed random permutation and maps the input sequence according to the permutation order. The length of the input sequence is assumed to be L. Fig(4) shows a random interleaver with L=8.[11,14]



Fig(4) : A random interleaver with L=8.

From Fig(4) , the interleaver writes in [0 1 1 0 1 0 0 1] and reads out [0 1 0 1 1 0 0 1].

4.2. Circular Shifting Interleaver

The permutation P of the circular-shifting interleaver is defined by

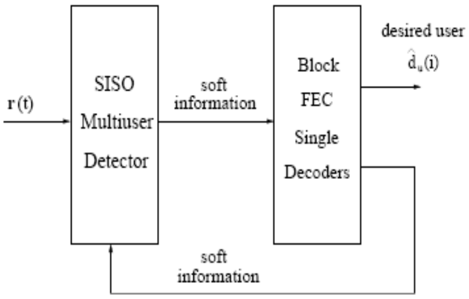
$$P(i) = (ai+s) \bmod L \qquad \ldots(4)$$

satisfying a<L, a is relatively prime to L, and s<l where i is the index, a is the step size, and s is the offset. The following example shows a circular-shifting interleaver with L=8, a=3, and s=0. [11,14]

Index 0 1 2 3 4 5 6 7
Circular-shift permutation 0 3 6 1 4 7 2 5

5. Multiuser Detector For Turbo Coded CDMA System

An optimal iterative multiuser detector for synchronous coded CDMA, based on iterative techniques for cross-entropy minimization is introduced. Fig(5) show the Iterative multiuser receiver structure Turbo coded Multiuser -CDMA system [5,6].



Fig(5): Iterative multiuser receiver structure.

6. Performance by Computer Simulation

Here all the implementation concepts have been verified in MATLAB R2009a and the simulation of the Efficient selection the of Random interleaver and circular interleaver for Turbo coded multiuser CDMA system is presented. The measurement for the performance is displayed as Bit Error Rates (BER) in comparison to signal to noise ratio (SNR) of the channel. The standard parameters used in our simulations which are affecting the performance of Multiuser-CDMA system are shown below.

R_s = symbol rate = 256 Ksymbols/sec.

m = Number of modulation level = 1 for DPSK
b_r = bit rate = m.R_s = 256 kbits/sec
T_b = bit duration = 1/br
Hadamard matrix dimension = N = 2^4 = 16
Number of users for Multiuser-CDMA system = 16 = Maximum number of users depend on the size of Hadamard matrix = processing gain (GP)
R_c = chip rate = G_p.R_s = 16.R_s
T_c = chip duration = 1/R_c

6.1. Performance Of Multiuser-CDMA System In AWGN And Rayleigh Fading Channels

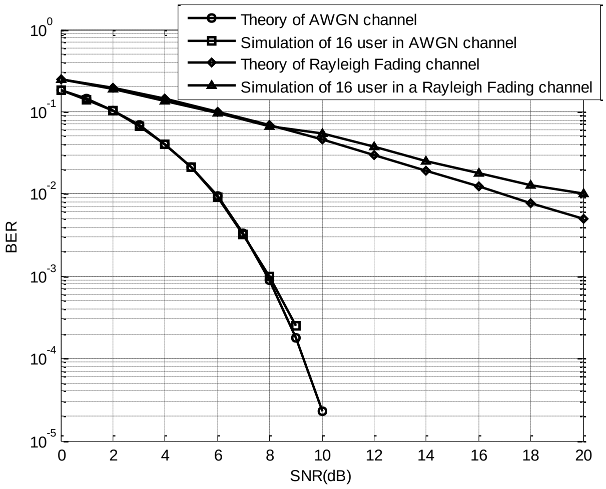
For Multiuser-CDMA system and at each user's terminal, the information data are modulated by DPSK modulation. Then, the bits of the modulation data are spread by a hadamard code sequence with processing gain G_{DS} = 16 (in this case, there are 16 different sequences for hadamard code one code for each user). A hadamard spreading sequence possesses have a good correlation properties and thus yields a good suppression of interference due to multi-path propagation and multi-user interference. The spread data of all 16 users are transmitted with equal and constant power to the base station at the same time and the base station detects the information data of each user by correlating the received signal with a code sequence allocated to each user compared with the theoretical value of CDMA system in AWGN or a Rayleigh fading channels.

From Fig(6), its clearly seen that in AWGN channel simulation the Orthogonal hadamard code provides the good performance .i.e. when the user codes are Orthogonal, there is no interference between the users after despreading (The cross correlation between the users is zero) and the privacy of the communication of each user is protected, because, the target user signal can be successfully recovered from the channel noise and the multi-user interference. Therefore, the simulation result is close to the AWGN channel theory.

Fading is a more realistic mobile channel; however, multiple paths are received from the signal that is transmitted through the channel. This phenomenon introduces ISI (inter symbol interference) which is another of the major interference factors for a Multiuser-CDMA system that significantly degrades the system performance. In this simulation, we assume a Rayleigh fading channel with a two paths in the multipath delay profile and it is assumed that the delayed wave have a mean power of 20 dB smaller than that of the direct wave and the delay path equal to symbol duration with a maximum Doppler frequency shift f_{dmax}=100 Hz. However, Rayleigh fading channel or time dispersive channels are common in wireless mobile channels which destroy the

orthogonal property in the Multiuser CDMA system. Under this scenario hadamard spreading codes can be a good choice to model the channel conditions as they provide an average interference level which is noise like when the number of users is large.

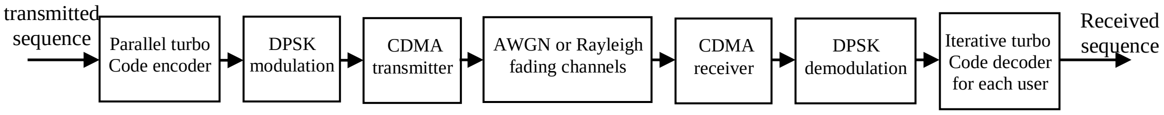
The BER performance of a synchronous Multiuser-CDMA in a Rayleigh fading channel with the same standard previous channel requirements compared with the theoretical Rayleigh fading channel is shown in the same Fig(6), it is noticed that the BER decreases when the SNR is increased, which is normal because the signal becomes stronger than the noise and multipath fading.



Fig(6) Performance of 16 User CDMA system in AWGN and two path Rayleigh fading channel

6.2 Parallel Turbo Code System

In this section, a Block diagram of the computer simulation is presented for parallel turbo codes uses two component Recursive Systematic Convolutional Codes (RSCs) of a rate R = 1/2 in a parallel concatenation with circular or random interleaver for 16 users CDMA system with 2^4 hadamard spreading code of processing gain Gp=16 and Differential Phase Shift Keying (DPSK) modulation over Additive White Gaussian Noise (AWGN) or a Rayleigh fading channel is shown in Fig(7).



Fig(7) Block diagram of the Turbo coded Multiuser CDMA system simulation

The turbo code is decoded by using Max Log algorithm (Log MAP SISO algorithm) with six iterations for each user in Multiuser CDMA system. We show that there are many parameters which are affecting the performance of turbo codes. Some of These parameters used in our simulations are shown below:

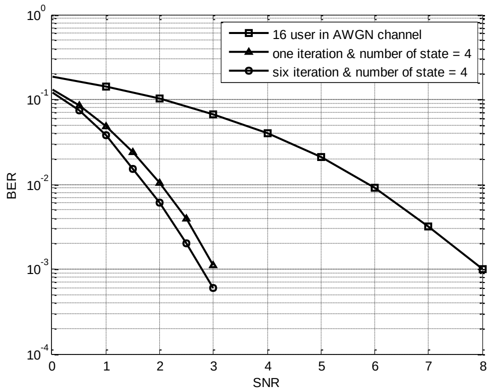
1. The number of decoding iterations used.
2. The number of convolutional states used.
3. The interleaver type.

4. The interleaver length.

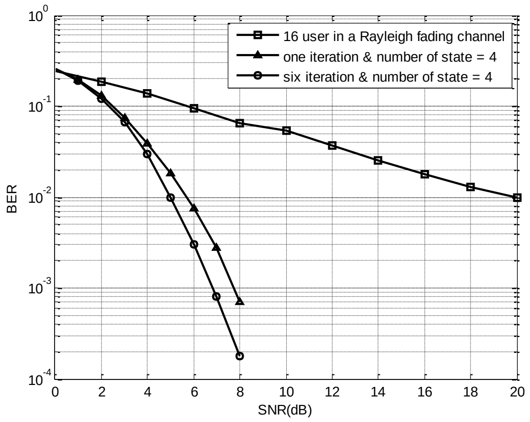
From these parameters, we can suggest efficient selection length for Random interleaver and Circular interleaver for Turbo coded Multiuser CDMA system.

6.2.1 The Effect Of Number Of Decoding Iteration Used

The simulation results pertaining to a rate Ro = 1/3 parallel turbo code formed by two equal four-states with identical generator of $(5, 7)_{octal}$ rate R = 1/2 recursive systematic convolutional codes have $d_{free}= 5$ joined by circular interleaver of length $N = 256$, are shown in Fig(8) and Fig(9) using MAX LOG iterative turbo-decoding algorithm applied for each user and for one and six iterations in AWGN or in a two path Rayleigh fading channel for 16 user CDMA system. With each iteration in the figures, the estimates of the message bits improve, and they usually converge to a correct estimate of the message. The number of errors corrected increases as the number of iterations increases. However, the improvement of the estimates does not increase linearly, and so, in practice, it is enough to utilize a reasonable small number of iterations to achieve acceptable performance. Therefore, as the number of iterations for the iterative turbo decoding algorithm increases, the turbo decoder performs significantly better. The simulation results show that, after 6 iterations there is little improvement achieved by using further iterations.



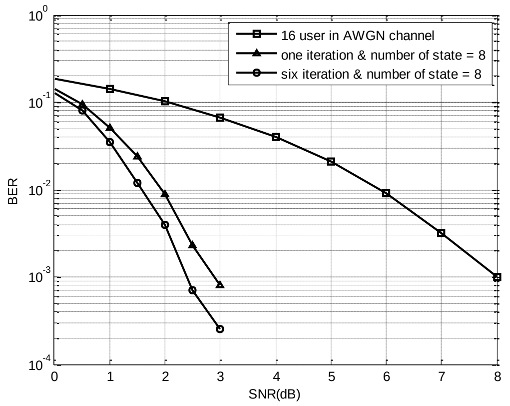
Fig(8) Performance of Rate 1/3 Parallel Turbo code with Circular interleaver of length 256 for 16 User CDMA system in AWGN channel



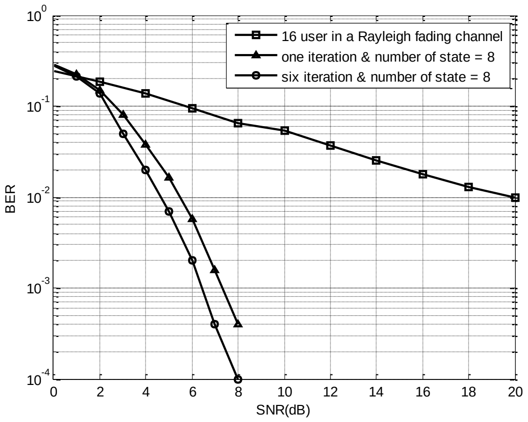
Fig(9) Performance of Rate 1/3 Parallel Turbo with Circular interleaver of length 256 for 16 User CDMA system in a Rayleigh Fading channel

6.2.2 The Effect of Number of State Used

Fig(10) and Fig(11) shows the performance of rate Ro = 1/3 turbo code based on eight-states convolutional code and identical generator of (15, 17) $_{\text{octal}}$ rate R = 1/2 RSC codes have d_{free}=6 joined with circular interleaver of length N = 256 for 16 user CDMA system for one and six iterations in AWGN or in a two path Rayleigh fading channel. From the figures, it is noticed that the BER is less than the same turbo code system used four states convolutional code for all values of SNR , which is normal because the generator of (15, 17) $_{\text{octal}}$ RSC have a free distance d_{free} is greater than the generator of (5, 7) $_{\text{octal}}$ RSC which introduce a BER less.



Fig(10) Performance of Rate 1/3 Parallel Turbo code with Circular interleaver of length 256 for 16 User CDMA system in AWGN channel

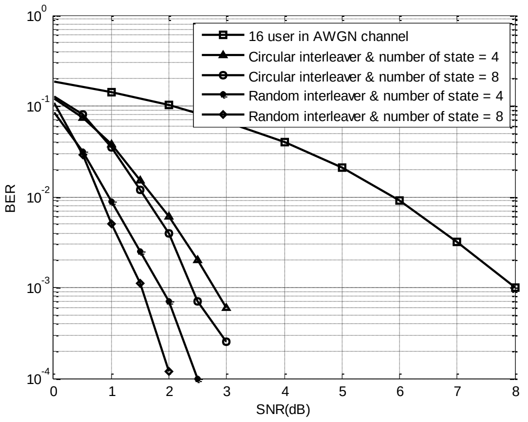


Fig(11) Performance of Rate 1/3 Parallel Turbo code with Circular interleaver of length 256 for 16 User CDMA system in a Rayleigh Fading channel

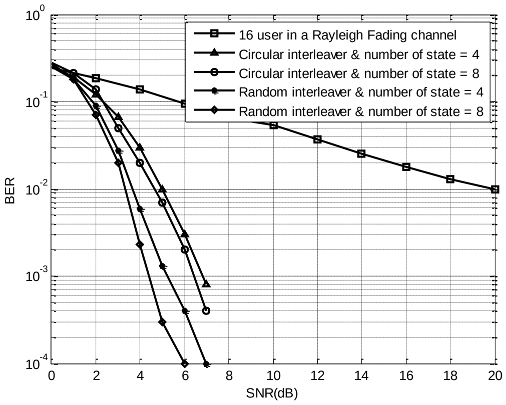
From the previous four figures (8 - 11) we can see that the Circular interleaver of length 256 have a moderate BER performance for 6 iteration Turbo coded with 16 user CDMA system in AWGN or Rayleigh fading channel.

6.2.3 Effect Of Interleaver Type

Fig(12) and Fig(13), the BER performance of parallel turbo codes for 16 users CDMA is evaluated as a function of type of interleaver. Simulations are done for the standard previous parallel turbo code parameters, involving the use of two R = 1/2-rate RSC of four states and identical generators of (5, 7) $_{\text{octal}}$ or for eight states and identical generators of (15, 17) $_{\text{octal}}$ encoders in a parallel concatenation and either circular or a random interleaver of length 256 are used in AWGN or in a two path Rayleigh Fading channel for six iterations only.



Fig(12) Performance of Rate 1/3 Parallel Turbo code with Circular and Random interleaver of length 256 for 16 User CDMA system in AWGN channel



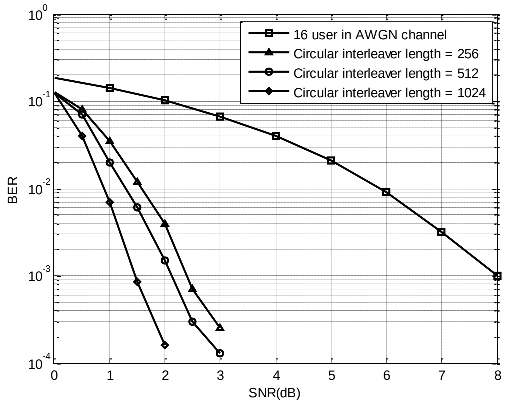
Fig(13) Performance of Rate 1/3 Parallel Turbo code with Circular and Random interleaver of length 256 for 16 User CDMA system in a Rayleigh channel

BER vs. SNR curves show good performance for random interleaver in comparison with circular shift interleaver. Because, the random interleaver is a permutation that maps the sequence of forward error correcting code FEC coded bits into the same sequence of data but with a new order. This can be understood as random interleaver tries to maximize the minimum free distance of the code, while the geometrical structure of circular shift interleaver shows weakness to maximize the distance of the codes at moderated and high values of SNR’s.

From the Fig(12) and Fig(13) we can see that the Random interleaver is better than Circular interleaver for all values of SNR dB and the length of 256 for both Random interleaver and Circular interleaver have a moderate error rate performance for eight state Turbo coded 16 User CDMA system in a two channels.

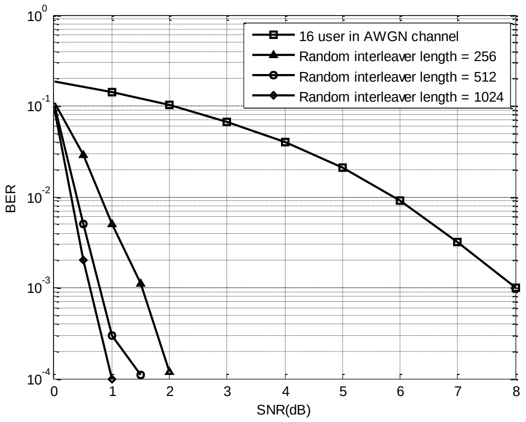
6.2.4 Efficient Selection of Interleaver Length

Fig(14) and Fig(15) show the performance of eight state Parallel turbo code as a function of interleaver length for circular and random interleavers for six iterations only. It has been well established that turbo code system performs better with large interleaver lengths. This can be explained as improvement in random interleaver treatments for burst errors produced by a Rayleigh fading channel, this improvement is taken from increasing the chance to break burst errors due to increasing interleaver length. Because a random interleaver is simply a random permutation of the message sequence and for large values of interleaver length, the random interleavers perform well and the overall Parallel turbo code forms a very powerful code for possible use in applications requiring reliable operation at very low signal to noise ratios, such as those in deep space communications systems. The performance shows a very significant interleaver gain, i.e., lower values of the bit error probability for a large Interleaver length compared with circular interleaver. It is interesting to note that the reduction in BER due to increasing interleaver length is a strong function of the number of iterations. In other words, the improvement due to increasing the interleaver size will only be achieved for sufficiently large number of decoding iterations.



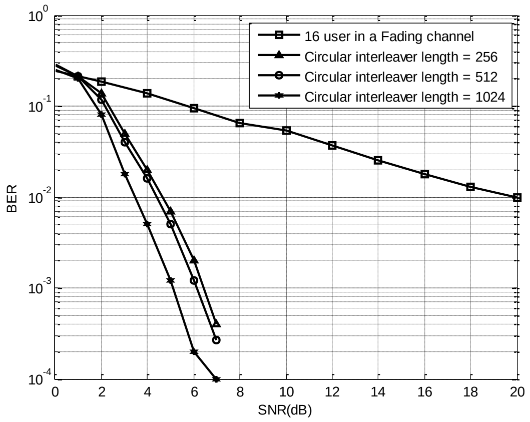
Fig(14) Performance of Rate 1/3 Parallel Turbo code with different Circular interleaver length for 16 Users CDMA system in AWGN channel

From the Fig(14) we can see that the Circular interleaver of length 1024 is significantly better BER performance than the Circular interleaver of length 256 and 512 which they gives the BER close to each other. i.e. the difference between Circular interleaver of length 256 and 512 ≈ 0.25 dB for all values of SNR dB while the difference between Circular interleaver 512 and 1024 started at 0.25 dB and increased to 0.75 dB. So that the efficient selection length for Circular interleaver is 1024 for turbo coded 16 user CDMA system in AWGN channel.



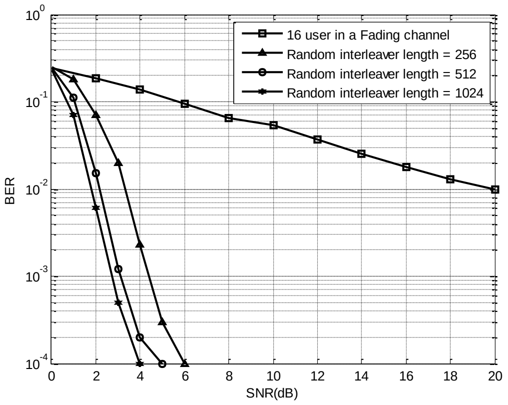
Fig(15) Performance of Rate 1/3 Parallel Turbo code with different Random interleaver length for 16 Users CDMA system in AWGN channel

From the Fig(15) it can be seen that the Random interleaver of length 1024 is significantly better BER performance than the Random interleaver of length 256 and 512 while the difference between Random interleaver of length 256 and 512 started 0.25 dB and increased to 0.8 dB and the difference between Random interleaver of length 512 and 1024 ≈ 0.2 dB for all values of SNR dB. So that the efficient selection length for Random interleaver is 512 for turbo coded 16 user CDMA system in AWGN channel for less complexity in system design and for high processing speed.



Fig(16) Performance of Rate 1/3 Parallel Turbo code with different interleaver length for 16Users CDMA system in a Rayleigh Fading channel

From the Fig(16) we can see that the Circular interleaver of length 1024 is significantly better BER performance than the Circular interleaver of length 256 and 512 which gives the BER close to each other. i.e. the difference between Circular interleaver of length 256 and 512 ≈ 0.3 dB for all values of SNR dB while the difference between Circular interleaver 512 and 1024 started at 0.25 dB and increased to 1 dB. So that the efficient selection length for Circular interleaver is also 1024 for turbo coded 16 user CDMA system in a Rayleigh fading channel.



Fig(17) Performance of Rate 1/3 Parallel Turbo code with different interleaver length for 16Users CDMA system in a Rayleigh Fading channel

From the Fig(17) we can see that the Random interleaver of length 1024 is significantly better BER performance than the Random interleaver of length 256 and 512 while the difference between Random interleaver of length 256 and 512 started 0.4 dB and increased to 1.2 dB while the difference between Random interleaver of length 512 and 1024 ≈ 0.4 dB for all values of SNR dB. So that the efficient selection length for Random interleaver is also 512 for turbo coded 16 user CDMA system in a Rayleigh fading channel for less complexity in system design and for high processing speed.

7. Conclusion

The Multiuser CDMA systems which represent one of the main spread spectrum technologies for the third generation of wireless communications was presented with a parallel turbo codes a compromise between different parameters which are effecting the performance of parallel turbo codes should be worked out to find the efficient selection of Circular and Random interleaver for turbo code.

Turbo codes have an impressive near-Shannon limit error correcting performance. The superior performance of Turbo codes over convolutional codes is achieved only when the length of the interleaver is large to reduce the error floor that occurs and for large interleavers size, most interleavers perform well when the interleaver length is large but form the simulation results we find that the Circular interleaver of length 1024 and Random interleaver of length 512 have a good reduction in BER for Turbo coded Multiuser CDMA system among the other lengths. Also, the type of interleaver structure affects the code performance. In this paper. Random interleavers of length 512 are found to be the best for turbo coded 16 user CDMA.

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