Analysis of W-CDMA system with Turbo Code in Realistic Wideband Channel

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Abstract

Turbo codes of long block sizes have been known to show very good performance in an AWGN channel and the turbo code has been strongly recommended as error correction code for IMT-2000 in 3GPP(3rd Generation Partnership Project). Recently, turbo codes of short block sizes suitable for real time communication systems have attracted a lot of attention. Thus, in this paper we consider the turbo code of 1/3 code rate and short frame size of 192 bits in ITU-R channel model.
We analyzed the performance of W-CDMA systems of 10MHz bandwidths employing RAKE receiver with not only MRC diversity but also turbo code.

Ⅰ. Introduction

In the wireless mobile communication systems, a channel coding scheme is essential for improving reliability of communication under fading environment. Recently turbo code becomes the center of interest among the various coding scheme because of it's excellent performance.
The turbo code proposed by Berrou et al is widely known as to show excellent performance which approaches to the Shannon limit in case of large frame size in the AWGN channel [1]. Recently many studies are continued for applying this powerful coding technique to the wireless communication systems, and excellent performance of the turbo code are shown even in Rayleigh fading channel [2].
Accordingly, this study is to analyze the performance of W-CDMA system with various bandwidths by applying the turbo code of short frame size to W-CDMA systems which can support softly the third generation wireless communication systems such as IMT-2000. No coding, the convolutional coding or the turbo coding schemes can be applied to transport channel in the 3GPP.
Usage of coding scheme and coding rate for the different types of transport channel in the 3GPP is shown in table 1.[11]

Type of TrCH	Coding scheme	Coding rate
BCH	Convolutional coding	1/2
PCH		
RACH		
CPCH, DCH, DSCH, FACH		1/3, 1/2
	Turbo coding	1/3
	No coding	

Table 1 Usage of channel coding scheme and coding rate in 3GPP

Ⅱ. Turbo Code

2.1 Turbo Encoder

A turbo code is the parallel concatenation of two RSC (Recursive Systematic Convolutional) codes, which are usually identical. The turbo encoder used in this paper is shown in Fig. 1. The encoder is composed of two RSC encoders with an interleaver between them.
In this paper, We considered the turbo code of 1/3 code rate and short frame size of 192 bits in realistic wideband multipath channel.
The internal interleaver consists of bits-input to a rectangular matrix with padding, intra-row and inter-row permutations of the rectangular matrix, and bits-output from the rectangular matrix with pruning. The bits input to the Turbo code internal interleaver are denoted by $x_1, x_2, x_3, \ldots, x_K$, where K is the integer number of the bits and takes one value of $40 \leq K \leq 5114$ [11].
Whereas a turbo code shows excellent performance, it has a shortcoming of increased delay time caused by long interleaver [3]. So, when real time processing becomes important like voice communication, there is a trade-off between the performance and delay time, as for the length of the interleaver. In this study, we use a random interleaver which has a block size of 192 bits to investigate the performance of turbo code of short block size suitable for real time communication systems.

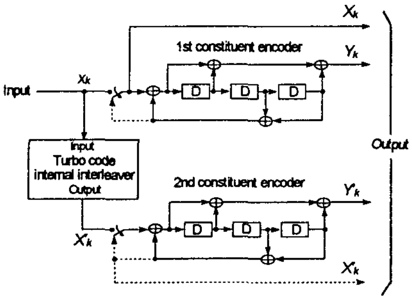


Fig. 1 Structure of rate 1/3 Turbo coder in 3GPP

In Fig. 1, the turbo encoder encodes the binary data d_k into the $\{X_k, Y_{1k}, Y_{2k}\}$, where the sequence X_k represents the systematic sequence. The sequences Y_{1k} and Y_{2k} are the parity check sequences for d_k and interleaved d_k. The interleaver is used to permute the information bits input to the second encoder. Let's assume the length of interleaver is N, and inspect the bit sequences more accurately. The information sequence is

$$d=(d_1, d_2, \cdots, d_k, \cdots, d_N),\ \ d_k \in \{0, 1\},$$

and the output sequences of an encoder are

$$Y_1=(Y_{11}, Y_{12}, \cdots, Y_{1k}, \cdots, Y_{1N}),\ Y_{1k} \in \{0, 1\}$$

$$Y_2=(Y_{21}, Y_{22}, \cdots, Y_{2k}, \cdots, Y_{2N}),\ Y_{2k} \in \{0, 1\}.$$

The output sequence Y_2 is produced by interleaved information sequence. The received sequence is represented as

$$R_1^N=(R_1, R_2, \cdots, R_k, \cdots, R_N),\ R_k=(x_k, y_k),$$

where the encoded sequences X_k and Y_k are transmitted over the channel and received as x_k and y_k.

In this system, the overall code rate of a turbo code is 1/3.

2.2 Decoding Algorithm

In a decoder, there are two algorithms, MAP (Maximam a-posteriori) algorithm, and SOVA(Soft Output Viterbi Algorithm) algorithm being transformed from Viterbi algorithm, which is used for finding soft output. MAP algorithm has a lot of computational complexity and it is difficult to implement. So, in this paper, we use SOVA algorithm which has small computational complexity and is easier implemented [4].

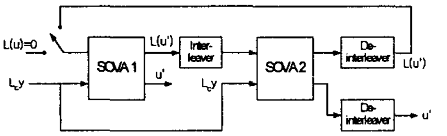


Fig. 2 Turbo Decoder

The schematic for a turbo decoder is shown in Fig. 2.

The SOVA algorithm proceeds as follows :

1. Initialize $M_0^{(m)}=0$ only for the zero state.

$$M_0^{(m)}=\begin{Bmatrix} 0, & zerostate \\ -\infty, & otherstate \end{Bmatrix}$$

2. Increase time t and compute the metric for each state in the trellis diagram.

$$M_t^{(m)}=M_{t-1}^{(m)}+u_t^{(m)}L_c y_{t,1}+u_t^{(m)}L(u_t)$$
$$+\sum_{j=2}^{N} x_{t,j}^{(m)} L_c y_{t,1}$$

m : allowable binary trellis branch

$M_t^{(m)}$: the accumulated metric for time t on branch m

$u_t^{(m)}$: the systematic bit for time t on branch m (i.e. $x_{t,1}^{(m)}$)

$x_{t,j}^{(m)}$: the jth bit of N bits for time t on branch m ($2 \le j \le N$)

$y_{t,j}^{(m)}$: the received value from the channel corresponding to $x_{t,j}^{(m)}$

L_c : the channel reliability value

$L(u_t)$: the a-priori reliability value for time t

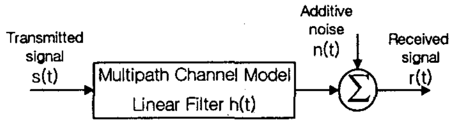
3. Find $\max\limits_m M_t^{(m)}$ for each state. Let $M_t^{(1)}$ denote the survivor path metric and $M_t^{(2)}$ denote the competing path metric.
4. Store $M_t^{(1)}$ and its associated survivor bit and state paths.
5. Compute $\Delta_t^0=\frac{1}{2}\left|M_t^{(1)}-M_t^{(2)}\right|$.
6. Compare the survivor and competing paths at each state for time t and update Δ_t^{MEM} for all MEMs where the estimated binary decisions of the two paths differ.
7. Go back to step 2 until the end of the received sequence.
8. Output the estimated bit sequence u' and its associated $L(u')$. $L(u')$ is passed on as the a-priori sequence $L(u)$ for the succeeding decoder.

Ⅲ. W-CDMA over Wideband Channel

The wideband multipath channel is generally modeled as a tapped delay linear filter, which is shown in eq. (1) and Fig. 3.

$$h(t)=\sum_{l=0}^{L-1}\sqrt{p_l}\,\alpha_l\,\delta(t-\tau_l)e^{j\theta_l} \qquad (1)$$

Here, p_l is the average power of the l-th component of the ITU-R M.1225 delay power profile, α_l is a Rayleigh distributed random variable representing the envelope of a zero-mean complex Gaussian time-invariant process, τ_l is the time delay, and θ_l is the phase of the process. We assume that the $\{\theta_l\}$ of the various paths are mutually independent random variables, and are uniformly distributed over $(0,2\pi)$. The time delay, τ_l, and the path strength component, $\sqrt{p_l}$, are obtained from the ITU-R delay profile.



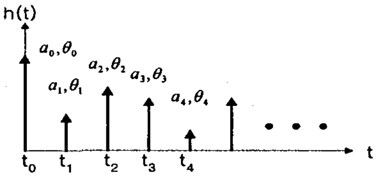


Fig. 3 Linear filter model

In this paper, we apply the ITU-R channel model which can resolve time by a 100 ns time bin, so we assume the channel bandwidth is 10 MHz, which is typical in many measurements. Let's assume the general situation for the analysis of W-CDMA signals. Total received signal is composed of K-DS waveforms(users), all of which are asynchronous one another. And coherent BPSK, perfect power control, and synchronization are assumed. Then k-th transmitted signal is given by eq. (2).

$$s_k(t) = m_k(t)c_k(t)\exp(j\omega_o t) \qquad (2)$$

Where $m_k(t)$ and $c_k(t)$ are the data and the spreading sequence of k-th user. Then total received signal $r(t)$ can be represented by eq. (3),

$$r(t)=\sum_{k=0}^{K-1}\sum_{l=0}^{L-1}\sqrt{p_l}\,\alpha_{k,l}m_k(t-\tau_{k,l})c_k(t-\tau_{k,l})\exp[j\{\omega_o(t-\tau_{k,l})+\theta_{k,l}\}]+n(t) \qquad (3)$$

where K is total number of users, L is total number of multipaths, and $n(t)$ is additive Gaussian noise.

The index $k = 0$ represents the signal from a desired user, whereas $k = 1, 2,$—, K-1 stands for signals from undesired users. The index $l = 0$ represents the first arrived signal while $l = 1, 2,$—, L-1 stands for second, third, · · ·-th multipath signal. And $\tau_{k,l}$ represents the delay time of k-th & l-th indexed signal, while $\theta_{k,l}$ represents the phase shift of k-th & l-th indexed signal caused by impulse response.

The output of a standard correlation receiver at $t = T$ is given by eq.(4).

$$\begin{aligned} Z &= \mathrm{Re}\left\lfloor \int_0^T 2r(t)c_0(t)\exp(-(\omega_o t+\theta_o))dt \right\rfloor \\ &= \mathrm{Re}\left\lfloor \int_0^T 2\{s_0(t)+s_i(t)+n(t)\}c_0(t)\exp(-(\omega_o t+\theta_o))dt \right\rfloor \\ &\equiv S+I+N \qquad (4) \end{aligned}$$

To find out the statistical properties of $Z(T)$, we need to analyze the statistics of each component S, I, and N, which comprise $Z(T)$, respectively.

Let's look through the statistics of wanted user signal S. Then, we can write the equation of S as follow [5].

$$S = \left|\sum_{l=0}^{L-1}\sqrt{p_l}\,\tilde{\alpha}_{0,l}\exp(j\tilde{\phi}_{0,l})R_c(\tau_{0,l})\right| \qquad (5)$$

In eq.(5), ~ stands for the notation of random variable. For further details the references deal with the equation of S [5].

We employ a RAKE receiver with maximal ratio combining (MRC) diversity to use all multipath components. Then, after employing MRC diversity, the output of a receiver can be represented by eq. (6).

$$Z_T = S_T + I_T + N_T \qquad (6)$$

And, the statistics of S_T should be modified as follows,

$$S_T = \sum_{i=1}^{M} G_i S_i\ , \qquad (7)$$

where G_i is the gain of i-th branch. The gain G_i is the ratio of signal voltage to noise and interference power and it is given by eq. (8) [6][7].

$$G_i = K\frac{S_i}{N} \qquad (8)$$

Usually, despread multiple access interference (MAI) is modeled as Gaussion, and noise is additive Gaussion noise [8][9].

In eq.(5), if L is large, S becomes the absolute value of complex addition of many complicated random variables. Instead of theoretical derivation of the pdf of S, $p(S)$, we find $p(S)$ by generating S numerically with a random number generator. And then this $p(S)$ becomes the fading coefficient of turbo code.

Ⅳ. Simulations

In order to analyze the performance, we consider outdoor to indoor and pedestrian test environment. The ITU-R M.1225 channel parameters are given in the Table.2[10].

tap	Channel B	
	Relative delay (ns)	Average Power (dB)
1	0	0
2	200	-0.9
3	800	-4.9
4	1200	-8.0
5	2300	-7.8
6	3700	-23.9

Table 2 Outdoor to indoor and pedestrian test environment tapped-delay-line parameters

We generate the probability density functions $p(S)$ of CDMA signals by generating S numerically by using eq.(6). This is shown in Fig. 4.

The S is normalized to have unit power.

This study is to analyze the performance according to the number of branches of rake receiver by passing the received signal through a RAKE receiver with a turbo code in ITU-R channel environments.

In this study, the turbo code has three memories and random interleaver as shown in Fig. 1, and the code rate is 1/3. We use an interleaver of 192bits short, which make the application of turbo code to real time processing.

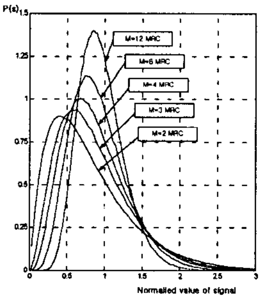


Fig. 4 Pdfs of 10MHz bandwidth systems in urban area

In a simulation, the turbo decoder uses SOVA algorithm, and the bit error rate(BER) is illustrated in Fig. 5 and 6 when turbo code is applied to each system whose number of branches of the rake receiver are M= 3, 4, 6, 12 respectively.

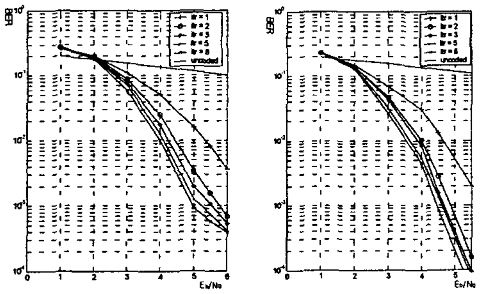


Fig. 5 BER of 10MHz bandwidth systems with M=3,4

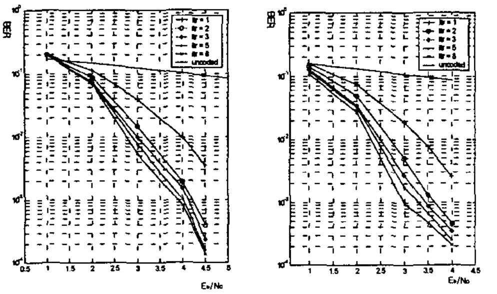


Fig. 6 BER of 10MHz bandwidth systems with M=6,12

V. Conclusions

In this paper, we analyze the performance of W-CDMA systems using turbo code in the wideband multipath channel through the simulations. To do so, we got the numerically generated received W-CDMA signal, and illustrated the performance by applying the turbo code

And we apply SOVA decoding algorithm to the data of short frame size to make the turbo coded system suitable for real time processing such as voice. And the performance is illustrated with executing iterative decoding.

	I=2	I=3	I=5	I=8
M=3	5.82	5.55	5.23	4.99
M=4	5.17	4.88	4.77	4.48
M=6	4.30	4.21	4.00	3.96
M=12	3.98	3.66	3.45	3.00

Table 3 Required E_b/N_0 for different number of branches and number of iterations at the BER of 10^{-3}

As the results of the simulations, it is shown that the same performance is achieved in case of three times iterative decoding with M=4 and eight times with M=3 at the BER of 10^{-3}. Also, the same performance is shown in the case of eight times iterative decoding with M=4 and twice with M=6. and, in case of twice with M=12 and eight times with M=6.

The turbo code has been specified as error correction code for IMT-2000, so we expect that these results can be useful as basic data for the implementation of turbo coded system.

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