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Performance Comparison of Turbo Coded Single Input Multiple Output System Using Selective Combining, Equal Gain Combining and Maximal Ratio Combining

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ABSTRACT

This paper compares the performance of a Turbo Coded Single Input Multiple Output (SIMO) system with uncoded SIMO system using selective combing, equal gain combing and maximal ratio combining. Turbo Coded system uses Turbo encoder to encode the input information before modulation, whereas uncoded system modulates input information without using turbo encoder. QPSK or 16 QAM or 64 QAM modulator modulates the information and transmit it from single transmit antenna. Receiving antennas of receiver receive transmitted information and combine using selective combing or equal gain combing or maximal ratio combining. It is observed that the turbo coded system with 2, 4, 6 and 8 receive antennas using selective combining provide 35, 28, 24 and 24 dB coding gain respectively, turbo coded system with 2, 4, 6 and 8 receive antennas using equal gain combining provide 34, 22, 20 and 19 dB coding gain respectively and turbo coded system with 2, 4, 6 and 8 receive antennas using maximal ratio combining provide 27, 17, 15 and 13 dB coding gain respectively compared to uncoded system at a BER 10^{-6}. It is also observed that turbo coded system using maximal ratio combining provides 20 to 26 dB coding gain at a BER of 10^{-6} compared to turbo coded system using equal gain combining. And turbo coded system using maximal ratio combining provides 23 to 26 dB coding gain at a BER of 10^{-6} compared to turbo coded system using selective combining.

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1. INTRODUCTION

Single Input Multiple Output (SIMO) is an antenna technology for wireless communication in which a single antenna at the transmitter and multiple antennas at the receiver are used to minimize errors and optimize data speed. However, only Multiple receive antennas technique can't satisfy the reliability requirement in future mobile systems, so it should be concatenated with channel coding to provide more coding gains. Forward Error correction (FEC) coding schemes are used as channel coding in most of the digital communication systems. Turbo Codes (TC) are a class of high-performance FEC codes which were the first practical codes to closely approach the channel for the single input single output(SISO) system capacity[1-3] and are specified as FEC schemes for most of the wireless systems. On the other hand, there are various techniques to recover the desire message at receiver. In this paper, Selective Combining (SC), Equal Gain Combining (EGC) and Maximal Ration Combining (MRC) are used to show the performance of the system. In SC, only one antenna's signal is considered at any given time. The antenna chosen however is based on the best signal-to-noise ratio (SNR) among the received signals. EGC combines the information from all the received branches weighting each with equal gain; and MRC combines the information from all the received branches but weights each with the respective gain of the branch. SC gives the most inferior BER performance, EGC has a performance better than SC and MRC gives the best performance.

Performance of SC, EGC and MRC has been widely studied [4-23, 26-30]. But turbo coded system with combining techniques of SC, EGC and MRC has not been studied much. [24] and [25] show the performance of SC, EGC and MRC with turbo code only for 2 receive antennas. This paper investigate the performance of single input multiple output (SIMO) system using SC, EGC and MRC with and without TC for 2, 4 ,6 and 8 receive antennas.

2. SYSTEM MODEL

It is considered that the system is equipped with single transmit and multiple receive antennas, M_R. Data are encoded by a turbo encoder and the encoded bits are modulated by a QPSK or 16 QAM or 64 QAM modulator before transmitting as shown in Fig.1. The combiner combines received signals to detect the symbol. The detected symbols are demodulated by demodulator and send to turbo decoder to get the output as shown in Fig.2.

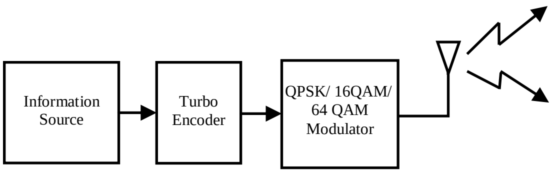

Figure 1. Block diagram of transmitter

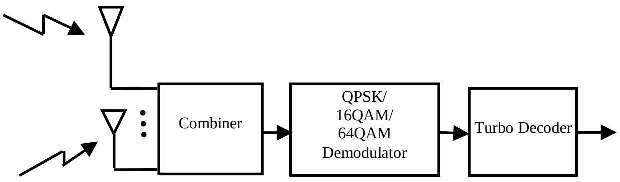

Figure 2. Block diagram of receiver

2.1. Encoding

The information source is encoded by a binary turbo encoder. The turbo encoder consists of two identical recursive systematic convolutional (RSC) encoders with parallel concatenation. The two RSC encoders are separated by a pseudorandom (turbo) interleaver [1-3]. The information bits are encoded by both RSC encoders. The first RSC encoder operates on the input bits in their original order, while the second RSC encoder operates on the input bits as permuted by the Turbo interleaver. If the input symbol is of length 1 and output symbol size is R, then the encoder is of code rate rc=1/R. The interleave size and structure of turbo code affect the code error performance considerably; no attempt was made to optimize their design of turbo code. Fig. 3 shows the block diagram of a turbo encoder of rate 1/3. In the diagram b_k^s is the systematic bits, and b_k^{P1} , and b_k^{P2} are the parity check bits. The QPSK or 16 QAM or 64 QAM modulator modulates the turbo encoded bits.

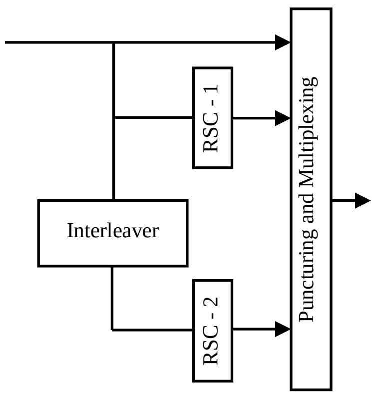

Figure. 3. Structure of Turbo Encoder

2.2. Decoding

The signal y_i , received at antenna i , is given by

$$y_i = h_i s + n_i \quad (1)$$

where, h_i is the channel for the ith receive antenna

s is the transmitted symbol and

n_i is the noise for ith receive antenna.

The received signals are combined using SC or MRC or EGC as follows:

2.2.1. SC

In this method, the combiner selects the antenna with the highest SNR and ignore observations from the other antenns. Assume that λ_i is the instantaneous SNR for the i^{th} branch, which is given as:

$$\lambda_i = \frac{|h_i|^2 E_b}{N_0}$$

So, the chosen receive antenna is one which gives

$$\lambda = \max(\lambda_i) \quad (2)$$

The probability that the SNR for the i^{th} receive antenna is lower than a threshold v is given by

$$p(\lambda_i \le v) = \int_0^v f\lambda_i \quad (3)$$

where $f_{\lambda_i}(\alpha)$ denotes the probability density function of λ_i , which is assumed to be the same for all antennas. If we have M_R independent receive antennas, the probability that all of them have an SNR below the threshold v is given by

$$P(\lambda_i \le v, ..., \lambda_{M_R} \le v) = [p(\lambda_i \le v)]^{M_R}$$

and this decreases as M_R increases. This is also the CDF of the random variable

$$\bar{\lambda} = \max\{\lambda_1, ..., \lambda_{M_R}\} \quad (4)$$

Hence, $\bar{\lambda} < v, iff \lambda_1, \ldots, \lambda_{M_R}$ are all less than v . Therefore the PDF follows directly from the derivation of the CDF with respect to v [5].

2.2.2. MRC

In MRC, the signals from all of the M_R branches are weighted according to thir individual SNRs and then added together to get the output. Here the individual signals need to be brought into phase alignment before adding. If the signals are r_i from each branch, and each branch has a gain G_i ,then

$$r_{M_R} = \sum_{i=1}^{M_R} G_i y_i$$

where, $y_i = h_i s + n_i$. So,

$$r_{M_R} = \sum_{i=1}^{M_R} G_i h_i s_i + \sum_{i=1}^{M_R} G_i n_i$$

The power spectral density of the noise after MRC is given by

$$S_v = 2N_0 \sum_{i=1}^{M_R} |G_i|^2$$

The instantaneous signal energy is

$$2E_s\left|\sum_{i=1}^{M_R}|G_i h_i|^2\right|$$

This results in the SNR applied to the detector as

$$\lambda_{M_R} = \frac{Es\left|\sum_{i=1}^{M_R}|G_i h_i|^2\right|}{N_0\sum_{i=1}^{M_R}|G_i|^2}$$

From Cauchy-Schwartz inequality defined as

$$\left|\sum_{i=1}^{M_R}|a_i b_i|^2\right| \le \left|\sum_{i=1}^{M_R}|a_i|^2\right|\left|\sum_{i=1}^{M_R}|b_i|^2\right|$$

We obtain, if $G_i = h_i$ for all i (perfect channel knowledge)

$$\lambda_{M_R} = \frac{E_S}{N_0}\left|\sum_{i=1}^{M_R}|G_i|^2\right| \quad (5)$$

$E_s|G_i|^2 / N_0$ is the SNR per antenna, which means that λ_{M_R} can be large even if the individual SNRs are small.

2.2.3. EGC

It is the same as MRC but with equal weighting for all branches. It does not require estimation of the fading amplitude for each imdividual branch. Instead, the receiver sets the amplitudes of the weighting factor to be unity.The performance of EGC is marginally inferior to MRC, but the complexities of implementation are significantly less.

The detected symbols are demodulated by QPSK or 16 QAM or 64QAM demodulator and send to turbo decoder to get the output. The turbo decoding is performed by a suboptimal iterative algorithm. The decoder consists of two identical concatenated decoders of the component codes separated by the same interleaver as shown in Fig. 4.

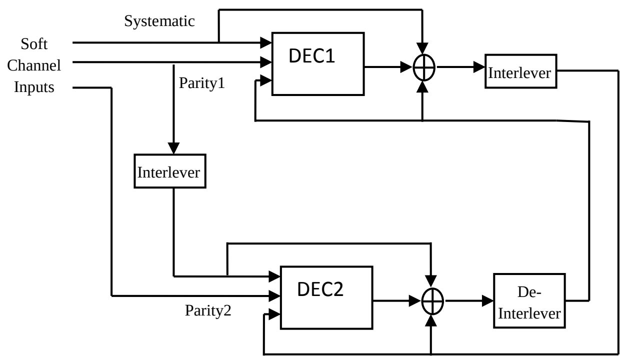

Figure. 4 Block diagram of turbo decoder

The component decoders are based on a maximum a posteriori (MAP) algorithm or a soft output Viterbi algorithm (SOVA) generating a weighted soft estimate of the input sequence. However researcher used the MAP decoder to decode the Turbo code [1-3]. If data $u = i$ is transmitted from a set of M different signal and turbo decoder receives signal M, then the a posteriori probability (APP) of a decision on $u = i$ given by expression:

$$P(u = i \mid y) = \frac{p(y \mid u = i)P(u = i)}{p(y)}, i = 1,\ldots, M \tag{6}$$

and

$$p(y) = \sum_{i=1}^{M} p(y \mid u = i)P(u = i) \tag{7}$$

where, $P(u = i \mid y)$ is the APP, $P(y \mid u = i)$ is the probability density function(pdf) of the received signal y given that signal set is transmitted (a propri probability), and p(y) is the pdf of the received signal. P(y) is a scaling factor for each specific observation. It can be shown using Bayes' decision rule that the optimum decision that minimizes the probability of error in detection of the signal is the decion on maximum a posteriori probability (MAP) which may be expressed as

$$u = i \quad \text{iff} \quad P(u = i \mid y) > P(u = k \mid y), \ \forall k = 0,\ldots, M, k \neq i \tag{8}$$

From (6), the APP's in (8) can be replaced by the following equivalent expressions canceling common term, p(y) from both sides:

$$u = i \quad \text{iff} \quad p(y \mid u = i)P(u = i \mid y) > p(y \mid u = k)P(u = k), \ \forall k = \{0,\ldots, M\}, k \neq i \tag{9}$$

Let the binary data, 0 and 1, be represent by -1 and +1 respectively. Then the equation (8) and (9) can be written as

$$P(u = +1 \mid y) \underset{H_2}{\overset{H_1}{\gtrless}} P(u = -1 \mid y) \tag{10}$$

and

$$p(y \mid u = +1)P(u = +1 \mid y) \underset{H_2}{\overset{H_1}{\gtrless}} p(y \mid u = -1) \ P(u = -1 \mid y) \tag{11}$$

which means that one should decide in favor of hypothesis $H_1, u = +1$, if the left hand side of equation (11) is greater than the right hand side. Otherwise one should choose hypothesis $H_2, u = -1$. Equation (10) and (11) can be written in a ratio format to give the likelihood ratio test:

$$\frac{P(u = +1 \mid y)}{P(u = -1 \mid y)} \underset{H_2}{\overset{H_1}{\gtrless}} 1 \tag{12}$$

and

$$\frac{p(y \mid u = +1)P(u = +1)}{p(y \mid u = -1)P(u = -1 \mid y)} \underset{H_2}{\overset{H_1}{\gtrless}} 1 \tag{13}$$

By taking the logarithm of the likelihood ratio, the posteriori log likelihood ratio is obtained as

$$L(u \mid y) = \log\left(\frac{P(u = +1 \mid y)}{P(u = -1 \mid y)}\right) \tag{14}$$

The MAP decoding rule can now be translated to

$$\hat{u} = sign[L(u \mid y)] \tag{15}$$

where $\hat{u}$ is the detected signal.

3. SIMULATION RESULTS

In this section, Computer simulation is carried out to show the BER performance of the proposed system. The results are evaluated for single Tx and 2, 4 and 8 Rx antennas with and without TC. Simulation with TC is referred as coded system and without TC is referred as uncoded system. For coded system, frame size= 378, rate= 1/3, encoder generator g = [1 0 1 1; 1 1 0 1; 1 1 1 1] and number of iterations =2 is considered to perform simulation. BERs are presented to compare the performance of coded SC system with uncoded SC system in Fig. 5. It is observed that the coded SC system provides 35, 28, 24 and 24 dB coding gain compared to uncoded SC system with single Tx antenna and 2/4/6/8 4 Rx antennas respectively, at a BER of 10-6 compared to uncoded SC system. And there is around 3-6 dB gain for increasing Rx antenna from 2 to 4, 4 to 6 and 6 to 8 of coded SC system with single Tx.

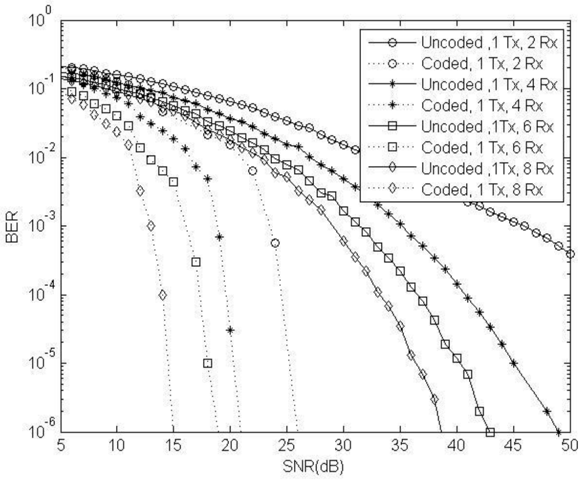

Figure. 5 BER performance comparison of coded SC system(1Tx & 2/4/6/8 Rx) and uncoded SC system with same diversity.

Fig. 6 shows the performance of coded EGC system with single Tx and 2/4/6/8 Rx antennas. It provides 27, 17, 15 and 13 dB coding gain for 2, 4, 6 and 8 Rx antenna respectively at BER of 10-6 compared to uncoded EGC system with same diversity. And there is around 2-5 dB gain for increasing Rx antenna from 2 to 4, 4 to 6 and 6 to 8 of coded EGC system with single Tx.

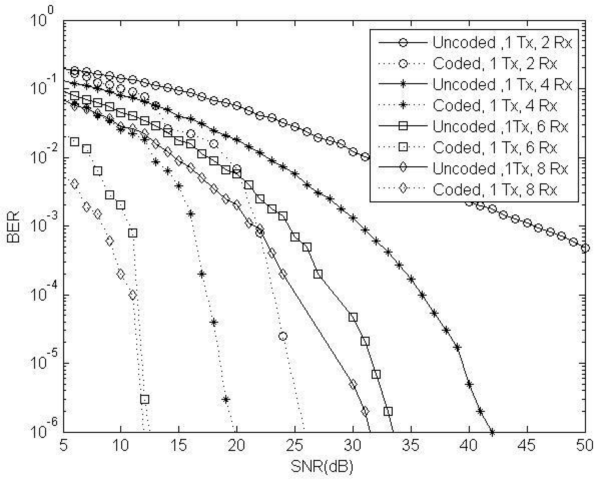

Figure. 6 BER performance comparison of coded EGC system(1Tx & 2/4/6/8 Rx) and uncoded EGC system with same diversity.

Fig. 7 shows the performance of coded MRC system with single Tx and 2/4/6/8 Rx antennas. It provides 27, 17, 15 and 13 dB coding gain for 2, 4, 6 and 8 Rx antenna respectively at BER of 10-6 compared to uncoded MRC system with same diversity. And there is around 1-5 dB gain for increasing Rx antenna from 2 to 4, 4 to 6 and 6 to 8 of coded MRC system with single Tx

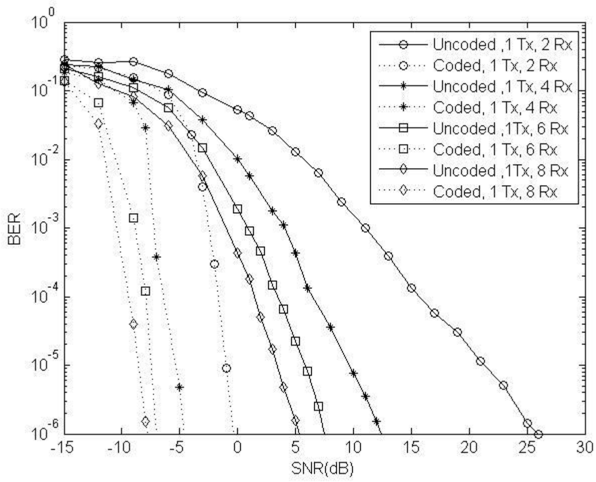

Figure 7 BER performance comparison of coded MRC system (1Tx & 2/4/6/8 Rx) and uncoded MRC system with same diversity.

4. CONCLUSION

From the simulations results, researcher observes that Turbo coded system with SC, EGC and MRC makes a significant difference over uncoded system with SC, EGC and MRC and turbo coded system with MRC gives the best performance.

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