

# Interleave-Division-Multiplexing Space-Time Codes<sup>1</sup>

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**Abstract** – This paper considers the use of interleaved low-rate turbo-type codes to exploit the expanded signal dimension of multiple transmit antenna systems. Performance close to the outage capacity is demonstrated for systems with arbitrary numbers of transmit antennas.

## I. INTRODUCTION

Turbo-type schemes have been extensively investigated for transmit antenna diversity systems [1,2]. The aim of this paper is to exploit the expanded signal dimension of multiple transmit antenna systems. The expanded dimension introduces a degree of freedom that can be exploited to improve power efficiency [1] or throughput [2]. In this paper, we will study a class of interleave-division-multiplexing (IDM) codes to improve the power efficiency. The principle is closely related to the so-called interleave-division multiple access (IDMA) communication systems [3] and hence the name.

## II. TRANSMITTER AND RECEIVER PRINCIPLES

We focus on a transmit diversity system with  $N$  transmit antennas and one receive antenna, referred to as an  $N \times 1$  system, in a quasi-static fading channel. Denote by  $J$  the frame length. Let

$$\mathbf{x}^{(n)} = \{x_1^{(n)} \dots x_J^{(n)}\}, \quad n = 1, 2, \dots, N$$

be the signal sequence transmitted from the  $n$ th transmit antenna.

At the transmitter side, a length- $J_d$  binary information sequence  $\mathbf{d}$  is first encoded into a length- $J_c$  binary sequence  $\mathbf{c}$  based on a forward error correction (FEC) code  $C$  ( $c_i \in \{+1, -1\}$ ). The coded sequence  $\mathbf{c}$  is then interleaved and segmented into  $2N$  equal-length sequences to form the real and imaginary parts of  $\{\mathbf{x}^{(1)}, \dots, \mathbf{x}^{(n)}, \dots, \mathbf{x}^{(N)}\}$ . Then, we have  $J = J_d/2N$ . The rate of the overall code is  $R = J_d/J$ . We also define the coding rate of  $C$  as  $R_c = J_d/J_c = R/2N$ , which can be very low for large  $N$  (say  $N \geq 4$ ) and moderate  $R$  (say  $R = 1 \sim 2$  bits/symbol). Thus, a low-rate code can be used as  $C$  to maximize the coding gain. A good choice is the turbo-Hadamard code studied in [4] that can achieve performance close to the ultimate Shannon limit of -1.6dB in AWGN.

At the receiver side, we employ an iterative algorithm, which is a greatly simplified version of the turbo APP-MMSE multiuser detection algorithm originally derived in [5]. The complexity involved is very low, growing only linearly with the number of transmit antennas [3,6]. The details of the receiver function can be found in [3,6].

## III. NUMERICAL RESULTS

Let  $N_{\text{info}}$  be the number of information bits in a frame and  $l$  the iteration number. The FEC codes used in our

simulation studies are selected as follows. For any given  $R$  and  $N$ , we first select a proper FEC code with a rate close to  $R_c$ , and then either repeat or puncture some bits to adjust the rate to match  $R_c$ .

We only consider systems with  $N \geq 4$  and  $R = 1$  bit/symbol. In this case,  $R_c \leq 1/8$  and the low-rate turbo-Hadamard code [4] can be used. A turbo-Hadamard code with  $M$  constituent codes has an overall rate of  $r/(r + M \times (2^r - r))$  [4], where  $r$  is the order of the Hadamard code used. We transmit the information sequence,  $\mathbf{d}$ ,  $M$  times, so that the rate is reduced to  $r/(M \times 2^r)$ . This rate matches  $R_c$  for properly selected  $M$  and  $r$ . The detailed parameters of the turbo-Hadamard codes used in Fig.1 are listed below, where  $G(D)$  is the generator of the convolutional code involved.

- **For  $N = 4$ :**  $r = 4$ ,  $M = 2$ ,  $R_c = 1/8$ ,  $N_{\text{info}} = 4096$ , and  $G(D) = (1+D+D^3)/(1+D^2+D^3)$ .
- **For  $N = 8$ :**  $r = 4$ ,  $M = 4$ ,  $R_c = 1/16$ ,  $N_{\text{info}} = 4096$ , and  $G(D) = 1/(1+D)$ .
- **For  $N = 16$ :**  $r = 6$ ,  $M = 3$ ,  $R_c = 1/32$ ,  $N_{\text{info}} = 4092$ , and  $G(D) = 1/(1+D)$ .

Fig. 1 illustrates the frame-error-rate (FER) performance of the IDM codes with  $R = 1$  bit/symbol over quasi-static Rayleigh fading channels. It is seen that such codes can achieve performance about 1.5dB away from the outage capacity. This approach can be applied to arbitrary numbers of transmit antennas.

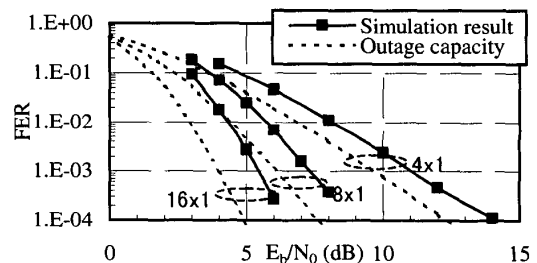


Figure 1. FER performance based on turbo-Hadamard codes over quasi-static Rayleigh fading channels.  $l = 18$ .

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