Combination lock-like differential codebook for temporally correlated channels

Y.J. Kim, X. Li, T. Kim and D.J. Love

A novel differential codebook, preserving inherent properties of 3GPP long-term evolution (LTE) codebooks, is proposed for temporally correlated channels. The steady-state achievable throughput performance of the proposed codebook shows at least 0.9 dB of SNR better than that of the conventional LTE codebook with the same amount of feedback information.

Introduction: Long-term evolution (LTE) and LTE-Advanced (LTE-A) systems have adopted codebook-based transmit beamforming schemes to achieve a good trade-off between beamforming gain and the required amount of feedback information [1, 2]. When the codebook is designed in standards, it is generally assumed that the multiple input multiple output (MIMO) channel coefficients are independent at every time instant. However, in practice, temporal correlation between adjacent channel realisations often exists so that the consecutive precoders are likely to be similar. Some well-defined differential codebooks accounting for the temporal correlation of the channel into the codebook design have been exploited and show robust performance [3, 4] (see more references in [2]). However, the properties of the conventional differential codebooks are far from those of LTE codebooks in terms of the complexity, nested property and constant modulus property. Thus, in this Letter, we propose a new differential codebook having LTE codebook properties.

We consider a limited feedback MIMO beamforming system with $M_t$ transmit and $M_r$ receive antennas. At the transmitter, a single data stream is transmitted. Both the transmitter and the receiver have a common channel realisation index and a codeword in $k$ in (5) extracts the set $\{w_j^k\}$ of possible differential codebooks constrained from 8-PSK alphabets, where $j \neq 1$ is the index of all possible codewords having 8-PSK constellations. Note that the distance function in (3) does not depend on the distance relations between the vectors in the set $\{w_j^0, \ldots, w_j^M\}$.

Table 1: Proposed differential codebook

<table>
<thead>
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<th>Index</th>
<th>Codeword</th>
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<tbody>
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<td>1</td>
<td>$[1 ; 1 ; 1 ; 1]^T$</td>
<td>3</td>
<td>$[1 ; e^{j \pi/3} ; 1 ; 1]^T$</td>
</tr>
<tr>
<td>2</td>
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<td>$[1 ; e^{j \pi/3} ; e^{j \pi/2} ; 1]^T$</td>
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<td>6</td>
<td>$[1 ; e^{j \pi/2} ; 1 ; 1]^T$</td>
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<td>8</td>
<td>$[1 ; e^{j \pi/3} ; 1 ; 1]^T$</td>
</tr>
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</table>

The transmitter and receiver compute the codebook update at time instant $k$ by multiplying the differential codebook $W_{diff}$ and the previous beamforming vector $W_{diff}^{k-1}$, which is described by

$$W_{diff} = W_{diff}^{k-1} \cdot \mathbf{H}$$

where the operator $(\cdot)\cdot(\cdot)$ in (5) extracts the set $W_{diff}$, in which the $r$th element of $W_{diff}$ is formulated as the Hadamard product of the $r$th element of $W_{diff}$ and $W_{diff}^{k-1}$. As the current codebook is updated at every time instant, the codewords in the codebook change continuously. The operation of the codebook update can be illustrated as a series of combination locks, each of which has a circular sequence of 8-PSK symbols. When the precoder of $W_{diff}$ is selected at the previous time instant, the operation of the codebook update can be shown as in Fig. 1. Finally, the optimum codeword index at time instant $k$ is determined, which maximises the capacity as

$$n_{opt} = \arg \max_{1 \leq i \leq 8} \log_2 (1 + \rho \|H_i W_{diff}^{k-1}\|^2)$$

between $w_j^0$ and a codeword in $\hat{W}_{diff}$, and all the elements of $w_j^0$ consist of 1. Note that the distance function in (3) does not depend on the distance relations between the vectors in the set $\{w_j^0, \ldots, w_j^M\}$. Because we are limited to 8-PSK constellations, it is fixed, and the remaining $(N - 1)$ codewords are determined one by one among all possible codewords having 8-PSK elements, showing the least chordal distances from $w_j$, as shown in Table 1.

Fig. 1 Codebook update example using $W_{diff}$ in Table 1 when previous precoder is $[1 \; e^{j \pi/4} \; 1 \; 1]^T$.
Simulation results: Monte Carlo simulations were performed to illustrate the steady-state achievable throughput performance of the proposed differential codebook compared with existing schemes. Throughout the simulation, we assume \((M_t, M_r) = (4, 4)\) for exhibition of the results in Fig. 2. The codebook size \(N\) is fixed to 16, which is the same as in the LTE system. When we generate \(\varepsilon\) of a first-order Gauss-Markov process, 3 km/h velocity, \(f_c = 2.5\) GHz, feedback interval of 5 ms, and an error-free feedback channel are assumed, where the typical temporal correlation coefficient is \(\varepsilon = 0.988\) [3]. The achievable throughput performance of the proposed codebook along with those of the ideal SVD codebook, differential rotation codebook without spherical cap radius adaptation in [3], quasi-diagonal codebook in [4], ideal equal gain transmission (EGT) codebook, and LTE release-9 codebook are shown in Fig. 2. Those curves are denoted with the legends of ideal SVD, codebook in [3], codebook in [4], ideal EGT and LTE, respectively. The proposed codebook shows 0.3 bit/s/Hz better performance than the LTE codebook when the SNR is fixed to 10 dB, and 0.9 dB SNR gain to obtain the same steady-state achievable throughput compared with the LTE codebook. Note that the proposed differential codebook with 8-PSK alphabets is a subset of the EGT codebook. As seen from Fig. 2, the achievable throughput of the proposed codebook almost approaches that of the ideal equal gain transmission. Moreover, as \(\varepsilon\) varies from 0.999 (1 km/h) to 0.872 (10 km/h), we can obtain similar simulation results.

Conclusions: A simple combination lock-like differential feedback MIMO system for slowly fading channels has been investigated. Owing to having only 8-PSK constellations, the proposed codebook can be designed quickly and reduce the transceiver complexity greatly. From the simulation results, the proposed codebook shows significant throughput gain, preserving perfect compatibility with LTE and LTE-A systems.

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References
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