Cyclic Prefix Overhead Reduction for Low-Latency OFDM Communications

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1. Introduction

Low latency is one of the most critical requirements for 5G mobile communications. To achieve latency as low as 1 ms, the packet duration should be less than 33 μs [1]. However, this cannot be met in the current version of LTE-A, since the OFDM symbol duration in LTE-A is equal to 67 μs. Therefore, the symbol duration needs to be decreased to achieve lower latency [2]. However, the reduced symbol duration will increase the overhead of cyclic prefix (CP) unless the length of CP is changed accordingly. As the required length of the CP is proportional to the delay spread of the channel [3], the delay spread should be reduced to shorten the CP length in accordance with the OFDM symbol duration. The objective of this paper is to develop a precoding scheme to shorten the effective delay spread of the channel so that the CP overhead can be reduced in an OFDM system.

2. System Model and Proposed Scheme

We consider the downlink of a MISO-OFDM system with $N$ subcarriers and $M$ antennas at the base station. The channel frequency response of a user corresponding to the $n$-th subcarrier ($n = 0, 1, \cdots, N-1$) and the $m$-th antenna ($m = 1, 2, \cdots, M$) can be expressed as

$$H_m(n) = \sum_{\ell=0}^{L-1} h_m(\ell) e^{-j2\pi \ell n/N},$$  \hspace{1cm} (1)

where $L$ denotes the length of the channel impulse response and $h_m(\ell)$ is the channel impulse response. Let $W_m(n)$ be the precoding weight corresponding to $H_m(n)$ and let $X(n)$ denote the transmit symbol on the $n$-th subcarrier, then the received signal on the $n$-th subcarrier is given as

$$Y(n) = \sum_{m=1}^{M} H_m(n)W_m(n)X(n) + v(n),$$  \hspace{1cm} (2)

where $v(n)$ represents the additive noise. As a result, the equivalent channel frequency response in the $n$-th subcarrier after the precoding can be written as

$$H_{eq}(n) = \sum_{m=1}^{M} H_m(n)W_m(n).$$  \hspace{1cm} (3)

Let $h_{eq}(\ell)$ be the channel impulse response corresponding to $H_{eq}(n)$, then the root mean square (rms) delay spread of the equivalent channel can be calculated as [4]

$$\tau_{\text{rms}} = \sqrt{\frac{1}{E} \sum_{\ell=0}^{L-1} (\ell - \bar{\ell})^2 |h_{eq}(\ell)|^2},$$  \hspace{1cm} (4)

where

$$E = \sum_{\ell=0}^{L-1} |h_{eq}(\ell)|^2 \quad \text{and} \quad \bar{\ell} = \frac{1}{E} \sum_{\ell=0}^{L-1} \ell |h_{eq}(\ell)|^2.$$

(5)

We design the precoding vector $W(n) \triangleq [W_1(n) \ W_2(n) \cdots \ W_M(n)], n=0,1,\cdots, N-1$ that minimizes the rms delay spread in (4). Specifically, we can formulate an optimization problem using an upper bound of (4) as the objective function and constraining the SINR for each subcarrier. The problem is nonconvex and so hard to solve in general. To find the optimal solution, we apply a semidefinite relaxation technique to transform the problem into a convex problem. The details of formulating the problem and finding the optimal precoding matrix are omitted here due to space limitation.

Figure 1 shows the channel impulse response of the original channels and that of the equivalent channel after the proposed precoding scheme, when the base station is equipped with two antennas ($M = 2$). The rms delay spreads of the original channels are 4.16 and 4.88 for the two antennas, whereas the rms delay spread of the equivalent channel is 2.28 by using the precoding. This confirms that the rms delay spread can be substantially reduced with the proposed precoding scheme.

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References