Joint Angular and Time Diversity of Multi-Antenna CDMA Systems in Wireless Fading Channels

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ABSTRACT

In this paper, a multi-antenna based receiver structure for direct sequence code division multiple access (DS/CDMA) system is proposed. The proposed scheme exploits the excellent time resolution of a CDMA RAKE receiver and uses an antenna array beamforming structure to resolve multipath returns in both angular and time domains. A much higher diversity gain than that based only on the time domain diversity can be achieved. This work suggests a new space-time diversity paradigm, namely angular-time diversity, which differs from traditional Alamouti-type space-time coded schemes. The impairments caused by multipath and multiuser interference are analyzed. The performance of the proposed receiver in multipath fading channel is explicitly evaluated. An expression for uncoded system bit error probability is derived. Simulation results show the performance improvement in terms of BER due to the use of multi-antenna in the receiver, and the results illustrate that the multi-antenna based receiver works effectively in resolving multipaths in both angular and time domains to achieve performance improvement due to angular and time diversity gain provided by the multi-antenna system.

Keywords: Angular and Time Diversity, CDMA, Channel, Fading Channel, Multi-Antenna System

1. INTRODUCTION

Direct sequence code division multiple access (DS/CDMA) is a modulation and multiple access technique currently being implemented in cellular mobile radio communication systems (Schilling, Pickholtz, & Milstein, 1990). The robustness of the CDMA based technologies has been well demonstrated by the successful commercial operation in 2G and 3G wireless communications around the world. There are several features that make CDMA an attractive transmission technique. One of the most salient features of CDMA is its ability to distinguish different multipath returns in a very cost-effective way to achieve a multipath diversity gain. This is an advantage that the other multiple access technologies (such as orthogonal frequency division multiple access -- OFDMA) may not have (Viterbi & Viterbi, 1993).
In a wireless communication system, the underlined physical layer should work reliably in an environment where multipath propagation exists. In a wireless fading channel, transmitted signal may reach a receiver at different incoming rays, which may arrive at the same receiver at different times. This translates directly into an induced time diversity. When the desired signal is propagated through different multipath rays, the signal itself can provide a very good time diversity with the help of a RAKE receiver, as long as we can distinguish them successfully. The resolution of multipath returns should be less than a chip duration in a CDMA system. If the time difference of the path delays is less than one chip duration, the multipath signals cannot be resolved and no multipath diversity gain can be achieved.

Another diversity approach to further improve the system performance is the use of spatial signal processing with an antenna array at a receiver in order to resolve signal rays arriving at different angles of arrival (Simanapalli, 1994; Naguib, Paulraj, & Kailath, 1994; Swales, Beach, Edwards, & McGeehn, 1990; Alamouti, 1998; Yoo & Goldsmith, 2006; Tarokh, Seshadri, & Calderbank, 1998). Using spatial signal processing with antenna arrays, we can achieve an angular diversity gain on top of the time diversity gain in a CDMA based wireless system. The joint exploitation of angular and time diversity can significantly improve the overall performance of a CDMA system, based on the existing beamforming or smart antenna technologies. In addition, the application of joint angular and time diversity techniques can also contribute to a great reduction of multipath interference and multiple access interference.

It is noted that multi-antenna techniques alone have been well discussed for a long time in the literature. Alexiou and Haardt (2004) analyzed the performance of smart antenna systems. In a smart antenna system, an angular diversity gain can be obtained. Exploitation of the spatial domain signal processing can help improve the performance of a wireless system due to the improvement in its link quality through the mitigation of impairments in mobile communications, such as multipath interference and co-channel interference. It can also help increase the data rate through simultaneous transmission of multiple data streams by different antennas, as suggested in the multiple-input-multiple-output (MIMO) systems. However, mobile terminals usually never use a large number of antennas due to their size and power constraints (Yoo & Goldsmith, 2006). Thus, the smart antenna or antenna array are normally only used in base stations.

The issues on performance analysis of a traditional DS/CDMA has been well addressed in the literature. However, very few works have been reported to discuss the issues on how to achieve a joint angular and time diversity gain in a CDMA based system. In the text followed, we would like to briefly summarize the researches related to either RAKE based time domain multipath resolution schemes or spatial domain signal separation schemes.

Jalloul and Holtzman (1994) proposed a way to approximate the bit error probability of a CDMA system which works based on the resolution of multipath signal energies. It was shown in the work that the approximation is accurate for the resolution of multipath energies within a range of realistic coefficient variation. System performance was also evaluated in terms of the capacity which was defined as the number of users that can be supported at a given bit error probability. In Jalloul and Holtzman (1994) it was suggested that when Walsh Hadamard code is used as the spreading code, the BER performance of the system under multipath environment is not acceptable. This is caused mainly by rampant multiuser interference induced by the poor correlation functions of the Walsh Hadamard code in multipath channel (the same applies to both down link and up link channels). To solve this problem, there are two schemes proposed in the literature. The first approach was suggested by Naguib and Paulraj (1996) who proposed to use an antenna array in the base station receiver for a direct-sequence code-division multiple-access (DS/CDMA) system working with $M$-ary orthogonal modulation. The base station uses an antenna.
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