Coded Multicarrier Code Division Multiple Access

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Abstract — **This paper presents a multicarrier signaling technique for an asynchronous Direct Sequence (DS) Code Division Multiple Access (CDMA) system which employs linear convolutional codes to achieve frequency diversity performance gains in excess of path diversity gains realized in conventional single carrier RAKE DS CDMA systems.**

I. Overview

DS CDMA is a popular signaling technique in which binary data sequences for multiple access users are modulated by unique spreading signature sequences having bandwidth much greater than that of the data. Waveforms are transmitted simultaneously over the same frequency band and are distinguished at the receiver via a correlation operation against the spreading code of the user-of-interest. We consider a slowly varying, Rayleigh fading multipath channel, where the spread bandwidth exceeds the coherence bandwidth of the channel, and, thus, the signals are said to fade in a frequency selective manner. In such systems, a RAKE receiver is often employed to combine the energy received over several resolvable propagation paths.

We present an alternative system where the available frequency bandwidth is decomposed into M distinct sub-bands, each of an bandwidth equal to the coherence bandwidth of the channel. The sub-channels, therefore, tend to fade non-selectively, and are assumed to fade independently. In short, we exchange path diversity for frequency diversity, wherein forward error correction may be utilized without the penalty of bandwidth expansion.

II. Summary

The data sequence for a given user is input to a rate 1/M convolutional encoder (where M is the number of carriers) and each of the M outputs are multiplied by a spreading sequence which, in turn, modulates the M carrier tones. The receiver utilizes coherent BPSK detection and weights the outputs of each correlator in an optimum fashion. These outputs are then used to calculate branch metrics in a soft decision Viterbi decoder. Whereas the conventional DS CDMA system experiences path diversity on the order of the number of resolvable paths, the coded multicarrier DS CDMA system experiences frequency diversity on the order of the number of carriers plus an effective diversity improvement on the order of the minimum free distance of the convolutional code [1]. The diversity gains realized make for significant improvements in user capacity, while preserving the desirable properties exhibited in DS CDMA systems: robustness to fading, tolerance to multiple access interference, and a narrowband interference suppression effect [2].

The performance of the coded multicarrier system is compared to that of a conventional single carrier system in the presence of additive white Gaussian noise, multiple access interference, and Gaussian partial-band interference. It can be shown that the outputs of the M sub-channel correlators are approximately conditionally Gaussian, conditioned on the respective channel fade amplitudes [3]. We derive the optimal correlator weights and branch metrics for the soft decision decoder using standard methods [1].

To obtain an upper bound on the average probability of bit error, we assume that the all-zero path is sent and consider the event that some competing path is selected. This is accomplished by developing a convolutional code generating function evaluated in terms of an exponential upper bound on the probability of a pairwise error event [1]. Since the variances of sub-channel correlator outputs may be different, due to partial-band interference, we consider the pairwise error event of a competing path containing precisely d_i code bit errors in the i^{th} bit location (i.e., i^{th} sub-channel). It can be shown that the Chernoff bound on this probability is

$$P_2(d_1,..,d_M) \le \prod_{i=1}^{M} \left(\frac{1}{1+\bar{\gamma}_i} \right)^{d_i},$$

where $\bar{\gamma}_i$ is the average signal-to-noise ratio of the i^{th} channel. It is then straightforward to develop a generating function for a particular convolutional code which enumerates not just the number of code bit errors over a path, but the location (i.e., sub-channel) of those bit errors, whereupon the probability of bit error may be union bounded as

$$P_b \le \left. \frac{dT(D_1,..,D_M,N)}{dN} \right|_{N=1,\ D_i=\frac{1}{1+\bar{\gamma}_i},\ i=1,..,M}.$$

To analyze and compare these systems, we selected raised-cosine chip wave-shaping filters with 50% excess bandwidth. Single carrier RAKE system performance is taken as equivalent to that of 4^{th} order path diversity reception using maximal-ratio combining [1]. The multicarrier system employs 4 carriers, and thus, rate 1/4 codes of varying constraint lengths [4]. We hold total system bandwidth, information rate, and energy-per-bit constant. The figure below depicts the upper bound on the BER for multicarrier systems as a function of the number of muliple access users for E_b/η_o fixed at 12 (dB). At a BER of 10^{-3}, significant capacity gains are realized as an increasing function of the code constraint length.

References

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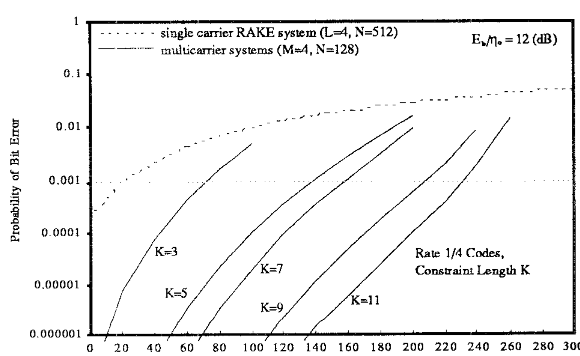

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