Spectral Efficiency of Multiuser Systems Based on CDMA with Linear MMSE Interference Suppression

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Abstract — Spectral efficiency of CDMA systems based on scalar linear MMSE interference suppression equalization (SLISE) [1] is calculated. The results enable a general approach to a comparison with CDMA systems using conventional demodulation.

I. INTRODUCTION

Recently, many receiver algorithms for code-division multiple-access (CDMA) systems have been introduced, e.g. [1, 2]. Their superiority to conventional demodulation (e.g. [3]) is usually demonstrated based on bit error rate (BER) for exemplary scenarios. A more general indicator of performance is spectral efficiency, which is determined in this paper for CDMA systems based on SLISE. This scheme is attractive especially for cellular environments, as inter-cell interference may be suppressed without additional receiver complexity.

II. COMMUNICATION MODEL AND BASICS

Asynchronous CDMA communication over nondispersive, time-invariant additive white Gaussian noise (AWGN) channels is considered. The delays and the carrier phases of the signals of all K users are assumed as independent and uniformly distributed random variables. The received signals have the same average power (perfect power control). The used spreading sequences consist of \( N \) chips which are independent random variables. For \( N \geq 1 \), the effect of their distribution is negligible. The transmitter uses convolutionally or trellis coded \( M \)-ary QAM or PSK. The transmission rate of each user is denoted by \( R \) [bit/symbol]. Pulse shaping is performed by using square-root cosine chip waveforms with zero roll-off.

The receiver comprises a chip matched filter followed by a discrete-time equalizer filter operating with chip frequency. The downsampling of the equalizer output signal leads to decision variables which are used for Viterbi decoding.

The equalizer filter is adjusted according to the MMSE criterion. For a given channel scenario, the maximum signal-to-interference (MSIR) ratio can be calculated following [1]. Since we are interested in the average system performance, the average MSIR is computed as the harmonic mean of the MSIRs of 4096 random channel scenarios. For convenience, this is done for a chip-synchronous model, which does not exhibit worst performance than a chip-asynchronous system if the filter has a sufficient number of taps.

III. SPECTRAL EFFICIENCY

Single-cell system: For zero roll-off, spectral efficiency of noncellular multiuser systems is defined as \( \gamma = RK/N \) [bit/(sec-Hz)] [3]. The max. BER given by system requirements is assumed as \( 10^{-3} \). It determines the MSIR that is necessary for the considered transmission schemes. MSIR is a function of \( K/N \) and \( SNR = R_0/N_0 \). Therefore, each value of \( K/N \) which has been used in the calculation of average MSIR leads to one point in the power-bandwidth–plane \( \gamma \) vs. \( E_b/N_0 \). Additionally, spectral efficiency for each user transmitting with rate equal to channel capacity and Gaussian distributed amplitude coefficients (label "Gaussian") was determined applying a more complicated algorithm.

In Fig. 1, numerical examples are depicted for \( N = 64 \). Well-known results for conventional CDMA [3] and single-user communication are also shown. Conventional CDMA systems are interference-limited so that spectral efficiency is bounded. 2PSK and 4PSK with low-rate coding are optimum. In contrast, spectral efficiency of systems with SLISE can be increased arbitrarily to cost of power efficiency. 4PSK leads to higher spectral efficiency than 2PSK for all \( E_b/N_0 \).

The results for systems where each user transmits with rate equal to channel capacity lead to similar conclusions. Surprisingly, conventional demodulation and SLISE have the same performance for \( 10 \log_{10}(E_b/N_0) \leq 2 \) dB. With increasing spectral efficiency, power efficiency decreases severely compared to the single-user case. The reason is the suboptimality of linear equalization. For high \( E_b/N_0 \), the loss compared to the single-user bound is given by \( e^{\log_2(2)} \).

CELLULAR SYSTEM: Spectral efficiency [bit/(sec-Hz/cell)] was computed for the uplink of systems with cells of hexagonal shape. Only static power loss with an attenuation proportional to distance to the power of 4 is taken into account.

The increased interference leads to reduction of spectral efficiency, which is more severe for SLISE than for conventional demodulation. Nevertheless, spectral efficiency of systems with SLISE can be up to three times higher than for conventional schemes. For systems with SLISE, there appear two main differences compared to single-cell environments. First, spectral efficiency seems to saturate for high \( E_b/N_0 \). Second, it cannot be increased significantly by using rates higher than 3. The reason is that some of the interference caused by so many users has the same effect as white noise.

REFERENCES