Time-Selective Signaling and Reception for Multipath Fading Channels

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Abstract — **Diversity techniques provide a powerful approach to combat fading. Due to the presence of multipath and Doppler shifts, the mobile wireless channel inherently provides diversity that can be exploited using appropriate signaling and reception. While existing CDMA systems exploit only multipath diversity using spread-spectrum signaling, we develop signaling and reception schemes that exploit joint multpath-Doppler diversity. Significant performance gain can be obtained even for the small Doppler spreads encountered in practice. Additionally, the time-selective signaling scheme allows for substantially higher level of diversity and thereby brings the fading channel closer to an additive white Gaussian noise channel. This facilitates the use of error control codes developed for the Gaussian channel.**

I. TIME-SELECTIVE SIGNALING AND RECEPTION

The signaling and reception schemes are developed based on a time-frequency representation of the channel derived in [2]. This representation decomposes the channel into a series of almost independent fading channels corresponding to the different multipath-Doppler-shifted signal components. The signaling waveforms are spread both in time and in frequency to achieve resolvable Doppler and multipath diversity at the receiver. A similar signaling scheme is developed in [3]. However, diversity is not explicitly used in this case. Although the symbol duration is increased, the data rate is maintained by allowing the symbols to overlap in time. This introduces inter-symbol interference (ISI) which is dealt with at the receiver. Since we focus on the effects of the channel, we restrict ourselves to the single-user case. The received signal, $r(t)$, can be represented as

$$r(t) \approx \sum_{i} \sum_{n,k} b^i h^i_{n,k} u^i_{n,k}(t) + n(t)$$

where b^i is the i^{th} transmitted bit (± 1), $u^i_{n,k}(t)$ is the time and frequency shifted version of the spreading code $q(t)$ (time-shifted by nT_c where T_c is the chip duration, and frequency-shifted by k/T_e where T_e is the symbol duration), $h^i_{n,k}$ is the corresponding fading coefficient and $n(t)$ is the additive white Gaussian noise. The number of multipath and Doppler components at the receiver are $\lceil T_m/T_c \rceil + 1$ and $\lceil B_d T_e \rceil + 1$ respectively, where T_m and B_d are the multipath and Doppler spread of the channel. The receiver performs joint multipath-Doppler diversity combining and ISI cancellation assuming perfect knowledge of the channel coefficients. The optimal maximum likelihood sequence detector is developed. Due to its computational complexity, sub-optimal linear detectors are developed. The two linear detectors studied are the decorrelating detector (zero-forcing equalizer) and a one-shot detector that ignores ISI. Analytical and simulation results indicate that the effect of ISI is negligible for realistic situations compared to the diversity gain achieved. Therefore, a simple one-shot detector that performs diversity combining and ignores ISI can be used.

II. PERFORMANCE

The time-selective signaling and reception scheme that exploits multipath and Doppler diversity jointly is compared with a spread-spectrum system that exploits only multipath diversity. Significant performance gains are obtained for both single path and multipath fading channels under realistic mobility assumptions. The Jakes fading model is used to simulate the channel with a mobile speed of 50 miles per hour and a carrier frequency of 1.8 GHz. A performance gain of about 6 dB is obtained at an error rate of 10^{-3} and a data rate of 10 kbps in the single path case by increasing the symbol duration by a factor of about 16 to 1.6 ms. Also, the degradation in performance due to inter-symbol interference (ISI) is negligible due to the excellent correlation properties of the spreading codes (m-sequences) used.

The asymptotic performance of the signaling and reception scheme as the signal duration increases is also studied. The constraints on the channel coefficients to ensure asymptotic convergence of the fading channel to an AWGN channel are derived. For details, see [1].

III. IMPACT OF DIVERSITY ON CODING

Due to the asymptotic convergence of the fading channel to an AWGN channel, we expect to use existing codes designed for the AWGN channel effectively in the presence of diversity. The impact of the additional Doppler diversity exploited by time-selective signaling and reception on coding is studied for a simple convolutional code (Rate = 1/2, Constraint length = 3) using simulations. The coding gain achieved for the system with joint multipath-Doppler diversity is larger than the coding gain for the system with multipath diversity alone and is almost the same as that achieved for an AWGN channel.

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