Efficient Multiuser Communication in the Presence of Fading

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Abstract — **New linear symbol-spreading strategies for efficient single- and multi-user communication in environments subject to fading due to time-varying multipath are introduced. For given power, bandwidth, and delay constraints, these new systems significantly reduce the computation required to achieve a prescribed level of performance. Several aspects of these systems and their performance will be developed.**

I. SPREAD-RESPONSE PRECODING

For single-user or frequency-division multiplexed wireless systems, we first develop a technique we refer to as "spread-response precoding," which replaces the interleaving typically used in conjunction with coding in such systems. In traditional bandwidth-limited systems for communication over fading channels, coding is used to combat the effects of both additive receiver noise and fading. Furthermore, achieving high performance generally requires the use of codes with a large number of states. However, the computational requirements inherent in the use of such large codes typically preclude their use in practice. With the new systems described in this paper, much of the burden of combatting fading is shifted to the spread-response precoder, allowing shorter codes to be used for a given level of performance. Since this precoding (and postcoding) is implemented using linear filtering, the net result is a significant reduction in computational complexity in the system.

The precoder is implemented using either linear time-invariant or periodically time-varying filters. The key characteristics of the precoding filters is that they are orthonormal or near-orthonormal transformations of the input symbols, and that their impulse response energy is widely spread in time. This spreading allows each coded symbol to see, in an appropriate sense, the average characteristics of the channel. In fact, from the perspective of the coded symbol stream, spread-response precoding asymptotically transforms an arbitrary Rayleigh fading channel into a nonfading, simple white marginally Gaussian noise channel in which intersymbol interference is transformed into a comparatively more benign form of additive white noise that is uncorrelated with the input.

II. SPREAD-SIGNATURE CDMA

In the multiuser case, spread-response precoding generalizes to a new class of orthogonal code-division multiple-access (CDMA) systems for efficient communication in environments subject to multipath fading phenomena. The key characteristic of these new systems, which we refer to as "spread-signature CDMA" systems, is that the associated signature sequences are significantly longer than the interval between symbols. Using this approach, precoding is embedded into the signature sequences in the system, so that the transmission of each symbol of each user is, in effect, spread over a wide temporal and spectral extent, which is efficiently exploited to combat the effects of fading.

Analogous to the single-user case, spread-signature CDMA systems asymptotically transform the multiuser Rayleigh fading channel into a collection of decoupled quasi-Gaussian channels. Optimizing the signal-to-noise ratio in the resulting quasi-Gaussian channel with respect to the choice of a linear equalizer leads to mininimum mean-square error type equalizers.

An optimum class of spread-signature sets for this application is developed out of multirate system theory, and efficient implementations are described. Estimates of the capacity and uncoded bit-error rate characteristics are computed with these optimized systems and compared with those of more traditional CDMA systems. The performance advantages appear substantial for practical systems. Furthermore, the use of these new systems requires no additional power or bandwidth, and is attractive in terms of computational complexity, robustness, and delay considerations. Some remaining challenges inherent in their use—including managing peak-to-average power requirements and developing suitable timing recovery strategies—are also described.

A detailed development of these results is presented in [1] [2].

REFERENCES

[1] G. W. Wornell, "Spread-Response Precoding for Communication over Fading Channels," submitted to *IEEE Trans. Inform. Theory*, Apr. 1994.

[2] G. W. Wornell, "Spread-Signature CDMA: Efficient Multiuser Communication in the Presence of Fading," to appear in *IEEE Trans. Inform. Theory*.