

Fading Multi-access Channels in the Wideband Regime: the Impact of Delay Constraints

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I. EXTENDED ABSTRACT

Incorporating delay constraints in Shannon theoretic settings is a perennial challenge. In fading channels, it is essential to specify: 1) the duration of a codeword with respect to the fading process coherence time, and 2) the time interval on which the average input power constraint is enforced. Although vanishing error probability is unattainable unless the number of degrees of freedom grows without bound, that number grows with the product of time duration and bandwidth. Thus, in the wideband regime, an asymptotic analysis is feasible even in a setting of fixed duration codebooks.

In this paper we consider a block-fading model [1] where a codeword spans a *frame* of N of slots, with fading constant over each slot and varying independently from slot to slot, and the power constraint is enforced on a per-codeword basis. Moreover, we assume that the sequence of fading coefficients affecting the transmission of a codeword is *causally* revealed to the transmitters [2] and we allow *variable-rate coding* so that users can coordinate their rates in order to be always inside the fading-dependent capacity region. Consequently, we define the *long-term average* capacity region as the set of all achievable rates averaged over an arbitrarily long sequence of codewords.

As shown recently in [4], the minimum energy per bit, on which traditionally information theoretic analysis of the wideband regime has focused, fails to capture the fundamental power-bandwidth tradeoff. To study this tradeoff, we analyze not only the minimum energy per bit, but also the “wideband slope” of spectral efficiency vs. E_b/N_0 (expressed in b/s/Hz/3 dB) at the point of minimum energy per bit.

We show that a “one-shot” power allocation policy that concentrates the whole transmit energy over one out of N slots, achieves the long-term average capacity region per unit-energy (i.e., optimal minimum energy per bit for all users) [3]. The solution is obtained through Dynamic Programming, and selects the slot $n^* = \min\{n \in \{1, \dots, N\} : \alpha_n > s_n\}$, where $\{\alpha_n : n = 1, \dots, N\}$ denotes the sequence of fading coefficients of a generic user and $\{s_n : n = 1, \dots, N\}$ is a sequence of decreasing thresholds [2] that depends only on N and on the fading statistics, but it is independent of the number of users K in the system.

The capacity region per unit-energy can be achieved either under a TDMA strategy, where each slot is divided into K subslots and each user applies the optimal policy on its subslot sequence, and under a superposition coding strategy, where different users may transmit over the same entire slot. Interestingly, we show that TDMA is strictly suboptimal in terms of wideband slope for any non-degenerate fading distribution. On the contrary, superposition coding with successive interference cancellation at the receiver, in conjunction with the one-shot power policy, achieves both the capacity region

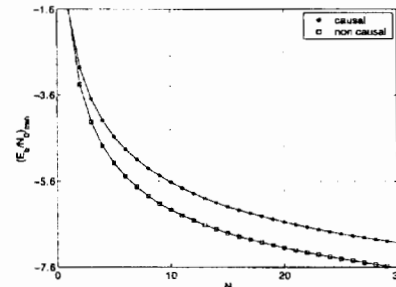


Figure 1: Minimum E_b/N_0 vs. N for Rayleigh fading.

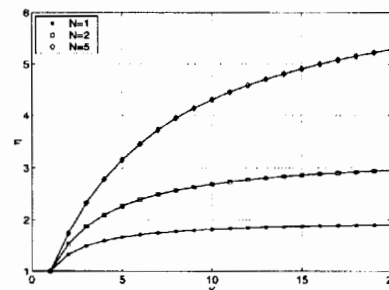


Figure 2: Bandwidth expansion of TDMA over superposition vs. K for different delays N in Rayleigh fading.

per unit energy and the optimal wideband slope.

Fig. 1 compares the minimum E_b/N_0 with Rayleigh fading achievable under causal state information with the minimum E_b/N_0 achievable under non-causal channel state information at the transmitters.

Fig. 2 shows the bandwidth expansion factor incurred by TDMA with respect to superposition coding for a symmetric system (the most favorable case for TDMA) with K users, for frames of length $N = 1, 2, 5$ and Rayleigh fading.

REFERENCES

- [1] L. Ozarow, S. Shamai and A. D. Wyner, “Information theoretic considerations for cellular mobile radio,” *IEEE Trans. on Vehic. Tech.*, vol. 43, no. 2, pp. 359-378, May 1994.
- [2] R. Negi and J. Cioffi, “Transmission over fading channels with channel state information and delay constraint” *GLOBECOM’99*, pp. 2550-2554, 1999.
- [3] S. Verdú, “On Channel Capacity per Unit Cost”, *IEEE Trans. on Inform. Theory*, Vol. 36(5), pp. 1019-1030, Sep. 1990.
- [4] S. Verdú, “Spectral Efficiency in the Wideband regime”, *IEEE Trans. on Inform. Theory*, June 2002.