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Realistic Information-Theoretical Limits for Wireless Networks

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SP Coding and Information School
(January 19th to 30th 2015 - Campinas SP-Brazil)



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How Interference-Limited are Wireless Networks?

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Motivation

Fundamental Limits of Cooperation

Angel Lozano, Robert W. Heath, Jr., *Fellow, IEEE*, and Jeffrey G. Andrews, *Fellow, IEEE*

Abstract—Cooperation is viewed as a key ingredient for interference management in wireless networks. This paper shows that cooperation has fundamental limitations. First, it is established that in systems that rely on pilot-assisted channel estimation, the spectral efficiency is upper-bounded by a quantity that does not depend on the transmit powers; in this framework, cooperation is possible only within clusters of limited size, which are subject to out-of-cluster interference whose power scales with that of the in-cluster signals. Second, an upper bound is also shown to exist if the cooperation extends to an entire (large) system operating as a single cluster; here, pilot-assisted transmission is necessarily transcended. Altogether, it is concluded that cooperation cannot in general change an interference-limited network to a noise-limited one. Consequently, the existing literature that routinely assumes that the high-power spectral efficiency scales with the log-scale transmit power provides only a partial characterization. The complete characterization proposed in this paper subdivides the high-power regime into a *degree-of-freedom regime*, where the spectral efficiency scales with the log-scale transmit power, holds only within clusters of limited size, and a *noise-limited regime*, where the spectral efficiency scales with the log-scale transmit power, holds only for the entire system.

It has been persuasively argued in a by-now vast literature that this limitation is not fundamental, but rather an artifact of each transmitter–receiver pair communicating autonomously rather than cooperatively (cf. [3]–[13] and references therein). If the various nodes could cooperate, the logic goes as follows: the corresponding interference channel (IC) could be converted to a broadcast channel (BC)—for the downlink—or a multiple access channel—for the uplink—with all the transmitters (respectively, receivers) jointly encoding (respectively, decoding). In the cellular context, it would seem from this line of thinking that an arbitrary number of base stations (BSs) could cooperate to achieve enormous spectral efficiency gains over the basic IC model, with the only limitation being the total transmit power that can be used.

Bounded Capacity?

Criticism on Lozano et al. 2013:

- Reduction of a network problem to a MIMO case.
- The assumed input distribution ($\sqrt{P}X_k$) is highly suboptimal

Theorem: For any random variable X with $E[|X|^2] = 1$ and $E[|\log |X||] > -\infty$, then:

$$\sup_{\text{SNR} > 0} I(\sqrt{\text{SNR}}X; \sqrt{\text{SNR}}HX + Z) < \infty$$

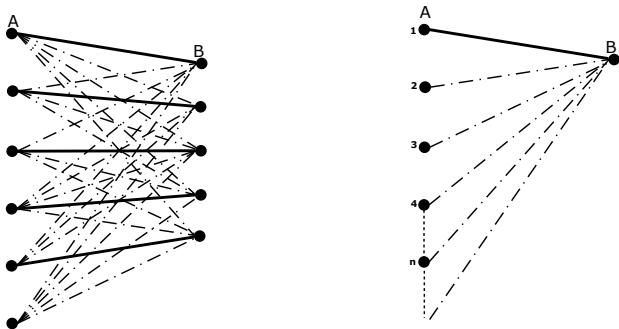
- By using input distributions that depends on P ; one obtains

$$\sup_{P_x} I(\sqrt{\text{SNR}}X; \sqrt{\text{SNR}}HX + Z) = \log \log \text{SNR} - 1 - \gamma + o(1)$$

A. Lozano, R.W. Heath Jr., J.G. Andrews, "Fundamental Limits of Cooperation," *2013 IEEE Transactions on Information Theory*, September 2013.

A. Lapidoth, S.M. Moser, "Capacity Bounds Via Duality With Applications to Multiple-Antenna Systems on Flat-Fading Channels," *IEEE Transactions on Information Theory*, October 2003.

Our Channel Model



$$Y_k = H_k X_k + \sum_{\ell=1}^{\infty} \tilde{H}_{\ell,k} \tilde{X}_{\ell,k} + Z_k$$

Our Channel Model

- Symmetric problem: each user transmits at the same rate
- $\{X_k\}, \{\tilde{X}_{1,k}\}, \{\tilde{X}_{2,k}\}, \dots$ IID with distribution Q^n satisfying:

$$\frac{1}{n} \sum_{k=1}^n \mathbb{E}[|X_k|^2] \leq P$$

\Rightarrow **My Ph.D thesis: channel capacity under this assumption**