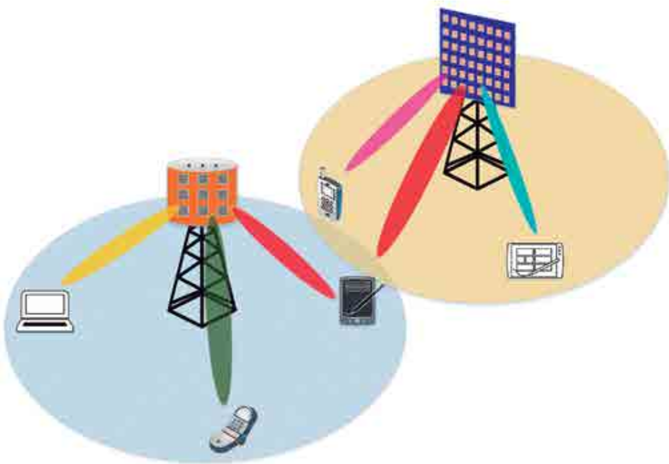
Large-Dimensional MIMO Physical Layer Network Coding

In order to serve an increasing number of users with higher data rates, the radio interface of wireless networks is undergoing a revolution in terms of the role that interference plays in the signals' processing. The project put together four emerging technologies that take advantage of interference to achieve larger throughputs with a much more efficient use of the spectrum.



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Indicators	
Funding	32k €
Journal Papers	3
Conference Papers	5
Concluded MSc	6

Two Main Publications

F. Rosário, F. A. Monteiro, A. J. Rodrigues, Fast Matrix Inversion Updates for Massive MIMO Detection and Precoding, "IEEE Signal Processing Letters", Vol. 23, No. 1, pp. 75 - 79, January, 2016

J. S. Lemos, F. A. Monteiro, I. Sousa, F. E. Ennes Ferreira, Efficient Message Exchange Protocols Exploiting State-of-the-art PHY Layer, "EURASIP Journal on Wireless Communications and Networking", Vol. 2017, No. 92, pp. 1 - 14, May, 2017

PROJECT WEBPAGE URL
https://www.it.pt/Projects/Index/1986

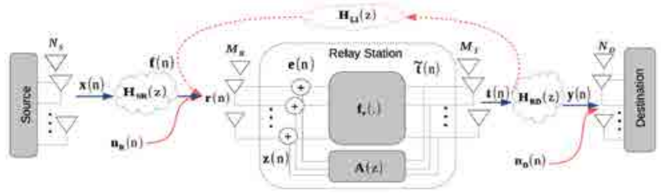

Fig. 1 Relay channel with non-linear loop-back interference (LI) cancellation.

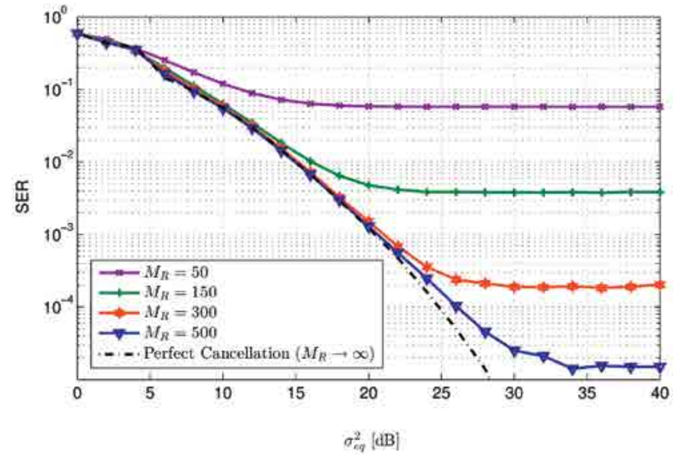

Fig. 2 End-to-end symbol error rate in the two-way relay channel applying physical layer network coding, using a massive mimo relay (for a varying number of antennas) operating in full-duplex.

GENERAL MOTIVATION AND OBJECTIVES

The most promising signal processing techniques to increase both the data rate of a wireless link and the overall capacity of wireless networks rely on the existence of interference.

Multiple-input multiple output (MIMO), i.e., multi-antenna signal processing, was the enabler for the data rates nowadays possible in the Wi-Fi standards and in 4G systems. The computational complexity required to detect signals in symmetric spatial multiplexing (SM) has limited current standards to a maximum of eight antennas (i.e., eight independent spatial data streams). A new type of SM, dubbed massive MIMO, emerged recently, and considers a highly asymmetrical link, with one end of the connection having many more antennas than the other. Massive MIMO is intended for a multi-user configuration where a base-station, possibly with hundreds of antennas, communicates independent spatial streams to (single-antenna) users. Both conventional or massive MIMO are non-orthogonal techniques that rely on the diversity that spatial interference creates. Other promising concepts not relying on any kind of orthogonality are:

- physical layer network coding (PLNC), in which the superposition of messages form new coded messages, from which the original information messages can be retrieved using mathematical tools from finite fields;
- power domain non-orthogonal multiple access (NOMA), where physical layer symbols can be added with distinctive powers and can still be recovered with appropriate successive interference cancellation. NOMA and PLNC were treated as concepts with much in common.

Since the origin of radio science, transceivers could never transmit and receive in the same frequency band at the same time due to self-interference. In-band full-duplex (IBFD) radios depart from that paradigm and almost double the spectral efficiency.

Although all these techniques contribute to both higher spectral and energy efficiencies, they place a much higher computational burden on the base-stations, relays, and/or terminals. The objectives of the project were: i) to assess the power and spectral gains of combining these novel physical layer techniques, ii) redesign the message exchanging protocols taking in consideration these techniques, and iii) tackle the complexity problems.

CHALLENGE

The main challenge in this project was to find ways of exploring the potential interplay between these techniques rather than just concatenating them.

WORK DESCRIPTION AND ACHIEVEMENTS

An outcome of the project was a fast and iterative matrix inversion method for massive MIMO processing at the base-stations. The method allows a differential update of the inverse channel matrix, making the process more computationally efficient when the number of users in the base station varies along time, and when some users have their channels changing faster than the others. The detection of symmetric MIMO antenna array was also tackled: a new randomised detection method (using a Gibbs sampler) was proposed, allowing quasi-optimal performance for up to 16×16 antennas (i.e., a large MIMO antenna array).

A number of new message exchange protocols have been proposed for networks where the terminals have to communicate through a relay. Assuming a physical layer with some of the aforementioned techniques, the protocols allow to exchange messages up to six times faster than with conventional time division multiple access.

Non-linear MIMO signal processing based on recursive least squares was proposed for IBFD, achieving state-of-the-art results. For relay-based communications, power optimisation techniques to maximise the sum data rate have been devised and, most importantly, it was found that using a massive MIMO relay naturally creates the conditions for using a very low-complexity lattice-based PLNC scheme. The project also compared two different ways of combining NOMA with both MIMO and massive MIMO.

Finally, a software network emulator was built in Java to assess packet-based linear random network coding for different user-defined network configurations.

Two MSc theses within the project were awarded (ex aequo (em itálico)) the Luís Vidigal Prize 2015 at IST, and one of the journal papers was highlighted by the IEEE Signal Processing Magazine in the section "Top Downloads in IEEE Xplore [Reader's Choice]" on the May 2017 issue, containing the most downloaded papers during the last 2 years in the respective journal.