Implementation of a Time-Reversal MISO OFDM Test-Bed

J.-C Prévotet, Y. Kokar, M. Hélard, M. Crussière

***Abstract*— This paper deals with the study and implementation of a complete OFDM Time Reversal Prototype in a multiple input, single output (MISO) context. After describing the principles and architecture in details, several pre-coding techniques are presented. Measurements results are discussed and performances are evaluated.**

***Index Terms*— MISO, Time Reversal, Test-bed, Pre-coding**

I. Introduction

Nowadays, wireless communication systems demand a constant increase of data rates and performances. In this context, a lot of multiple-input multiple-output (MIMO) schemes such as classic beamforming techniques, spatial multiplexing techniques, orthogonal space-time codes [1], etc. have been studied and have shown significant improvements in terms of diversity and throughput.

Regarding MIMO schemes, a lot of systems are based on the availability of channel state information (CSI) at the transmitter side. One of the most famous techniques is based on singular value decomposition (SVD) that makes it possible to exploit spatial diversity [2].

In the proposed study, we decided to focus on wireless systems that are composed of several small cells, or access points, dispatched in a close indoor environment. Regarding the nature of the transmission channel, we decided to investigate the MISO Time Reversal (TR) technique since it provides very interesting performances in such a context [3]. It has also been demonstrated that such a technique exhibits a level of performance that is comparable with SVD as the number of transmitting antennas grows [4], [5].Another important property of TR is that it allows building much simpler and thus cheaper receivers while adding some complexity at the transmitter side.

In this paper, we concentrate on the time compression and spatial focusing performances of TR in an indoor environment.

The rest of this paper is organized as follows: in section II, the time reversal concepts are introduced and detailed. In section III, a first MISO hardware/software platform is described. Section IV describes several configurations that have been implemented and tested on the testbed. In section V, experimental results and measurements are provided.

II. Time Reversal Strategy

TR principles are presented in details for acoustic and electromagnetic waves in [6] and [7] respectively.

This well-known strategy consists in pre-filtering the transmitted signal by applying the time reversed and conjugated image of the channel impulse response. This technique relies on the idea that the propagation channel is reciprocal between the transmitter and the receiver. TR relies on the knowledge of the channel at the transmitter side For OFDM systems, it has been shown that TR can be applied in either time and frequency domain and exhibit the same level of performance. In the frequency domain and in a MISO OFDM scheme, the received symbol can be expressed as:

$$R_{m,n} = \frac{1}{\sqrt{N_t}} \sum_{k=1}^{N_t} \left|H_{m,k}\right|^2 D_{m,n} + N_{m,n}$$

where N_t is the number of transmit antennas, $H_{m,k}$ is the complex channel coefficient on the *m*-th subcarrier of the ODFM symbol for the *k*-th transmit antenna. $D_{m,n}$ is the data symbol and $N_{m,n}$ is the noise term associated to the *m*-th subcarrier of the *n*-th OFDM symbol.

III. Proposed Platform Description

The prototype consists of one transmitter (Tx) and one receiver (Rx) implemented on separate WARP FPGA-based motherboards [8].

Fig. 1 depicts the overall architecture of the prototype including the interfaces and cables between the boards. The transmitter is composed of 3 RF modules connected to 3 transmitting antennas. On the receiver side, 1 target antenna is connected to RF board.

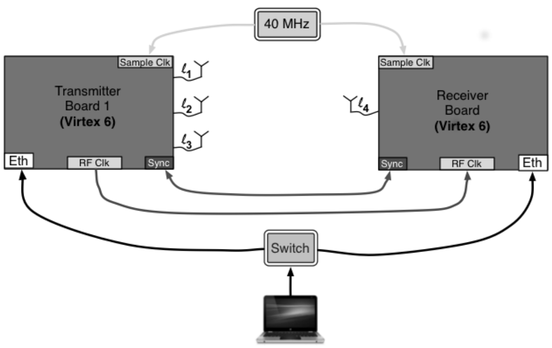

Fig. 1. System Description

IV. Studied configurations

Since the proposed software-defined platform is very flexible, it makes it possible to test several configurations in order to evaluate and compare multiple approaches. In this work, three techniques have been implemented.

A. Classic OFDM

The first configuration is a simple OFDM chain without data pre-coding at the transmitter side.

B. Time Division Duplex Time Reversal (TDD TR)

This configuration stands for the simple time reversal strategy in which data are pre-coded with the following factor:

$$V_{m,k} = \frac{H^*_{m,k}}{\sqrt{Nt}}$$

where $H^*_{m,k}$ is the conjugate of the channel coefficient on the *m*-th subcarrier for the *k*-th transmit antenna and *Nt* is the number of transmitting antennas.

C. Equal Gain Transmission (EGT)

EGT aims at maximizing the SNR at the receiver side. In the MISO-OFDM context, the pre-coding vector is:

$$\boldsymbol{V_{m,k}} = \frac{\boldsymbol{e^{-j\varphi H_{m,k}}}}{\boldsymbol{\sqrt{Nt}}}$$

where $V_{m,k}$ represents the pre-coding function associated to subcarrier *m*, and $H_{m,k}$ the channel coefficient on the *m*-th subcarrier for the *k*-th transmit antenna, φ is the argument of the channel coefficient and *Nt* is the number of transmitting antennas.

V. Measurements and Comparisons

A. Classic OFDM configuration

In this simple OFDM MISO 3x1 configuration (see Fig. **2**), it may be noted a phase difference among all subcarriers that makes it difficult to retrieve initial data without effective equalization.

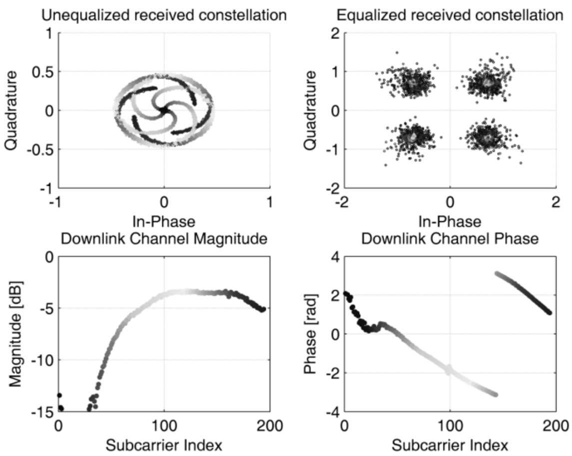

Fig. 2. MISO OFDM 3x1

B. TDD Time Reversal

In this configuration, Time Reversal is implemented. It may be seen that the results obtained in this configuration are better than the OFDM case. It can be observed that the resulting phase is close to zero which will make it possible to retrieve the initial signal without an equalization step (cf. Fig. **3**). We can also notice a magnitude degradation since the received signal varies according to the power of 2 of the channel coefficients' module.

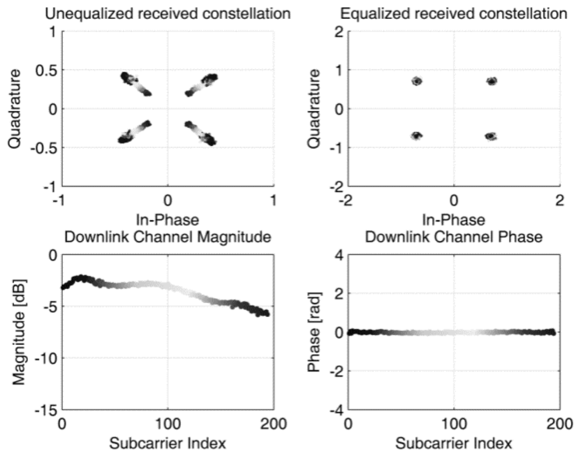

Fig. 3. TDD TR

C. TDD EGT

In the EGT configuration, only the phase is modified which has no incidence on the magnitude of the signal. In this configuration, the phase is also close to zero which makes it possible to get rid of the equalization step (cf. Fig. **4**).
Regarding the signal magnitude, we can see that the weakening is less noticeable in compliance with theory (magnitude variation in H instead of H^2)

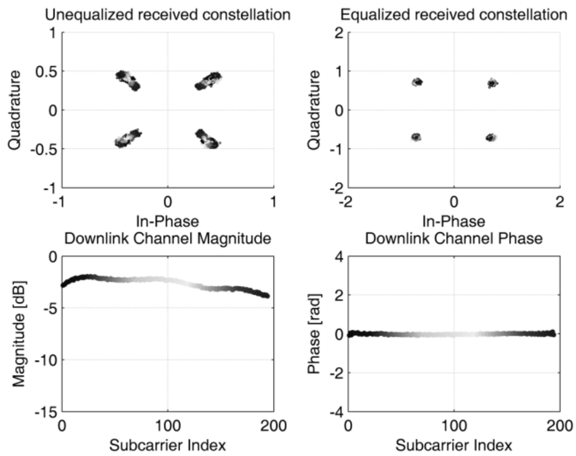

Fig. 4. TDD EGT

D. Discussion

The measures that have been performed on the developed prototype confirm the results that have been previously described in theory in [3].
The expression of the received signal for EGT differs from the received signal in the TR case by the power of the modulus of the channel coefficients. This may be observed on the downlink channel magnitude in Fig. **3** and Fig. **4** respectively. In both cases, the resulting phase is close to zero.
Both strategies exhibit the same level of complexity in a hardware point of view.

VI. Conclusion

In this paper, we have presented a flexible hardware test bed capable of implementing Time Reversal OFDM MISO algorithms. The presented MISO prototype permits the study of different pre-coding techniques on a real channel and the comparison of these techniques with other

approaches. In this paper, three pre-coding algorithms have been evaluated and compared.
This prototype constitutes a first step towards a more sophisticated MIMO real–time demonstrator.

ACKNOWLEDGEMENT

This work has been supported by Agence Nationale de la Recherche (ANR) VERSO 2010 project TRIMARAN.

REFERENCES

[1] G. Foschini, «Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas,» *Bell LabsTech journal,* vol. 1, n° %12, pp. 41-59, 1996.

[2] S. Zhou et G. Giannakis, «Optimal transmitter eigen-beamforming and space-time block coding based on channel mean feedback,» *IEEE Transactions on Signal Processing,* vol. 50, n° %110, pp. 2599-2613, 2002.

[3] T. D. e. al., «Performance of time reversal precoding technique for MISO-OFDM systems,» *Eurasip Journal on Wireless Communications and Networking,* vol. 260, 2013.

[4] T. Dubois, M. Hélard, M. Crussière et I. Maaz, «time reversal applied to large MiSO-OFDM systems,» chez *Personal Indoor and Mobile Radio Communications (PIMRC)*, London, 2013.

[5] F. R. e. al., «Scaling up MIMO,» *IEEE Signal Processing Magazine,* january 2013.

[6] M. Fink, «Time reversal of ultrasonic fields - part i basic principles,» *IEEE Trans. Ultrason., Ferroelectr. Freq. Control,* vol. 5, n° %139, pp. 555-566, 1992.

[7] G. Lerosey, J. D. Rosny, A. Tourin, A. Derode, G. Montaldo et M. Fink, «Time reversal of electromagnetic waves,» *Phys. Rev. Lett.,* vol. 92, n° %119, 2004.

[8] m. communications. [En ligne]. Available: http://http://www.mangocomm.com/.