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# MEASURED PERFORMANCES OF A SIMO MULTI-STANDARD RECEIVER

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## Abstract

SIMO algorithms ensure important increasing of radio communications robustness, but their performances strongly depend on channel propagations conditions and antenna characteristics. This article presents performances of different SIMO treatments applied on WLAN (802.11b and 802.11g) transmissions in a multi-standard and multi-channel context. These performances are obtained by measure, under different propagation channels and for realistic working conditions.

## 1 Introduction

Combining different standards communication in the same receiver structure, based on concept of Software Defined Radio (SDR) is a very promising issue for future wireless systems [1, 2]. Moreover using SIMO (Single Input Multiple Output) processing improves wireless systems performances. Furthermore, a multi channel receiver seems to be an interesting evolution with the arrival of communication standard defined on overlapping channels, such as 802.11 systems. Thus a software demonstrator simulating the running of a multi-channel multi-standard and multi-antenna receiver was developed using Advanced Design Systems (ADS) from Agilent Technologies [3]. At this time we focused our study on a 4 arms receiver capable to deal with 802.11g and 802.11b cohabiting signals in a 36 MHz bandwidth. However in order to have a better estimation of SIMO processing performances, an evaluation on those algorithms in real working conditions is necessary. Indeed, antenna coupling, channel correlation and channel propagation properties have an important influence on those performances. Based on capacities of our 2x2 radio platform using the Agilent connected solution equipments [4], our work presents measured performances of a SIMO multi-standard multi-channel receiver.

## 2 The Measurement procedure

### 2.1 Description of the platform

A complete test bed platform was installed, using Agilent Technologies equipments and ADS software (Fig. 1). This

platform is made of one arbitrary waveform generator (ESG 4438C) and a vector spectrum analyzer (VSA 89641) with two RF inputs. These equipments are connected to a PC running with the ADS software. With this platform, any signals of a maximum RF frequency of 6 GHz could be generated by ADS and emitted to a real propagation channel. Our platform ensures a reception bandwidth of 40 MHz, that is why it is possible to make cohabit two 20 MHz WLAN signals, emitted on two different carrier frequencies spaced by 20 MHz. The recorded signals are transferred to the software and all of the baseband processing are applied in order to combine the different received signals (SIMO processing) and to demodulate the data.

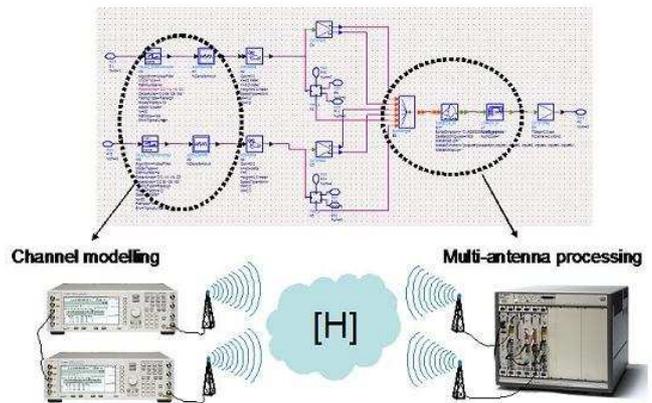


Figure 1: 2x2 MIMO transmission with the radio platform

### 2.2 Description of the measure

Our aim is to study SIMO performances under realistic working conditions. In this context, antenna coupling, channel correlation, and also different propagation conditions must be introduced in the measurement system. Depending on the current capabilities of our platform only 1x2 SIMO configuration is possible.

Correlation of received signals and antenna coupling introduce loss of information diversity, and then a reduction of SIMO performances. Envelope correlation  $\rho$  between two signals  $x$  and  $y$  is compute according to (1) [5]

$$\rho = \frac{E[(x - \bar{x}) \cdot (y - \bar{y})]}{\sqrt{E((x - \bar{x})^2) \cdot E((y - \bar{y})^2)}} \quad (1)$$

where  $E(\cdot)$  denotes the expected value and  $\bar{x} = E(x)$ .

Table 1 presents correlation value in function of the antenna spacing  $d$  (a fraction of wave length  $\lambda$ ) in the case of a NLOS (Non Line of Sight) transmission configuration. For each distance value, we also give the BER (Bit Error Rate) value obtained thanks SIMO processing applied to the two recorded signals used to compute the correlation.

$d$	0.3	0.5	0.75	1	1.25	1.5
$\rho$	0.45	0.43	0.02	0.07	0.1	0.12
BER	0.02	0.03	0.03	0.01	0.02	0.01

Table 1: Correlation value in function of antenna spacing

A very low envelope correlation ( $\rho < 0.7$ ) is observed. A quite constant BER is also obtained, proving that for all distance between the two antennas, correlation has no influence on system's performances.

For different antenna spacing, coupling between the two arms is compute and the maximum value, obtained for a distance of  $0.3 \lambda$  is equal to -20 dB. That is why, coupling effect between receiving antennas could be considered as negligible.

Finally, characterisation of the propagation channel was realized. The measured NLOS channel used has a delay spread much less important (about 76 ns,  $\tau_{rms} = 35$  ns) than the often used channel model ETSI-A for office environment (delay spread = 390 ns,  $\tau_{rms} = 50$ ns) [6].

### 3 Measured performances

#### 3.1 Validation for a SISO configuration

At first, in order to validate the structure of our radio platform, first tests were realized in a SISO configuration under AWGN and multi path propagation. Figure 2 presents results we obtained for an 11 Mbps AWGN 802.11b transmission.

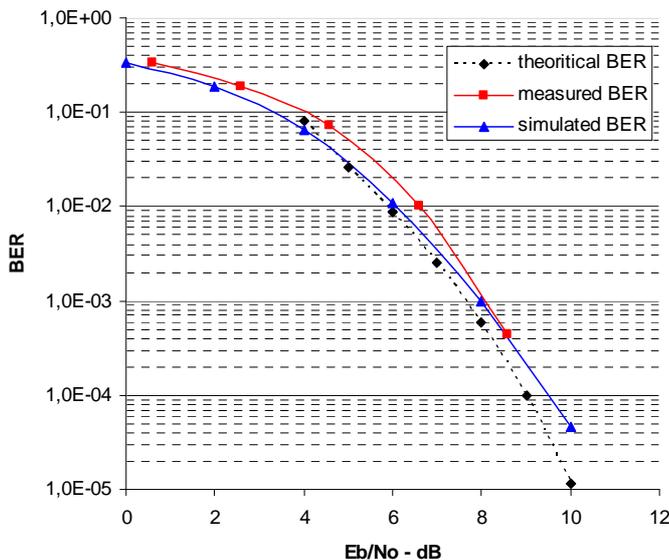


Figure 2: 11 Mbps 802.11b SISO performances

For each  $E_b/N_0$ , 10 000 frames of 100 octets are emitted and demodulated to accurately estimate the corresponding BER. The theoretical 11 Mbps 802.11b BER variation was computed according to (2) [7]

$$BER = 1 - \frac{1}{\sqrt{2\pi}} \int_{-X}^{\infty} \left( \int_{-v-X}^{v+X} \exp\left(-\frac{y^2}{2}\right) dy \right)^{\frac{N}{2}-1} \cdot \exp\left(-\frac{v^2}{2}\right) dv \quad (2)$$

Where  $X = \sqrt{\frac{2 \cdot E_b}{N_0}}$  and  $N=8$  in the case of an 11 Mbps

transmission.

Figure 3 presents BER variation for a 36 Mbps 802.11g transmission under different channel propagation conditions. A very good match between simulated and measured AWGN results can be observed (only 1 dB of deviation, but measures were no realized in anechoic chamber).

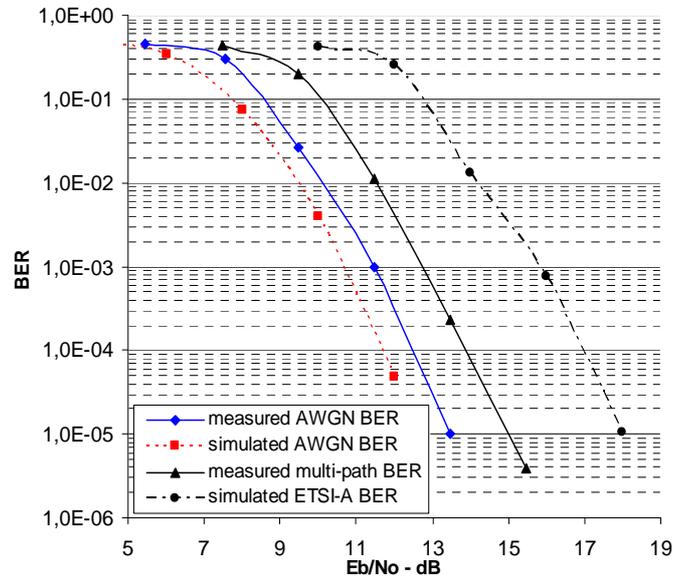


Figure 3: 36 Mbps 802.11g SISO performances

Simulated performances of the mono-antenna 802.11g receiver for propagation under the ETSI-A channel are also presented. An important deviation (about 4 dB) between these simulated results and BER variation under the measured multi-path channel is observed. That is due to the fact that only two echoes are detected during the characterization of the propagation channel used for measure, while 18 taps model for the ETSI-A channel. Of this fact, it is normal to observe better performances of the channel equalizer for propagation under the measured channel than under the simulated ETSI-A channel. It is important to note that at this time, BER variations are obtained in the case of a static channel and that no fast fading is introduced to validate our platform and measurement system. Introduction of fast fading will be described in the next section.

### 3.2 1x2 SIMO measure

SIMO performances strongly depend on channel correlation, and also antenna coupling [8]. That is why studying SIMO processing introducing channel correlation and also antenna coupling is relevant. All of SIMO algorithms used to increase 802.11b and 802.11g transmissions are described in [3]. These algorithms are based on the knowledge of the training sequence in WLAN frame permitting the estimation of the optimal complexes coefficients to apply on each base band received signal thanks the MMSE (Minimum Mean Square Error) criterion. Assuming channel propagation stays constant during one frame; coefficients are computing using different variants of well-known SMI algorithm. SMI and Rake-2D can be used to increase 802.11b transmission and SMI and SF-MMSE are available for 802.11g system. The different algorithms have not the same complexity but also not the same performances.

In order to introduce correlation fading and also antenna coupling, the both signals treated by the 1x2 SIMO receiver are recorded at the same time. After propagation under a real wireless channel, RF signals are recorded by VSA 89621 with a patch antenna; each element separated by  $0.5 \lambda$ . Figure 4 presents BER variations for an 11 Mbps 802.11b transmission under a measured AWGN channel.

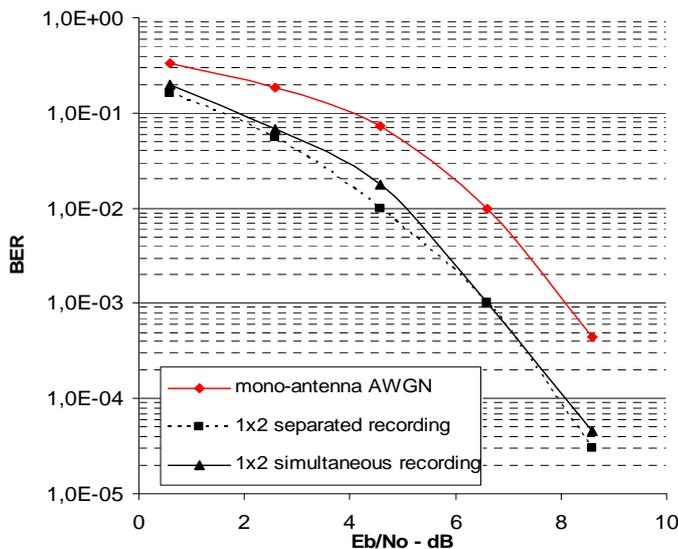


Figure 4: 802.11b BER performances

With this figure a comparison of BER curves obtained thanks SMI processing applied to separated or simultaneous recorded signals is possible. Even if performances are quite better for a receiver running with separated signals, a very low difference in the case of simultaneous recording can be observed. That tends to prove the low influence of antenna coupling on SIMO processing. Finally, about 2 dB of gain thanks SMI is obtained compared to the mono-antenna receiver, running with the best (higher SNR) of the both recorded signals.

BER variations for a 36 Mbps 802.11g communication in the case of a static multi-path propagation are represented by figure 5. SIMO algorithms are applied to simultaneous

recorded signals, and SF-MMSE [9] is used applying optimal coefficients to the different 52 OFDM sub-carriers grouped by 13.

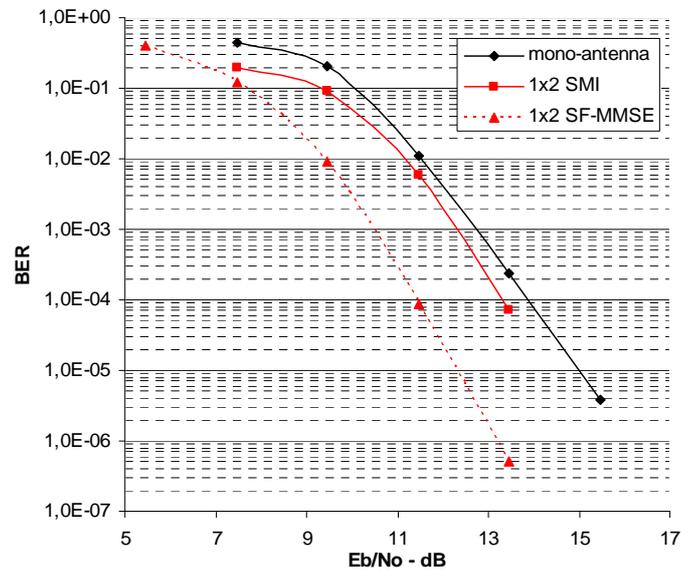


Figure 5: 802.11g BER performances

Only 1 dB of gain thanks SMI processing is obtained compared to a single antenna receiver dealing with the best signal recorded (switch antenna selection). It is due to the fact that difference of received signals power on both antennas was very important during these measures. However, using SF-MMSE algorithm to combine different incident signals ensure an increasing of system performances of 3 dB.

But propagation under static multi-path channel do not really corresponds to realistic working conditions, that is why to have a more precise estimation of our system's performances, it is necessary to introduce fast fading in the measurement procedure. In this context, speed was imposed to the antenna during measurement. In order to choose the maximum imposed speed, we must keep in mind that the propagation channel has to stay constant during the time of one frame. In the demonstrator developed with ADS and running with Ptolemy tool, speed of the terminal is fixed to 10 km/hr, i.e. 2.78 m/s, which results in a maximum Doppler shift of 22 Hz. The Doppler spread and coherence time are inversely proportional to each other, yielding a coherence time of 45 ms. Duration of a 802.11g or 802.11b frame depends on the data rate and also on data size to transmit. In our conditions of work, the longest frames are obtained for 11 Mbps 802.11b transmissions. Packet size of these frames is 100 octets, so the duration of one frame is 290 usec. So, channel could be considered constant.

Figure 6 presents BER performances of the single antenna receiver and the 1x2 SIMO receiver running with signals recorded at the same time after propagation under the multi-path channel by the moving terminal in the case of a 36 Mbps 802.11g transmission. The SIMO processing used is the SMI, and BER curves of the single antenna receiver were obtained with one of the two recorded signals. Indeed, in this case of

measure, signal power level on each arm of the SIMO receiver are quite equivalent.

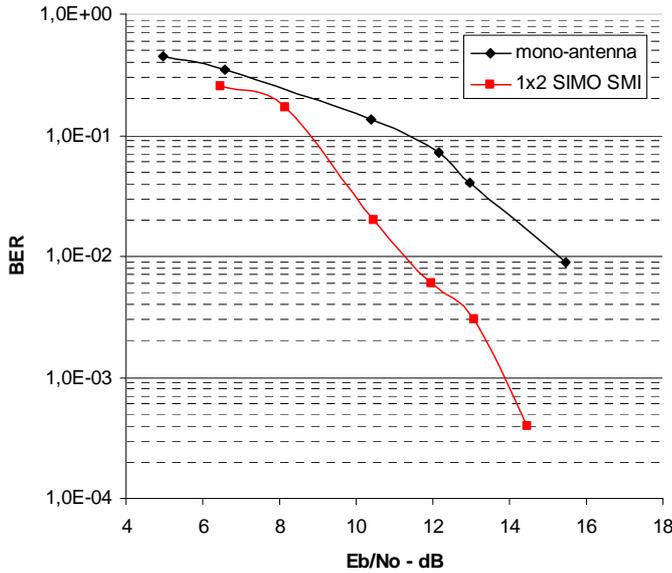


Figure 6: 802.11g BER performances

In these conditions of work, estimate  $E_b/N_0$  at the input of the receiver is quite difficult due to the fast variation of the signal power level. That is why BER curves are not so smooth as usual. About 5 dB of gain is observed thanks SMI processing for a BER value of  $10^{-2}$ . We also observe an important variation of the curve's slope. The well know result that with SIMO processing under fast fading propagation, BER decreases more quickly than in the case of a single antenna reception is verify.

### 3.3 Multi-standard configuration

Nowadays, with the growth of number of communication standard, users would like to have only one terminal to achieve multiple wireless standards. The most promising technology to achieve such receiver is SDR technology, which allows users to switch communication systems by changing software alone. At this time we focus our study on a system able to run with 802.11g and 802.11b transmission. Cohabitation between these two standards seems to be relevant to study because they share the same RF carrier and are defined on overlapping channels. In this context, designing a receiver based on SDR concept and sampling a frequency band wider than those of a single communication channel seems to be a relevant study. This allows taking advantage of the knowledge of adjacent channel interferes and to increase transmission performances. [4] describes the architecture of the multi standard (802.11b/g) multi channel (40 MHz of bandwidth reception) SDR terminal we propose. This part of the article presents performances of a multi-standard multi-channel terminal using 1x2 SIMO processing able to run with two 802.11 signals cohabiting at the same time. SIMO algorithms ensure to combat fading and multipath effect, but we will show that these algorithms also ensure mitigation of interferences. Others adjacent channel

cancellation processing exist [10]. Performances of these algorithms will be probably studied later.

An important parameter to study the comportment of the multi-channel terminal is the number of communications channels between the two signals of interest.

The first tested configuration is the cohabitation of two 36 Mbps 802.11g emitted throu an AWGN propagation channel on different carrier frequencies. Table 2 presents performances of our receiver working under this configuration. The both 802.11g signal are emitted with a sufficient power to guaranty a received power ensuring a no transmission error in a single user configuration. That is why these results allow studying performance of the SMI processing as an interferer canceller. We can observe that for spectral overlap of 100% and 75% (channel bandwidth of a 802.11g signal is 20 MHz), BER for a single antenna receiver stay very high and that SIMO processing do not mitigate effect of interferences. However in the case of two and three adjacent channels between the both signals of interest, an important performances increasing thanks SMI is observed.

channel spacing (MHz)	BER signal 1 SISO	BER signal 1 SMI	BER signal 2 SISO	BER signal 2 SMI
0	0.5	0.49	0.5	0.47
5	0.45	0.44	0.45	0.4
10	0.16	0.002	0.24	0.003
15	0.1	0	0.09	0

Table 2: 802.11g AWGN multi channel performances

Cohabitation of signals of different communication standards is also interesting. Figure 7 presents performances of a terminal dealing with:

- An 11 Mbps 802.11b signal emitted with a low power corresponding to a received signal level just above noise level at the frequency carrier of 2.372 GHz.
- A 36 Mbps 802.11g signal at 2.382 GHz, emitted with a varying signal level. So, the channel spacing is 10 MHz, and both signals are spectrally overlapped of 50%.

We can observe about 3 dB of gain using SMI processing compared to BER variation of a single antenna receiver. In multi-standard configuration, BER performances are just translated compared to the mono standard transmission.

Finally, table 3 presents BER value in the case of an 802.11b and an 802.11g signal are received at the same time by the multi-mode terminal after propagation under an AWGN channel. Both signals are received to a sufficient signal level to guaranty no transmission error in the case of a mono standard communication. With theses results we can observe that 802.11b transmission less suffers from interference than 802.11g. This could be explained by the fact that 802.11b bandwidth is quite less broad than 802.11g standard. It is also necessary to recall that modulation schemes used are different for the two studied standards (11 CCK for the 802.11b

transmission and 16 QAM for a 36 Mbps 802.11g communication). Other studies must be carry out to conclude about the robustness to interferences of WLAN signals.

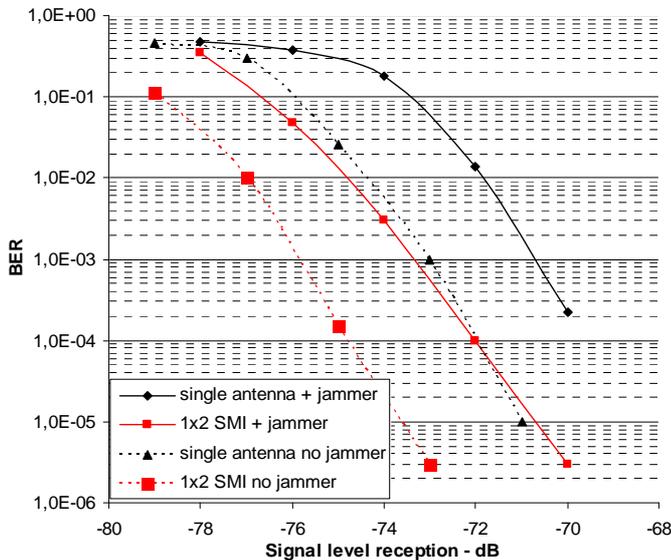


Figure 7: 802.11g suffering from 802.11b interference performances

channel spacing (MHz)	802.11b SISO	802.11b SMI	802.11g SISO	802.11g SMI
0	0.5	0.004	0.5	0.2
5	0.45	$4.9 \cdot 10^{-4}$	0.45	0.05
10	0.16	0	0.24	0.03
15	0	0	0	0

Table 3: multi-standards multi-channel performances

With table 3, we can also observe the contribution of SMI processing to mitigate interference effect and to decrease transmission error. In the case of two channel 25% overlapped, even if the terminal uses a single antenna, no transmission error is obtained.

## 4 Conclusions

SDR concept combined with multi-channel and SIMO processing in the same terminal is a very promising issue to develop future wireless receivers ensuring high data rate and robust transmissions. The aim of this work was to expose performances results of several SIMO processing applied to real communication standards in realistic working conditions. Theses results were obtained by measure, taking so into account a most realistic as possible propagation channel, antenna coupling, channel correlation and fast fading.

We have first presented results obtained in a single user transmission to detail effect of different propagation parameters and then in the second part of this article, several results obtained by measures simulating the running of a 40 MHz dealing with different 802.11 signals are given. With theses results we can study the effect of adjacent channel

interference in the case of WLAN communication for different value of the channel spacing between the two signals of interest. Results are also given to prove the utility of spatial diversity to mitigate not only fading channels but also interference channels.

Incoming works are dealing with more analysis and estimation of WLAN performances in a multi-channel configuration. Studies about implementation of more efficient multi-antenna algorithms in order to permit better interferences mitigation could also be interesting.

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