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The Relay and the Nonlinear Distortion Noise in OFDM Cooperative Systems

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***Abstract* - In this Paper, an analysis of the amplification performed in the Relay is presented. The input and output of the amplifier is analyzed from the statistical point of view to establish if there is certain predictable behavior in the NLD. In addition, based on the results of this analysis, a technique to improve the performance of the cooperative system is presented.**

Index Terms* – *Orthogonal frequency division multiplexing (OFDM), Non Linear Distortion (NLD), Additive White Gaussian Noise (AWGN), Bit Error Rate (BER), Signal to Noise Ratio (SNR), Maximum Ratio Combiner (MRC), Output Back Off (OBO), Probability Density Function (PDF), Complementary Density Function (CDF).

I. INTRODUCTION

The OFDM symbol has a Gaussian behavior. The signal is distorted by a channel and thermal noise before being amplified. The statistical behavior of such signal may give additional information on how to approach the problem of NLD in cooperative systems. In principle, if the input of the amplifier is Gaussian, then the NLD can be represented as additive Gaussian noise [1]. If this is the case, existing techniques could be applied to improve the performance of the system.

II. NLD IN FADING CHANNELS

The input of the amplifier y_{SR} can be expressed as:

$$y_{SR} = h_{SR} * x_{SR} + n_{SR} \qquad \text{Eq 1.}$$

It is known that x_{SR} and n_{SR} is complex Gaussian variables with known variance. It is also known that h_{SR} can be modelled as a Rayleigh fading channel, which in principle can be considered as a complex Gaussian variable as well, with known parameters [2, 5].

The behavior of y_{SR} depends on how fast h_{SR} changes. Therefore, an analysis of two cases is presented:

- A slow fading channel, where the conditions of h_{SR} between adjacent OFDM symbols also vary randomly but close to the conditions of the previous state.
- A very fast fading channel, where the conditions of h_{SR} between adjacent OFDM symbols change randomly and independently from its previous state.

From the simulations point of view, this means that for the first case, a set of strongly correlated channels are generated for all the symbols to be transmitted, whereas in the second case a new channel is generated every time a new symbol is transmitted. The slow fading channel has a Doppler spread $f_c \approx 10Hz$, resulting from the following parameters in the simulations:

- Delay Profile: 1, 2, 3, 4 chips
- Power Profile: 0, -1, -3, -9
- Channel Impulse Response Length: 4
- Terminal Velocity: 5 km/h
- Carrier Frequency: 2 400 MHz
- Bandwidth: 6 000 Hz

In figure 1 the PDF of y_{SR}, for a slow fading h_{SR}, is shown together with a Gaussian Distribution with the same variance.

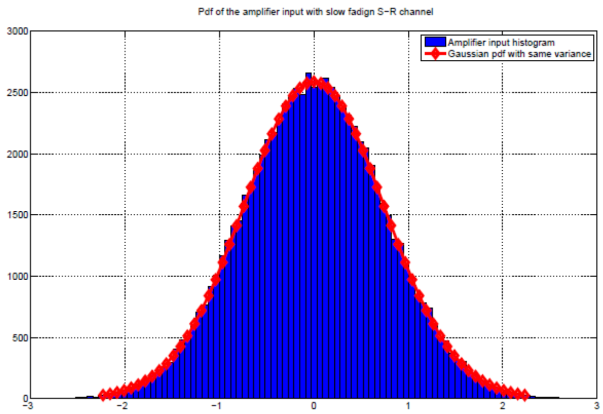

Figure 1: PDF of the amplifier input, slow fading case.

The input of the amplifier can be modeled as a Gaussian behavior. The NLD can be represented as an additive Gaussian noise. Therefore the effects of the NLD can be measured and mitigated with techniques similar to those used for AWGN.

Figure 2 presents the PDF of y_{SR}, for a fast fading h_{SR}, together with a Gaussian distribution with the same variance[3,4]. In this case, the behavior is close but not equal to the Gaussian case. Strictly, the NLD may not be modeled as an additive Gaussian noise. In figure 3 the complementary CDF of y_{SR} is compared to that of a Gaussian. It can be seen that h_{SR} presents a behavior similar to a Gaussian distribution for values close to the mean but differs significantly for higher values. When the coherence time of h_{SR} is much larger than the OFDM symbol duration, the channel can be considered to have almost deterministic behaviour.

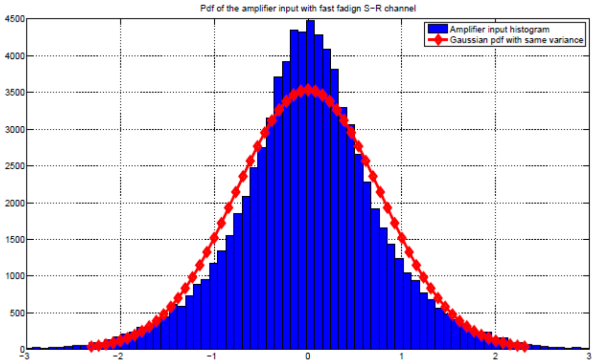

Figure 2: PDF of the amplifier input, fast fading case.

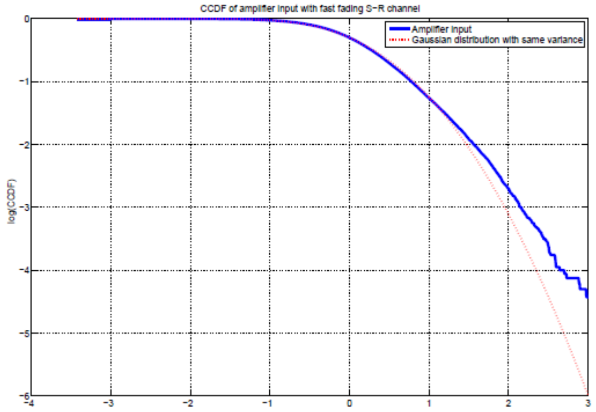

Figure 3: CCDF of the amplifier input, fast fading case.

Therefore, y_{SR} is basically the addition of two Gaussian variables, one of which is much smaller, resulting in a Gaussian variable as well. This is not the case for a fast fading h_{SR}. The OFDM symbol is affected by a random variable that changes for each OFDM symbol. As a result, y_{SR} is the result of a convolution of two Gaussian variables plus a third Gaussian variable. Furthermore, the distribution of the output of a nonlinear amplifier with this input may be even more complicated. Finding a new model for the NLD noise under these circumstances may therefore be very challenging [6, 9]. However, since the distribution does not differ dramatically from that of a Gaussian, it is worth to evaluate the results of considering it Gaussian.

III. THE POSITION OF THE RELAY

For AF cooperative systems, when the NLD is not considered, the best position of the relay is at half of the distance between the source and the destination. If there is an NLD term at the relay, this situation may change. In this section we analyze the performance of the cooperative system varying the distance between the source and the relay.

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Two cases are considered. The path-loss model considered is $d^{-\alpha}$ where α = 4 are used to describe the loss in a wireless environment.

The first case considers the relay to be always between the source and the destination. Figure 4 describes this case [11, 13].

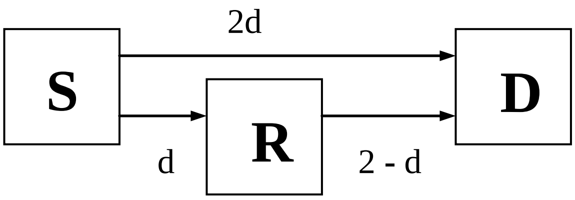

Figure 4: Distances between S and R, in-line case.

In figure 5 the BER curves for different distances between S and R. When the relay is far from the destination, the performance is very poor. The performance improves as the relay comes closer to the destination. In this case, the best performance is achieved when the relay is in the middle between S and D [10].

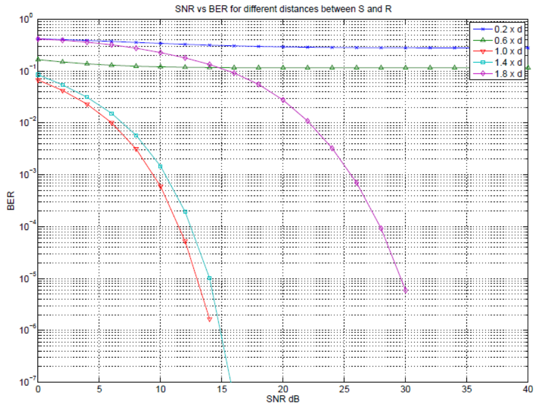

Figure 5: BER for different distances between S and R, in-line case.

The second case considers the relay to be somewhere between the source and the destination. This means, in practice, that a triangle is formed among R, S and D.

Figure 6 describes this case.

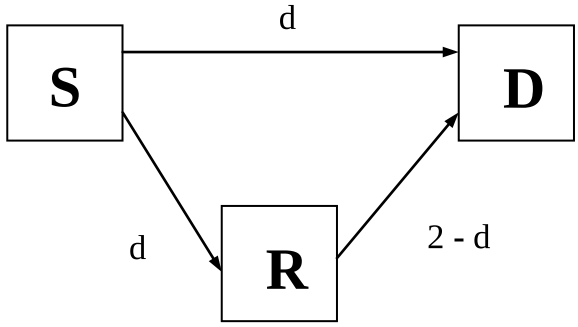

Figure 6: Distances between S and R, general case.

As seen from figure 7, the performance is better when the relay and the destination are closer. In this case, since the overall S-R-D distance is larger compared to the S-D distance, the received signal from the S-R-D branch has suffered more fading. It can be seen from these results that the system is in general more sensitive to fading after the amplification than to fading before the amplification [12].

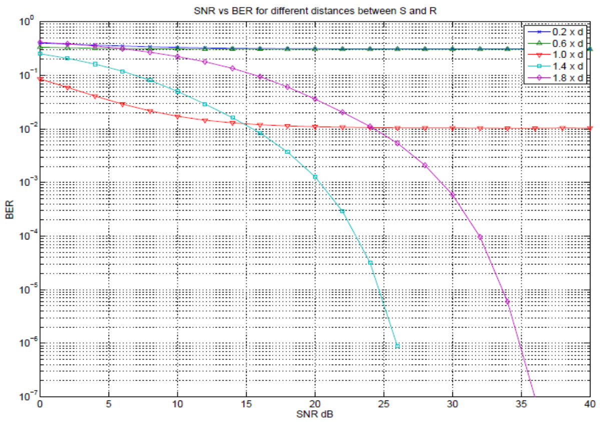

Figure 7: BER for different distances between S and R, general case.

In this case, the best performance is also achieved when the distance between R and D is 0.6 of the distance between S-D. Larger distances from the destination impact the performance significantly.

IV. THE NLD NOISE AT THE RECEIVER

From the information presented in previous sections, it is possible to identify two possible actions to increase the performance of the cooperative system: to consider the NLD distortion as an AWGN and compensate its effects at the destination or to control the choice of a relay so that it is in the zone where the performance is optimized.

The choice of the relay could be implemented by a control mechanism for the whole system that may require additional signaling or specific protocols. This is beyond the scope of this thesis and therefore will not be investigated. Considering the NLD as an AWGN provides a possibility of compensating the effects of it at the receiver using traditional tools. The following section shows how the NLD noise can be used to optimize the MRC.

V. OPTIMISATION OF THE MRC

The NLD noise can be modeled as a Gaussian variable in the case of the slow fading channel and it is close to a Gaussian variable in the case of a Fast Fading Channel. In this section a method for improving the MRC, by considering the NLD noise at the receiver, is presented. The input of the amplifier can be expressed as:

$$y_{SR} = h_{SR} * x_{SR} + n_{SR} \qquad \text{Eq 2}$$

The output of the amplifier is then:

$$x_{RD} = F(y_{SR}) \qquad \text{Eq 3}$$

$$= F(h_{SR} * x_{SR} + n_{SR}) \qquad \text{Eq 4}$$

The output of the amplifier can be modeled as the scaled version of the input plus a noise term:

$$x_{RD} = K y_{SR} + d(y_{SR}) \qquad \text{Eq 5}$$

$$= K\,(h_{SR} * x_{SR} + n_{SR}) + d(y_{SR}) \quad \text{Eq 6}$$

$$= K h_{SR} * x_{SR} + K n_{SR} + d(y_{SR}) \quad \text{Eq 7}$$

Performing the change of variables:

$$\hat{n}_{SR} = K n_{SR} + d(y_{SR}) \qquad \text{Eq 8}$$

The signal sent by the relay to the destination can be expressed as:

$$x_{RD} = K h_{SR} * x_{SR} + \hat{n}_{SR} \qquad \text{Eq 9}$$

VI. PERFORMANCE OF THE OPTIMISED MRC

In figure 8 the results of this method are presented for the case of a slow fading channel, using 512 OFDM symbols as training sequence. The Doppler spread of the channel is $f_c \approx 10Hz$.

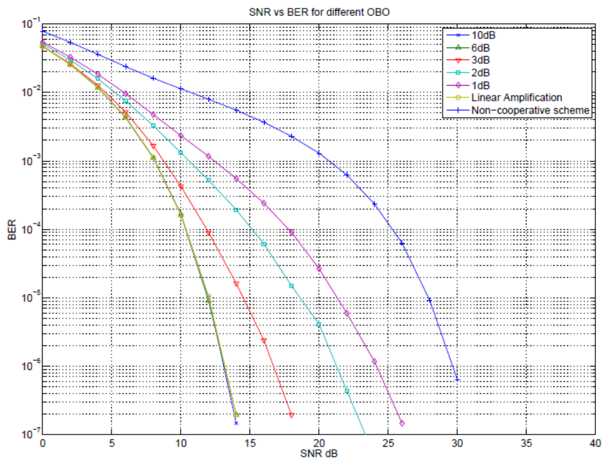

Figure 8: BER for different OBO with optimized MRC and slow fading channel.

As it can be seen from the figure, the performance of the cooperative system is significantly enhanced by the use of this method. Since the NLD noise is considered additive, the MRC uses this additional term to define the weight of the S-R-D branch in a more realistic way.

In the case of the slow fading channel, the NLD noise has a Gaussian distribution, resulting in effects equivalent as having AWGN. Therefore, the use of the MRC considering the NLD noise term results in an optimal combiner.

In figure 9 similar results are presented for the fast fading channel case. In this case the channel varies randomly between OFDM symbols but remains the same within one OFDM symbol.

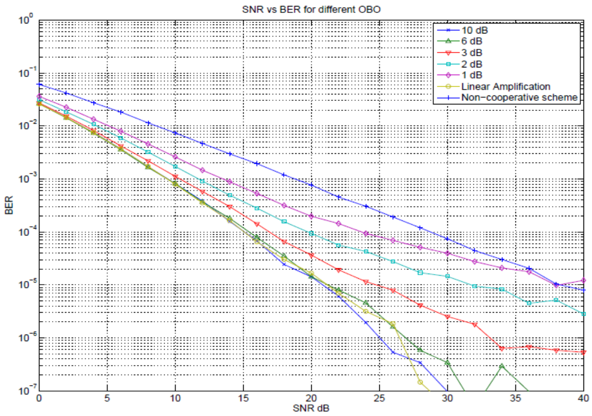

Figure 9: BER for different OBO with optimized MRC and fast fading channel.

It is important to consider that for the case of a fast fading channel, the input of the amplifier has, close to, but not Gaussian behavior. However, the results show that making the assumption of the NLD as an additive Gaussian term improves the performance of the cooperative system.

VII. ESTIMATION OF THE NLD VARIANCE

Figure 10 shows the BER of the cooperative system for different number of training OFDM symbols. This process is performed for two level of OBO: 1 dB and 6 dB.

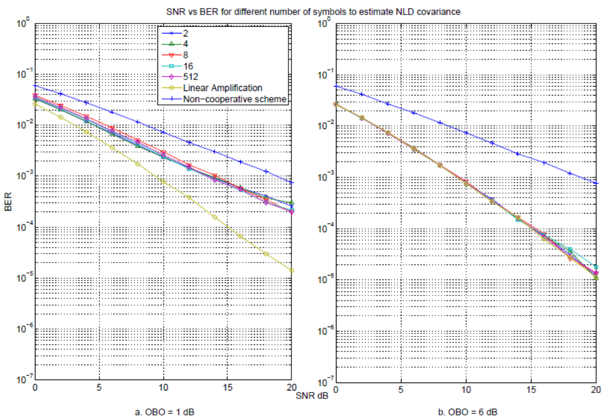

Figure 10: BER for different lengths of NLD training sequence.

The results are good even for short training sequences. In addition, increasing the length of the training sequence improves the performance only marginally. A short training sequence represents a less negative impact in the resources of the system. The optimized MRC outperforms the regular MRC without the need of long training sequences, minimizing the effects in the system rate and the processing load in the relay.

VIII. CONCLUSION

In this paper the role of the relay is analyzed. The first section provides a statistical analysis of the amplifier input signal. According to the literature, if the input is Gaussian, the output can be modeled as a scaled version of the input plus an additive Gaussian noise term. The input is shown to be Gaussian for a low fading channel and close to Gaussian for a fast fading channel. Some analysis about the position of the relay is also presented. Results show that the position of the relay also affects the performance of the amplifier. Unlike linear systems - where the optimal position is at the middle between the relay and the destination - the optimal position is slightly closer to the destination. Choosing the best relay according to the position requires additional control and signaling processes.

Considering the NLD as an additive Gaussian noise, and including it in the MRC, improve the performance of the system significantly. Only short sequences are required to calculate NLD, so the effects on system rate and processing load of the relay are minimized. In the case of the low fading channel, it could be considered to be the optimal combiner. In the case of the fast fading channel, the performance is greatly improved but it cannot be considered the optimal combiner. This, because it is not clear if with other model for the NLD, the performance could be improved. This paper proposed a method for optimizing the combiner and improve the performance of nonlinear cooperative systems.

IX. REFERENCES

[1] S. H. Muller and J. B. Huber, “A theoretical characterization of nonlinear distortion effects in OFDM systems,” IEEE Trans. Commun., vol. 48, no. 10, pp. 1755– 1764, Oct. 2000.

[2] L. Ding, “Digital predistortion of power amplifiers for wireless applications,” Ph.D. dissertation, School of Electrical and Computer Engineering, Georgia Institute of Technology, Mar. 2004.

[3] F. Gregorio, T. Laakso, and J. Cousseau, “Receiver cancellation of nonlinear power amplifier distortion in SDMA-OFDM systems,” in Proc. IEEE Int. Conf. Acoust., Speech, Signal Process., ICASSP 2006, May 2006.

[4] E. V. del Meulen, “Three-terminal communication channels,” Adv. Appl. Prob- ability, vol. 3, pp. 120 – 154, 1971.

[5] T. Cover and A. Gamal, “Capacity theorems for the relay channel,” Information Theory, IEEE Transactions on, vol. 25, no. 5, pp. 572 – 584, September 1979.

[6] J. N. Laneman and G. W. Wornell, “Energy-efficient antenna sharing and relaying for wireless networks,” in IEEE WCNC, September 2000, pp. 7–12.

[7] A. Sendonaris, E. Erkip, and B. Aazhang, “Increasing uplink capacity via user cooperation diversity,” in Proc. IEEE ISIT, vol. 51, no. 11, August 1998, p. 156.

[8] A. Nosratinia, T. Hunter, and A. Hedayat, “Cooperative communication in wireless networks,” Communications Magazine, IEEE, vol. 42, no. 10, pp. 74– 80, October 2004.

[9] L. Lai, K. Liu, and H. E. Gamal, “The three-nodewireless network: Achievable rates and cooperation strategies,” IEEE Trans. Info. Theory, vol. 52, no. 3, pp. 805–828, March 2006.

[10] J. N. Laneman, G. W. Wornell, and D. N. C. Tse, “An efficient protocol for realizing cooperative diversity in wireless networks,” in Proc. IEEE ISIT, vol. 42, no. 10, June 2001, p. 294.

[11] Q. Zhao, “Distributed modulations for wireless relay networks,” Ph.D. dissertation, Dept. Elec. Comput. Eng., Stevens Inst. Technol., Hobokonen, NJ, Nov. 2006.

[12] H. Li and Q. Zhao, “Distributed modulation for cooperative wireless communications,” Signal Processing Magazine, IEEE, vol. 23, no. 5, pp. 30 – 36, September 2006.
[13] D. Chen and J. Laneman, “Modulation and demodulation for cooperative diversity wireless systems,” IEEE Trans. Wireless Commun., vol. 5, no. 7, pp. 1785 –1794, July 2006.
[14] A. Scaglione, D. L. Goeckel, and J. Laneman, “Cooperative communications in mobile ad hoc networks,” Signal Processing Magazine, IEEE, vol. 23, no. 5, pp. 18 – 29, September 2006.