COMPENSATING THE NON-LINEAR DISTORTIONS OF AN OFDM SIGNAL WITH NEURAL NETWORKS

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This paper presents a non-linear distortion compensator for OFDM (Orthogonal Frequency Division Multiplexing) systems. OFDM signals are sensitive to non-linear distortions and different methods are studied to limit them. In the proposed technique, the correction is done at the receiver level by a higher-order neural network. Simulations show that the neural network brings perceptible gains in a complete OFDM system. In this paper we first present the OFDM, and explain why the non-linearities are a problem with this kind of modulation. Then we explain how we chose the neural network architecture, and finally some simulation results are presented.

1. Introduction

Multicarrier modulation, and especially OFDM, is now widely used for high-speed communications over frequency selective channels. Examples of use are DAB (Digital Audio Broadcasting), DVB-T (Digital Video Broadcasting on Terrestrial networks), HiperLAN/II and IEEE 802.11a (radio local area networks). An OFDM system uses several low-rate sub-carriers to transmit data and can be used in time dispersive channels, such as multipath channels, with good efficiency [1]. Unfortunately, as an OFDM signal is the sum of multiple sinusoidal waves, it has a high peak to average power ratio (PAPR). This means that it is very sensitive to the non-linearities of the high power amplifier (HPA) [2]. The first obvious solution is to use a very linear HPA, but this solution is expensive and consumes too much power for portable systems.

Several methods are studied to solve this problem. The PAPR can be reduced with special coding techniques [3], or the signal can be pre- or post-distorted to compensate for its non-linearity. A post-distortion system uses a compensator in the receiver that corrects the received signal [4]. We propose a new type of compensator that uses a neural network to correct the non-linearity introduced by the HPA.

2. OFDM

The basic idea of OFDM is to transmit data on parallel QAM (Quadrature Amplitude Modulation) or QPSK (Quadrature Phase Shift Keying) modulated sub-carriers. Let N be the number of sub-carriers, $C_k, k=0\ldots N-1$ the N complex symbols to be transmitted simultaneously, and T_S the OFDM symbol duration. The complex envelope of the ODFM base band signal is:

$$S(t)=\sum_{k=0}^{N-1} C_k e^{2i\pi k\frac{t}{T_S}} \tag{1}$$

The OFDM symbol can be easily generated using a IFFT algorithm, and the reception can be done with a FFT to recover the C_k symbols. The most interesting property of OFDM is that the channel equalization can be done in the frequency domain, after the FFT, and is a simple multiplication of the C_k symbols.

3. Proposed system

To compensate for the non-linearities at the receiver, the proposed system uses a neural network before the QAM/QPSK demodulator, as shown in Fig. 1.

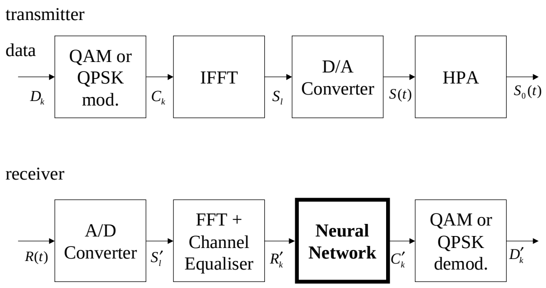

Fig. 1: Proposed system: the neural network corrects the received symbols

The main problem is that the non-linearity from the HPA is in the time domain, whereas the neural network is in the frequency domain. It can’t be moved before the FFT because in this case it would have to do the channel equalizing, which is much more complicated in the time domain. In the frequency domain the non-linearity is a bit more complicated: intermodulations appear between the different carriers, so in fact each received symbol R'_k is a non-linear combination of the N transmitted symbols C_k.

The neural network has to reverse this combination: it must find back the C_k symbols, given the R'_k symbols.

4. Neural network architecture

We have shown [5] that the neural network doesn't have to learn the correction to apply to each carrier. If it can do the compensation for one carrier, it can be used to correct the other carriers, with a simple shift of its inputs. This means that we can divide the size of the output space by N, and thus have a simpler network, with only one complex output.

Several neural network architectures are adapted for multidimensional function approximation. The most popular are RBF and multilayer perceptrons [6]. The RBF network is not really adapted to this problem because the input data is scattered in all the dimensions, and not regrouped in a small number of regions: the C_k symbols aren't correlated, and all have uniform distributions. So a RBF would require too much prototypes.

Multilayer perceptrons are more promising for this task. However the noticeable effect of the non-linearities in the frequency domain is intermodulation, which introduces higher-order disturbance on the carriers. That's why higher-order networks [7] have also been studied.

Indeed the networks that have shown the best performance for this task, both in terms of convergence and generalization, are higher order networks, and especially the Ridge Polynomial Network (RPN) [8].

Given an input vector $\boldsymbol{X} \in \mathbb{R}^d$, weight vectors $\boldsymbol{W_{ij}} \in \mathbb{R}^d$, biases $\boldsymbol{b_{ij}} \in \mathbb{R}$, and an activation function σ, the RPN's output is given by:

$$y = \sigma\left(\sum_{j=1}^{M} \prod_{i=1}^{j} \left(< X, W_{ji} > + b_{ji} \right) \right) \qquad (2)$$

<,> is the inner product, and d is the input space dimension. The network is trained using an incremental method described in [8], with a Levenberg-Marquardt algorithm [9] to improve the convergence speed.

5. Simulation and results

This architecture has been tested successfully on a 4-carrier OFDM system. To train the network, a learning base has been created using Cadence's SPW (Signal Processing Workshop). The OFDM system simulated uses 4 carriers, a QAM16 modulation, and a channel with additive white gaussian noise (AWGN). The signal to noise ratio (SNR) used is E_b/N_0=13dB. 8192 symbols are used as learning base, and 8192 others are used as validation set. Then the trained neural network is simulated in a complete OFDM system, using SPW. The intensity of the non-linearity is measured with the input back off (IBO) which is the ratio between the normalized maximum (saturation) output power and the average input power. The lower the IBO, the higher the distortion. The bit error rate (BER) is used to measure the system performance.

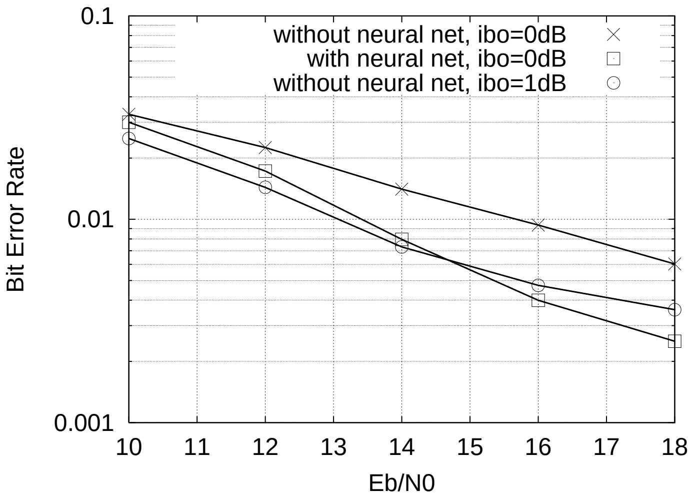

Fig. 2:Bit error rate of the OFDM system with and without the neural network. A QAM16 modulation is used on 4 carriers.

It is useful to look at the necessary SNR to obtain a given BER. If we want a BER of 10^{-2} with an amplifier that has an IBO of 0dB, we need a SNR of 16dB without the neural network, and 13.5 dB with the network. This means that with the network we can divide the power of the emitted signal and amplifier saturation by 1.8 (2.5dB) and still have the same performance. The emitter will consume less power and it is very interesting for portable systems.

At E_b/N_0=15dB, the system with the neural network has the same performance than the system without the network and with an amplifier that has a higher IBO (1dB). Thus the neural network manages to correct some non-linear distortions introduced by the HPA and the whole system acts as if it had a higher quality amplifier.

These results are very promising and show that neural networks can be efficiently used in an OFDM system.

6. Conclusion

We have proposed a non-linear compensator for OFDM signals based on a neural network. The neural network is placed in the receiver, and corrects the non-linearities introduced by the transmitter's high-power amplifier. The Ridge Polynomial Network showed good results in simulations and can improve the performance of OFDM systems, or keep the same performance with a lower power consumption. These results are very promising for this compensator, but the system currently only runs on 4-carrier modulations, and we carry on our research to adapt it to other systems with more carriers, closer to practical OFDM uses.

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