Performance of PSK/QAM OFDMA system in the Presence of HPA Non-Linearity

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Summary
In this paper, we investigate the performance of OFDMA with higher order QPSK/QAM mapping in the presence of HPA non-linearity in particular the amplifier TWTA. We consider OFDMA scheme with an AWGN channel and analyze their performance in terms of the BER in the system.

Key words:
HPA, Non-linearity, OFDMA, TWTA

1. Introduction

Recently, Orthogonal Frequency Division Multiplexing (OFDM) technique has been under intensive investigation for its application to high speed wireless multiple access communication systems [1], [2].

Due to the fact that OFDM is based on using a number of subcarriers, the frequency division multiple access (FDMA) method that assigns clusters of subcarriers to different users has been recognized as a basic multiple access scheme for OFDM [3]. OFDM using such a FDMA method, herein referred to as OFDM-FDMA (OFDMA).

Orthogonal frequency division multiple access (OFDMA) has recently attracted much attention as a promising multiplexing technique for future broadband wireless communications, including the fourth generation (4G) cellular networks. In an OFDMA system, several users simultaneously transmit their own data by modulating an exclusive set of orthogonal subcarriers [4].

One of the main disadvantages is the high PAPR of transmitted signals, which means

that the linearity requirement on the transmitter amplifier is quite stringent and the amplifier's power output back-off has to be large in order to reduce distortion.

In this paper we investigate the impact of HPA non-linearities (caused by a Traveling Wave Tube Amplifier (TWTA)) on the OFDMA systems for different PSK/QAM modulation scheme.

The paper is organized as follows: Section-2 and section-3 describe the system model and the HPA model respectively. Section-4 presents the results obtained and discusses the performance of the scheme and finally, section-5 provides concluding remarks.

2. Model OFDMA

In this section, we introduce the uplink signal model of OFDMA. Consider an OFDMA system consisting of N subcarriers and K users. The N subcarriers include all available subcarriers and virtual subcarriers in the guard band [5]. All subcarriers are sequentially indexed with $\{n\}$; n=0,1,...,N-1 .

Among the N subcarriers, the K th user is assigned to a subset of $p^{(k)}$ subcarriers with the index set $\left\{c_0^{(k)}, c_1^{(k)}, ..., c_{p^k-1}^{(k)}\right\}$.

The superscript $(.)^{(k)}$ denotes the kth user.

An OFDMA block is the signal generated by one inverse fast fourier transform (IFFT) operation including the cyclic prefix (CP).

Let $\left[X_{g,0}^{(k)}, X_{g,1}^{(k)}, ..., X_{g,p^{(k)}-1}^{(k)}\right]$ be the $p^{(k)}$ modulation symbols the kth user will transmit during the gth OFDMA block. For data bearing subcarriers, the modulation symbols are data symbols, such as phase shift keying (PSK) or quadrature amplitude modulation (QAM). For virtual subcarriers, the modulation symbols are effectively padded zeros in IFFT. For pilot subcarriers, the modulation symbols are pilot symbols or training symbols for estimating the channels.

Fig.1 illustrates the signal generation and transmission of the kth user. The $p^{(k)}$ modulation symbols are first mapped into a set off N modulation symbols, according to

$$s_{g,i}^{(k)} = \begin{cases} X_{g,p}^{(k)} \text{si } i = cp^{(k)} & p = 0,1,...p^{(k)}-1 \\ 0 \text{ otherwise.} \end{cases} \quad (1)$$

The N symbols, $\left\{s_{g,i}^{(k)}, i = 0,1,...,N-1\right\}$, are modulated onto the N subcarriers via an N -point IFFT. The CP is also added to avoid inter-block interference (IBI) caused by multipath fading. As a result, the base band signal of the gth OFDMA block transmitted from the kth user can be represented as

$$x^{(k)}(t) = \sum_{g=-\infty}^{+\infty}\sum_{i=0}^{N-1} s_{g,i}^{(k)} F_{g,i}(t) = \sum_{g=-\infty}^{+\infty}\sum_{p=0}^{p^{(k)}-1} X_{g,p}^{(k)} F_{g,cp^{(k)}}(t) \qquad (2)$$

Note $F_{g,i}(t)$ is given by

$$F_{g,i}(t) = \begin{cases} e^{j2\pi(i\Delta f)(t-T_{cp}-gT_b)} & gT_b \le t < (g+1)T_b \\ 0 \ \text{otherwise.} & \end{cases} \qquad (3)$$

Where Δf is the subcarrier spacing, T_{cp} is the length of CP and $T_b = T + T_{cp}$ is the duration of one OFDMA block, $T = 1/\Delta f$

The signals are transmitted through slowly time-variant multipath fading channels, i.e. fading coefficients are assumed to be constant during one OFDMA block. The channel between the kth user and the uplink receiver is characterized by

$$h^{(k)}(\tau, t) = \sum_{l=1}^{L^{(k)}} \alpha_l^{(k)}(t)\delta(\tau - \tau_l^{(k)}) \qquad (4)$$

Where $L^{(k)}$ is the total number of paths, $\alpha_l^{(k)}$ and $\tau_l^{(k)}$ are the complex gain and time delay of the lth path. At the uplink receiver, the signal of one OFDMA block is the superposition of signals from all K involved users. Assume all K users are synchronized in time, the received sampled signal in the absence of noise can be written as

$$y(nT_s) = \sum_{k=1}^{K}\sum_{l=1}^{L^{(k)}} \alpha_l^{(k)}(nT_s) x^{(k)}(nT_s - \tau_l^{(k)}) \qquad (5)$$

where $T_s = T/N$ is the sampling interval. As we will focus on the signal of one OFDMA block, the index g in the following is neglected for convenience. ET $H_p^{(k)}$ denotes the channel frequency response on the $c_p^{(k)}th$ subcarrier of the kth user's channel during one OFDMA block. We have

$$H_p^{(k)} = \sum_{l=1}^{L^{(k)}} \alpha_l^{(k)} e^{-j2\pi c_p^{(k)}\Delta f \tau_l^{(k)}} \qquad (6)$$

From (2)-(6), after the removal of CP, the remaining N signal samples of one OFDMA block at the uplink receiver is given by

$$y(nT_s) = \sum_{k=0}^{K-1}\sum_{p=0}^{p^{(k)}-1} H_p^{(k)} X_p^{(k)} e^{-j2\pi(c_p^{(k)}\Delta f)nT_s} = \sum_{k=0}^{K-1}\sum_{p=0}^{p^{(k)}-1} H_p^{(k)} X_p^{(k)} e^{-j(2\pi/N)nc_p^{(k)}} \qquad (7)$$

Where $n = 0, 1, \dots, N-1$.

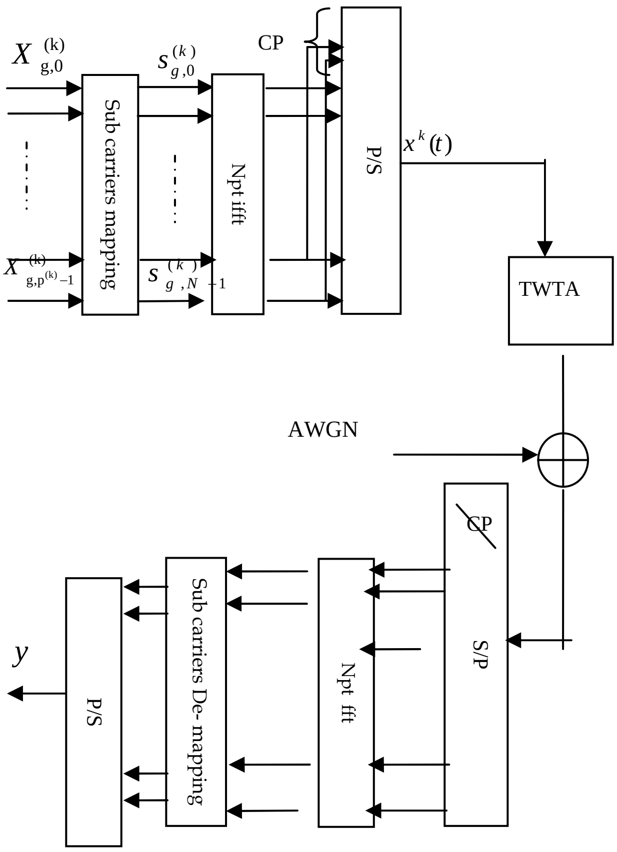

Fig. 1: Uplink OFDMA transmitter structure

3. High-Power Amplifiers

In order to increase power efficiency, satellites are equipped with HPAs, such as traveling wave tube (TWT) amplifiers [6] (Fig.1). HPAs have nonlinear transfer functions, which are characterized by amplitude conversion (AM/AM) and phase conversion (AM/PM). Equation (8) give an example of a typical TWT model used in satellite communications, where and are the AM/AM and AM/PM conversions, respectively [7]:

$$a(r) = \frac{\alpha r}{(1 + \beta r^2)} \qquad \phi(r) = 0 \qquad (8)$$

Where r is the amplifier input signal amplitude. Fig.2 illustrates the nonlinear behavior of the amplitude conversion.

The amplifier input back off (IBO) is defined as the ratio between the amplifier input saturation power (P_{sat}) to the input signal power (P_{in})

$$IBO(dB) = 10\log\left(\frac{P_{sat}}{\langle P_{in}\rangle}\right) \tag{9}$$

Assuming that PAPR is defined as the ratio between the peak envelope power and the average power:

$$PAPR(x) = \frac{\max_{t\in[0,T]} |x(t)|^2}{\frac{1}{T}\int_0^T |x(t)|^2\,dt} \tag{10}$$

Thus, Crest Factor (CF) can de written as:

$$CF(x(t)) = \sqrt{PAPR(x(t))} \tag{11}$$

The HPA nonlinear transfer function causes severe nonlinear distortions to the input signal, especially when the HPA is operated near its saturation region (i.e., for maximal power efficiency). The distortions are particularly important when multilevel modulation schemes are employed, such as M-array quadrature amplitude modulation (M-QAM) (M>4) [6], [8].

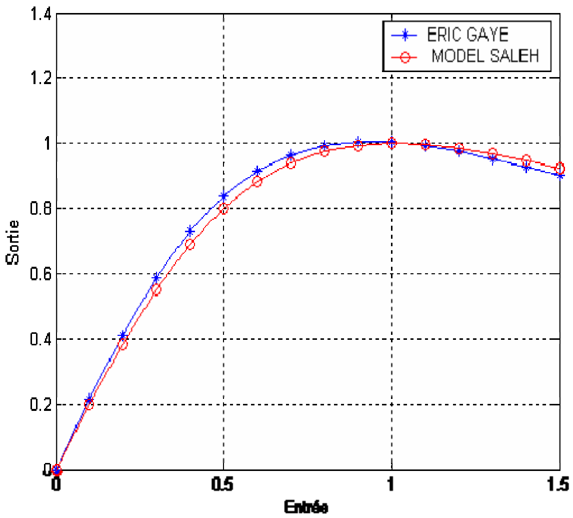

Fig. 2: HPA amplitude conversion

This results in a significant degradation of the satellite channel bit error rate (BER) performance. Because of this nonlinear problem, early satellite systems have been restricted to simple (and, therefore, spectrally inefficient) modulation schemes, such as quadrature phase shift keying (QPSK) modulation, which are sensitive to the nonlinear problem than spectrally efficient modulation schemes. Section 4 presents a simulation.

4. Simulation

In this section, the simulation results for the systems described in section-2 are presented. OFDMA systems with 4 users have been considered. For simulation parameters, the number of sub-carrier N=512 is considered and data formats are QPSK and 4QAM for all branches. Modulation schemes are used to generate a transmitted OFDMA block for each user. The average SNR per subcarrier for each user is assumed to be the same, and knowledge of channels is assumed. Then OFDMA system is simulated using MATLAB. The Bit Error Rate (BER) is used to measure the system performance. Fig.3 presents the performance of 16QAM/OFDMA with TWTA for different IBO (input back off). In this simulation we have use the chain OFDMA with the amplifier TWTA. Besides fig.4 presents the performance of 4 QAM/OFDMA with TWTA, when the number of subcarrier is equal at 512.

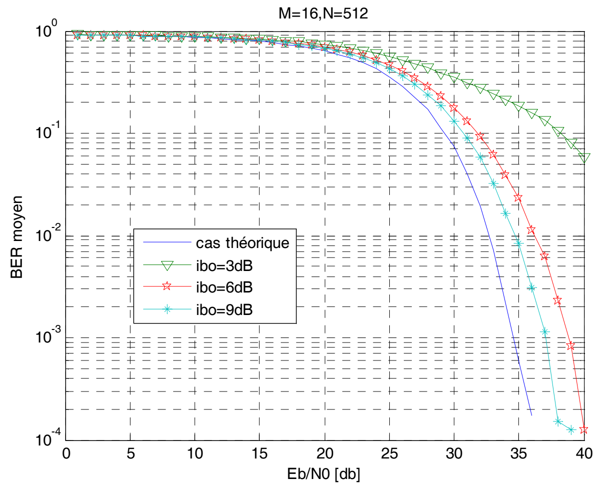

Fig. 3: Performance of 16QAM/OFDMA with TWTA (N = 512)

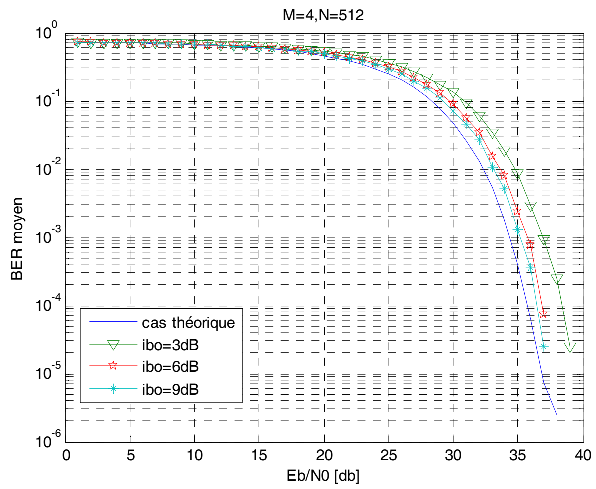

Fig. 4: Performance of 4QAM/OFDMA with TWTA (N = 512)

Fig. 5 shows the performance of stems at IBO = 3dB. Comparing the performance of the full system implementation and the modulation is QPSK/4QAM/OFDMA system.

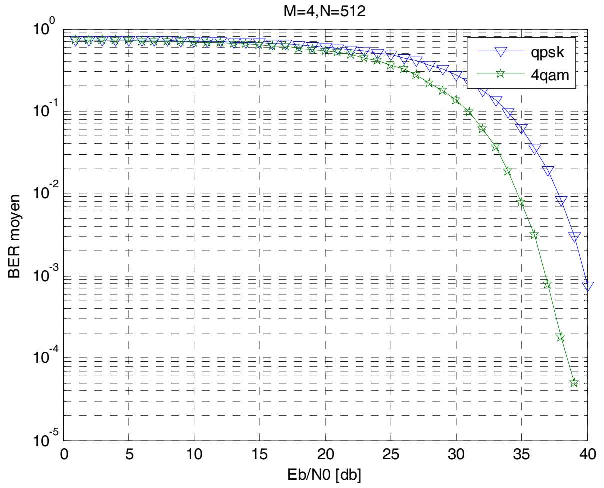

Fig. 5: Performance of 4QAM/QPSK/OFDMA with TWTA (IBO=3dB, N = 512)

5. Concluding Remarks

In this paper, we have analyzed of the effects of a TWTA on the performance of OFDMA signal with various different PSK/QAM formats in terms of the performance of BER. Results show that for the same level of non-linearity (or IBO), the overall performance of OFDMA signals with QAM is better than that of QPSK signal.

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