Coded 4-PAM OFDM for High Rate Data Links

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***Abstract*- Orthogonal Frequency Division Multiplexing (OFDM) is one of the best solutions for wideband communication applications. M-ary PAM – OFDM achieves comparable power and bandwidth efficiencies with less system complexity to ordinary OFDM systems that use M-ary QAM or M-ary PSK. Basically, OFDM is sensitive to Carrier Frequency Offset (CFO) and to phase noise. Performance evaluation of M-ary PAM OFDM over AWGN impaired with CFO and white phase noise is investigated in this paper with simulation. Also, the coded 4-PAM OFDM is proposed and its performance is evaluated over AWGN impaired with CFO and phase noise with simulation in comparison with un-coded 4-PAM OFDM.**

I. Introduction

Modern Communication systems employ Orthogonal Frequency Division Multiplexing (OFDM) due to its high spectral efficiency. In traditional wire line and PCM communications Pulse Amplitude Modulation (PAM) was widely used. However, higher data rates are required in emerging communication applications. The proposal of M-ary PAM OFDM is introduced in [1]. M-ary PAM-OFDM achieves comparable power and bandwidth efficiencies compared to ordinary OFDM systems that use M-ary QAM and M-ary PSK. Furthermore, employing M-ary PAM OFDM requires less computational burden and less system complexity compared to ordinary OFDM systems. Basically, M-ary PAM OFDM achieves bandwidth saving on the expense of losing power efficiency; resulting in a high Peak-Average Power Ratio (PAPR) [1]. One way to reduce PAPR is to introduce coding [2]. Coding also serves for increasing capacity; supporting the increasing demand for higher data rate communications.

OFDM is sensitive to Carrier Frequency Offset (CFO) and to phase noise, which degrade the system performance because of the loss of sub-carrier orthogonality, as well as the introduction of Inter-Carrier Interference (ICI). The effect of CFO on OFDM has been studied in [2]. Also, the effect of phase noise on OFDM has been studied in [3].

In this paper the performance of M-ary PAM OFDM over AWGN channel impaired with CFO and white phase noise is evaluated. The proposed coded 4-PAM OFDM is introduced and its performance over AWGN channel with phase noise and CFO compared to un-coded 4-PAM OFDM is studied.

The organization of this paper is as follows. A brief overview of M-ary PAM OFDM is presented in section II. White phase noise model and performance evaluation using simulation of M-ary PAM over AWGN channel impaired with white phase noise are given in section III. Moreover, performance evaluation of M-ary PAM OFDM over AWGN channel with CFO is evaluated via simulation in section IV. In section V proposed coded 4-PAM OFDM is introduced and its performance is compared to un-coded 4-PAM OFDM over AWGN channel with white phase noise and CFO with simulation. Finally, conclusions are discussed in section VI.

II. Overview of M-ary PAM OFDM

M-ary QAM-OFDM or M-ary PSK OFDM, either modulation schemes when applied on OFDM systems, the minimum frequency separation that guarantees orthogonal sub-carriers is $1/T$, where T is the symbol duration. However, if the sub-carriers differ only in their frequencies and amplitudes and their phases are the same, then the minimum required frequency spacing is $(1/2T)$; as shown in Fig.1. ; resulting in a less complex system. Also, M-ary PAM OFDM can be implemented using Discrete Cosine Transform (DCT), which is an efficient algorithm and can be implemented using real additions [1].

M-ary PAM OFDM as defined in [1]

$$s(t) = \sum_{k=0}^{N-1} A_k \cos(2\pi \frac{k}{2T} t) \quad (1)$$

M-ary PAM OFDM exhibits a bandwidth saving ratio compared to M-QAM and M-PSK OFDM given by [1]

$$\text{Bandwidth Savings} = \frac{2(N+1)}{N+3} \quad (2)$$

However, there is a tradeoff between bandwidth saving and power efficiency. PAPR compared to M-ary PSK OFDM [1]

$$\text{P}APR_{\deg r(PO)} = \frac{3(M-1)}{M+1} \quad (3)$$

The number of required samples for M-ary PAM OFDM is half that required for either M-ary QAM or M-ary PSK OFDM systems. Moreover, this results in a reduced system complexity [1], [5].

[1] VT-MENA program: Virginia Tech -Middle East and North Africa program

T. Sobh (ed.), Innovations and Advanced Techniques in Computer and Information Sciences and Engineering, 553–556.

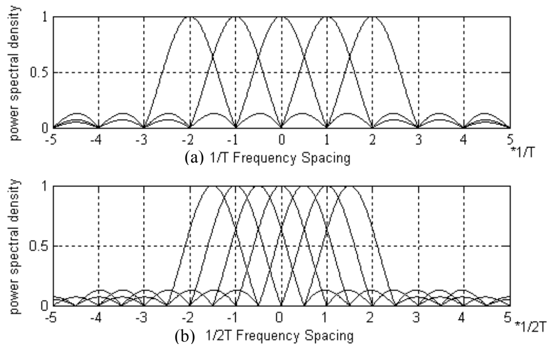

Fig. 1. Spectra of OFDM subcarriers (a) QAM or PSK OFDM, the subcarrier separation is $1/T$. (b) MASK OFDM, the subcarrier separation is $1/2T$ [3]

III. Performance Evaluation of M-ary PAM OFDM Over AWGN Channel with White Phase Noise

Phase noise is modeled as a phase modulation of the carrier for simulation purposes [4]. The presence of phase noise degrades the performance of OFDM systems causing ICI [4].

The effect of phase noise $\varphi(n)$ on the received signal $r(n)$ in terms of the transmitted signal with AWGN $x(n)$ as in [4]:

$$r(n) = x(n).e^{j\varphi(n)} \quad (4)$$

As phase noise variance increases, the degradation in system performance becomes more severe [4]. Simulation model of OFDM system is shown in Fig. 2. System BER performance evaluation via simulation of the effect of white phase noise on M-ary PAM OFDM was performed and the results are shown in Fig.3 for the case of no-phase noise and for the case of the presence of phase noise with noise variances σ^2= 0.02 rad^2 and for σ^2= 0.07 rad^2 as shown in Fig.4.

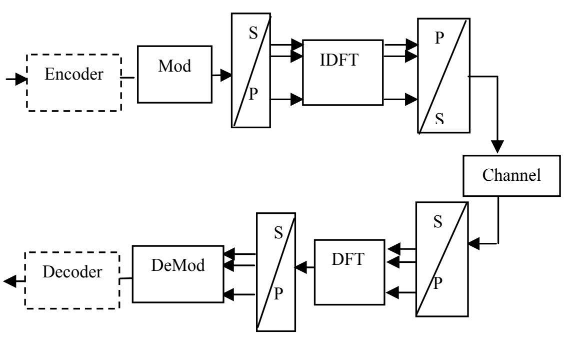

Fig. 2. Simulation model of OFDM transceiver (128 carriers) over AWGN channel [2]

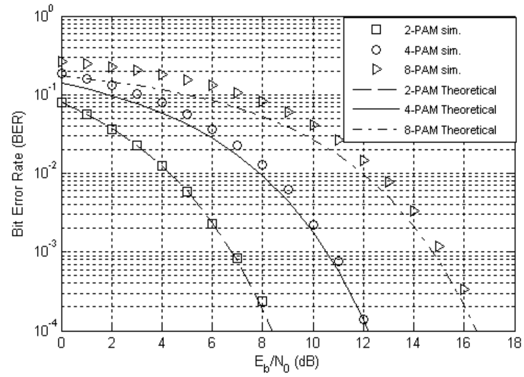

Fig. 3. BER of M-ary PAM OFDM (128 carriers) over AWGN channel theoretically and via simulation

Signal to noise ratio degradation due to phase noise [4]

$$\deg r_{SNR} = 10.\log(1+\sigma^2 \frac{E_s}{N_0}) \text{ dB} \quad (5)$$

It can be shown from Fig.3 that BER performance degrades as phase noise variance increases. Substituting in (5), for the case of 2-PAM OFDM at signal to noise ratio of 6dB and phase noise variance of 0.02 rad^2 signal to noise ratio degradation is equal to 0.49dB, and for noise variance of 0.02 rad^2 degradation is equal to 1.52dB for the same BER. Simulation results verify these values.

IV. Performance Evaluation of M-ary PAM OFDM Over AWGN Channel with CFO

OFDM systems are sensitive to CFO, and for a large number of sub-carriers inter-carrier orthogonality is destroyed and ICI is introduced. Consequently, the system performance degrades [3].

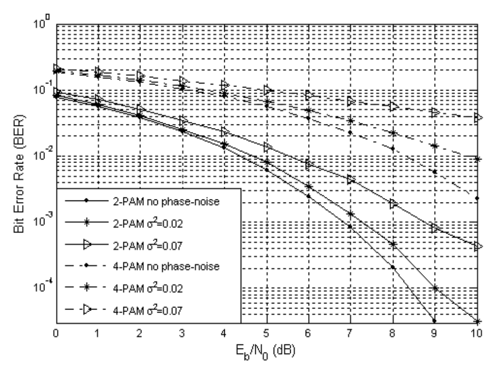

Fig. 4. BER of M-ary PAM OFDM (128 carriers) over AWGN channel impaired with phase noise