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## Multi-symbol Encapsulation and Discrete Cosine Transform in Multiple Access System

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### ABSTRACT

Multi-carrier modulation system has received much attention in modern communication technology and is finding attractive applications. However, cyclic extension of each transformed block to robust the transmission performance restrict the achievable spectral efficiency. This work presents and assesses a new physical layer of a multi-carrier wireless communication system based on multi symbol encapsulated approach. The study introduced and discussed the discrete cosine transform DCT-based MC modulation with single zero padded extension for multiple consecutive transformed blocks. Simulation results show that our scheme simultaneously decreases error rate and reduces the PAPR by 3 dB in presence of nonlinear power amplifier model. Differences with respect to the conventional system also are pointed out. Moreover, the simulation over slow fading channel depicted that encoded signals in MC scheme based on MSE-DCT performs better if a blind estimation based on matched filter approach is considered. The simulation study proves that such a prefilter would be appropriate to compensate the distortion induced by the channel.

**Key words:** Multi-carrier transmission, discrete cosine transform, multi-symbols encapsulation, peak-to average power ratio, slow fading

### INTRODUCTION

Multi-carrier, MC technology has received much attention in modern communication systems. It has been adopted in many wired and wireless communication standards due to its ability to deal with severe multipath channel fading. In MC systems, a number of data symbols are transmitted at separated sub-carriers in parallel thus increasing the symbol length which reduces the sensitivity to interference. There have been intense research efforts aimed at designing different multi-carrier transceiver scheme with different spectral containment. Among those designs are the Discrete Cosine Transform DCT-MCM (Al-Dhahir and Minn, 2006; Cero *et al.*, 2009; Mustafa, 2009), Discrete Wavelet Multi-Tone DWMT (Daly, 2003; Mustafa and Hikmat, 2011). Each divides the available frequency band into a large number of orthogonal sub-bands. However, cyclic extension of each transformed block to robust the transmission performance and mitigate the Inter-symbol Interference ISI, restricts the transmission spectral efficiency especially over a channel of long impulse response.

Moreover, Peak to Average Power Ratio (PAPR) is one of the serious problems in wireless communication system uses multi carrier modulation technique DFT-based system. Thus, the transmitted signal is sensitive to non-linear distortions that will degrade the error performance and introduce high adjacent channel interference with spectrum regrowth. Several techniques for

reducing PAPR of multi-carriers signal have appeared in the literature; However, most of these techniques introduce additional complexity. In study of Wang *et al.* (2010), a joint companding transform and Hadamard transform method is proposed to reduce peak-to-average of OFDM signal. Two different approaches are pointed out (Barsanti and Larue, 2011) to reduce PAPR in DVB system; Active Constellation Extension method and the Reserve Carrier Algorithm. Vijayarangan and Sukanesh (2005) have offered an overview of the proposed technique to reduce the PAPR in conventional MC system. Simultaneously, the research community has proposed different methods to compensate the nonlinear distortion induced by the power amplifier (Mustafa, 2007; Friese, 1996).

In this study, DCT-based multi-carrier system was considered. The DCT has been considered one of the best tools in digital signal processing and therefore, it has many applications, e.g., in the area of multimedia and telecommunications. DCT is a linear Fourier-related transformation similar to the DFT. By repeating the samples in a time reversed order and performing a DFT on the length sample set a DCT is obtained.

DCT is an orthogonal linear transform, i.e., the inverse transform matrix is obtained with a matrix transpose (Strang, 1999). DCT can be implemented by a fast transform that does not require extensive increase of system complexity.

Moreover, the DCT basis is well-known to have excellent spectral compaction and energy concentration properties which prevent excessive leakage into the adjacent bands. It is more robust in the presence of Inter Channel Interference ICI. However, main complexity disadvantage of DCT-MCM with respect to DFT-MCM is the need for prefilter at the receiver to make the Channel Impulse Response (CIR) symmetric in order for it to be diagonalizable by the DCT (Bouzegzi *et al.*, 2008).

To achieve higher bandwidth efficiency in our scheme, Multi-Symbol Encapsulation is considered. Zero padding is added to each frame of a number of IDCT blocks. Many simulations have been carried to outline and assess the scheme over non-linear AWGN and a flat faded channel.

### **MSE-DCT BASED MC SCHEME**

DCT-based MC scheme is presented in Fig. 1. The generic user  $i$  transmits a sequence of complex information symbols by mapping them to a subset of subcarriers on the  $N$ -size IDCT modulator. Complex sequence vector  $N \times 1$  of baseband symbols is modulated by means of IDCT to generate a transformed symbol. IDCT and DCT blocks can be simply exchanged, since IDCT matrix is the transpose of DCT matrix.

The orthogonal DCT is classified into many different types with slightly different even/odd boundary conditions at the two ends of the matrix. The first definitions of the forward and inverse DCT were given by:

$$y_k = \frac{b_k}{\sqrt{N}} \sum_{n=1}^N x_n \cdot \cos \frac{\pi(2n-1)(k-1)}{2N}$$

$$k = 1, \dots, N \tag{1a}$$

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=1}^N b_k \cdot y_k \cdot \cos \frac{\pi(2n-1)(k-1)}{2N}$$

$$n = 1, \dots, N \tag{1b}$$

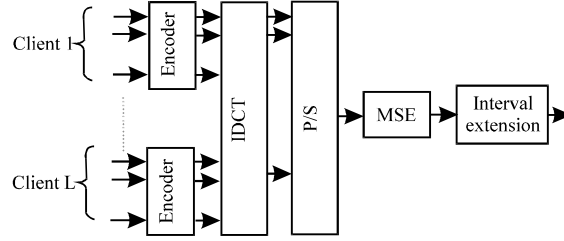


Fig. 1: Block Diagram of multi-access MC system based on MSE-DCT scheme

Where:

$$b_k = \begin{cases} 1 & k=1 \\ \sqrt{2} & 2 \leq k \leq N \end{cases}$$

DCT operators map an N-size real sequence into another N-size real sequence and hence binary signaling or parsed in-phase and quadrature components of complex data word must be used in each sub-channel individually. Further, DCT scheme can be used with all the sub-carriers allocated to transmit only the estimated phase of the different constellation points (QPSK, DPSK), where the amplitude is constant, thereby improving the data rate to the double.

In MSE-based transmission, M output symbols are serialized and encapsulated in a frame. To leverage the achievable bandwidth efficiency, each frame is extended by zero padding intervals of a length longer than the expected channel impulse response, instead of extending each transmitted block.

If we represent the N-size sequence as  $X = [x_1, \dots, x_N]$  and  $Y = [y_1, \dots, y_N]$  and denote the NXN DCT matrix by:

$$\Gamma = \left\| \frac{b_k}{\sqrt{N}} \cdot \cos \frac{\pi(2n-1)(k-1)}{2N} \right\| \quad (2)$$

Thus, Eq. 1 can be rewritten as  $Y = X\Gamma^{-1}$  and  $X = Y\Gamma$ . M output symbols of Y is encapsulated in a frame to get a vector  $\mathbf{Y}$  of  $MN \times 1$  size. Then, D trailing zeros is added to each frame by  $\mathbf{Y}\mathbf{Z}$ , where,  $\mathbf{Z} = [I_{MN}; \mathbf{0}_D]^T$ .  $I_{MN}$  denotes an identity matrix which is followed by D zeros and  $(.)^T$  is the transposition operator.  $(M.N+D)$  is the number of the received samples.

We have found gain in some parameters related the MC scheme we use. Table 1 shows the gain we have achieved in some parameters relevant to the MC scheme we use compared to the conventional scheme. The reduction in envelope fluctuation is discussed later on.  $\eta_1$  denotes a gain in the spectral efficiency if MSE is considered to transmit a frame of four independent output symbols.  $\eta_2$  is the double of  $\eta_1$  that is obtained by using either PAM or PSK or DPSK to encode the subcarriers.

However, the main complexity disadvantage of DCT-based system with respect to conventional system is the need for a prefilter at the receiver to make the Channel Impulse Response (CIR) symmetric in order for it to be diagonalizable by the DCT.

In this work, an estimator of unknown parameters based on the match filter approach is employed at the receiver, similarly to that have been considered (Bouzegzi *et al.*, 2008). The

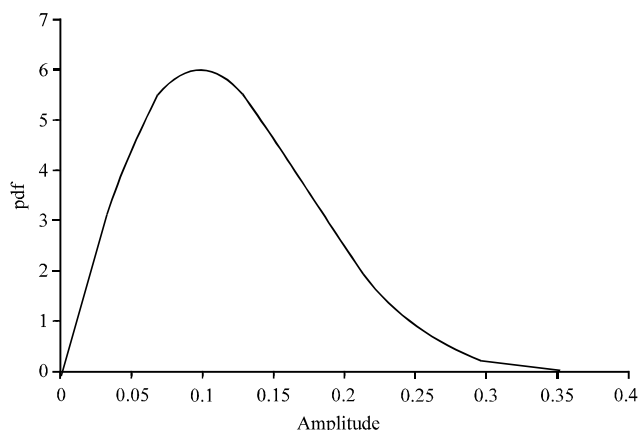


Fig. 2: Distribution of DCT-based scheme signal amplitude

resulting signal is applied on the DCT subcarriers. The idea is to build an estimator that maximize signal-to-noise ratio.

### SIMULATION RESULTS

It is well known, there is a tradeoff between bandwidth efficiency and error performance, such that lower number of encapsulated symbols in a frame enhances the performance but with sacrificing in symbol rate.

Cyclic extension is added to each inverse Fourier transformed symbol, while zero padding extension is considered in our proposed scheme. One extension interval is used for each frame of number of consecutive output symbols. With Fourier transformation, the conjugate symmetry condition is imposed on the system under the same transformation size  $N = 512$  to provide fairest comparison possible. The results are averaged over 3 independent iterations for the demodulator.

**Non-Linear distortion:** We have analyzed the distribution of time domain transformed amplitude as depicted in Fig. 2. The Probability Density Function (PDF) depends on the probability of occurrence of each discrete sample level. The distribution of MC signal with 512 sub-carriers and 16-QAM is founded where the amplitude  $a_n$  has Rayleigh distribution with PDF given by:

$$P(a_n) = \begin{cases} \frac{a_n}{\sigma_s^2} e^{-a_n^2/(2\sigma_s^2)} & a_n \geq 0 \\ 0 & \text{elsewhere} \end{cases} \quad (3)$$

For Rayleigh distribution, as seen the signal levels around the mean value have higher probability than other levels, while the occurrence of the large signals has the smallest probability. It is reasonable cast a way to change the statistic of the amplitude for the benefit of PAPR reduction. Notice that PAPR is a random variable for each transmitted block. It has been found from a large number of independent runs for the MSE-DCT-based and traditional MC scheme that within each block, the peak power is reduced using DCT-based system of about 6.5 dB and a reduction of PAPR of about 3 dB are achieved. Table 1 lists these achievements as a gain through using MSE-DCT scheme.

Table 1: The gain that MSE-DCT scheme would achieve

Parameter	Gain
Reduction in peak power	6.5 dB
Reduction in PAPR	3 dB
$\eta_1$	1.19
$\eta_2$	2.38

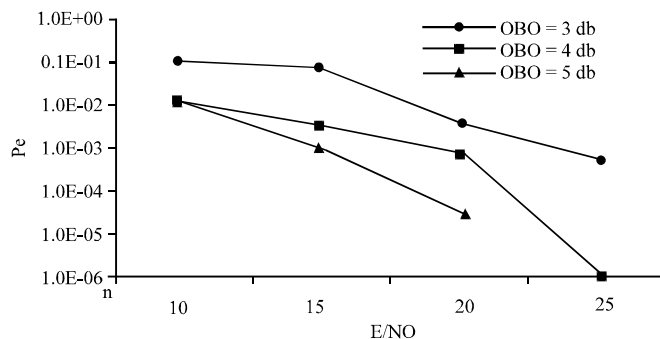


Fig. 3: Pe in MC scheme based on MSE-DCT in the presence of non-linear distortion

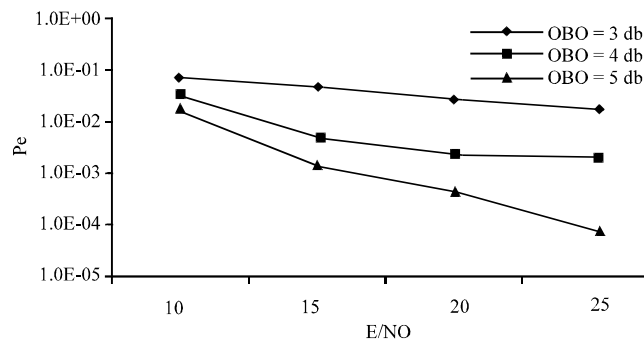


Fig. 4: Pe in conventional MC scheme in the presence of non-linear distortion

Non-linear power amplifier is applied with AM/AM response of clipping scheme at the saturation point at three different Output Back Off (OBO) 3, 4 and 5 dB. OBO is defined as the ratio of the maximum possible amplifier output power to the average output power.

We have compared the error performance of the new MC scheme based on MSE-DCT (Fig. 3) and the traditional Fourier-based MC scheme (Fig. 4) over a noisy channel. The complex-valued noise is assumed to be independent and identically distributed, zero-mean white Gaussian noise. Its variance is equal to  $N_0$  per real dimension.

In the traditional MC scheme, low OBO generates an almost flattened error curves indicating saturation of the power amplifier. These results can be directly compared with the results for the MSE-DCT based Scheme. It is found that the simulated performance approaches the linear transmission due to the overall net improvement in the PAPR. However, lower OBO causes non-linear distortion that diverge the performance from the linear case.

**Flat fading channel:** In flat fading, the coherence bandwidth of the channel is larger than the bandwidth of the signal. Therefore, all frequency components of the signal will experience the same magnitude of fading. Flat fading has an impulse response given by:

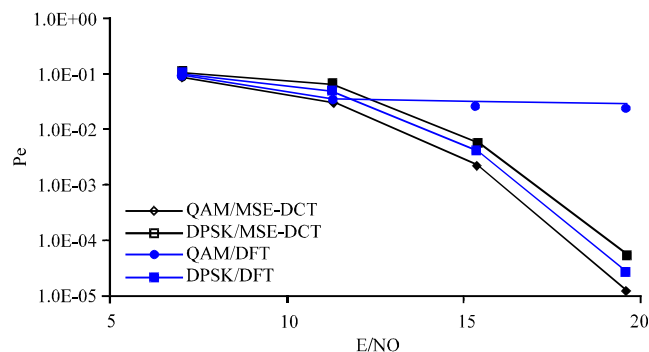


Fig. 5: Performance comparison between conventional MC scheme and MC based on MSE-DCT. The assessment is over flat fading channel without channel estimation

$$g(t, \tau) = \beta(t) \cdot e^{j\theta(t)} \cdot \delta(t) \quad (4)$$

where,  $g(t, \tau)$  is the impulse response at observation time  $t$  to an impulse applied at time  $t - \tau$ . This channel is considered to be slowly time-varying such that the amplitude  $\beta(t)$  and the phase shift  $\theta(t)$  can be considered constant during one symbol interval (Mustafa, 2007). To assess the performance of MSE-DCT based MC schemes over fading channel, the error curves are examined as a function of signal energy-to noise  $E/N$ .

Figure 5 shows the performance of different encoded sub-carriers where MSE-DCT based system approaches the linear transmission. The distortion arose from fading channel can be compensated by increasing  $E/N_0$ . As depicted the DPSK signals in both MC systems have the same performance depending on the phase tracking of the decoder. It is clearly observed that the amplitude and phase shift of the reflected signals have a much stronger influence on the systems using QAM than on DPSK modulation systems.

**Slow fading channel:** By the assumption of transmission over a slow fading channel, the coherence time of the channel is large relative to the delay constraint of the channel. The amplitude and phase change imposed by the channel can be considered roughly constant over the period of use. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver. In this regime, the number of encapsulated symbols in a frame gets higher and subsequently increases the bandwidth efficiency. The coherence bandwidth measures the separation in frequency after which two signals will experience uncorrelated fading.

Extra simulations have been carried out to investigate the performance of the system based on MSE-DCT scheme over a slow fading channel. The receiver employs a blind estimation based on a matched filter approach. Figure 6 graphs the detected output simulated error rates versus  $E/N_0$ , to compare and contrast system's behavior with and without a matched filter. The blind detection process with no channel state information results in irreducible error however, DPSK track and predicts the channel response by itself. Though, a matched filter at the receiver results in better performance.

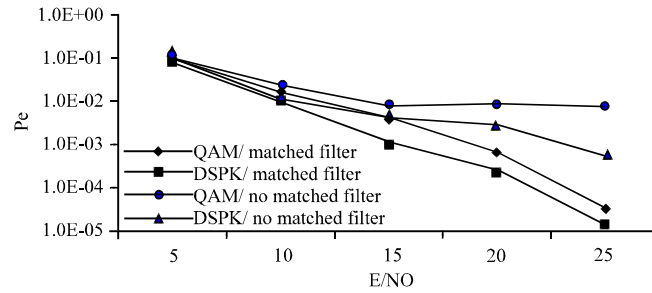


Fig. 6:  $P_e$  in MC scheme based on MSE-DCT over slow fading channel. A matched filter is employed for higher reliable system

## CONCLUSIONS

Extensive computer simulations have been carried out to demonstrate and compare the performance of a new multi-carrier scheme based on MSE-DCT multi-carrier scheme with that of the conventional scheme. A reduction in PAPR and leverage in bandwidth efficiency have been achieved. Performance enhancement of the proposed system has been recorded in the presence of nonlinear distortion due to the reduction in PAPR power of MSE-DCT based signal. It is more flexible to present linear transmission with no compensation of the non-linearity in the system. Moreover, the simulated results concludes that the new scheme with a blind channel estimation based on matched filter concept, performs better compared to the conventional system.

However, the results could be greatly improved to meet the specification requirement that could be implemented in the future to further enhance the simulator, where the results can be extended to any system which uses the MCM technique.

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