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# A PERFORMANCE COMPARISON AND PAPR ANALYSIS OF PRE-CODED WEIGHTED CYCLIC PREFIX OFDM

**Yogita P. Patil[1], Mr.Sayed Shoaib Anwer[2]**
*[1]Research scholar, [2]Assistant professor*
*MGM college of Engineering, Nanded (M.S.), (India)*

## ABSTRACT

*In this paper, we present weighted cyclic prefix orthogonal frequency division multiplexing (WCP-OFDM) as a generalization of traditional cyclic prefix OFDM (CP-OFDM). It allows the use of non-rectangular sub channel pulse shape in order to mitigate interference caused by time frequency selective channels. The precoding step may be required to reduce PAPR at the output of transmitter performance comparison is performed in terms of bit error rate.*

## I INTRODUCTION

Mobile radio applications in terrestrial environment usually imply multipath propagation and motion induced the Doppler spread. However, Doppler spread introduced by time variant channels breaks the orthogonality between sub channels causing inter channel interference [1, P 735]. cyclic prefix orthogonal frequency division multiplexing (CP-OFDM) diagonalizes multipath invariant channels if a guard interval is longer than the channel impulse response.it relies on how complexity implementation using fast fourier transform (FFT) algorithm and it allows perfect reconstruction of the transmitted signal thanks to the single tap per sub channel equalizer.

Filter bank based multicarrier modulations (FBMC) represent a more general transmission scheme. This technique allows the design of various pulse shape filters, as compliant as possible with multipath time variant channel. Despite attractive performances, FBMC systems are rarely recommended in standardized applications because of their computational complexity. Indeed, they require the use of polyphase matrix filtering whose complexity increases with the length of the prototype filters [3].

In this work, we focus on short prototype filters that ensure a low-complexity implementation. Thus, we consider here the case of filters with the same length as rectangular pulses used in CP-OFDM. The difference with CP-OFDM is that the pulses do not need to be rectangular. Such a generalization of CP-OFDM is referred to as weighted cyclic prefix (WCP)-OFDM. The major problem of Orthogonal Frequency Division Multiplexing (OFDM) is its High Peak-to-Average Power Ratio (PAPR). The High PAPR increases the complexity of Analogue to Digital

(A/D) and Digital to Analogue (D/A) converters and also reduces the efficiency of Radio Frequency High Power Amplifier (RF HPA). we present here Discrete Fourier Transform (DFT) pre coder.

In this study, we compare the PAPR of CP-OFDM with a time-frequency optimized WCP-OFDM. We also define a DFT-precoding block which leads to a single carrier (SC) block transmission scheme with frequency domain equalization. We compare the performances of both systems with LDPC channel coding and assuming a time-frequency selective channel.

## II GENERAL FRAMEWORK OF PROPOSED METHOD

We briefly introduce a generalized multicarrier transceiver system through a discrete –time formulation, in order to underline digital implementation.

### 2.1 WCP-OFDM Trans-Multiplexer Structure:

Let $\{c_{m,n}\}\,(m,n) \in \Lambda$ denote a complex symbol sequence which we want to transmit where Λ = {0,……,M-1} X Z. We assume independent and identically distributed symbols. Their average power is given by $\sigma^2$ = E{$|c_{m,n}|^2$}. Each $\{c_{m,n}\}$ is distributed in the time-frequency plane at coordinates ( m/M , nN ) where N is the number of samples per sub-channel symbol period and M represents the number of sub-channels. We call N/M the oversampling ratio. The output of the discrete-time transmitter writes

$$s[k] = \sum_{(m,n)\in\Lambda} c_{m,n}\,\gamma_{m,n}[k], \quad k \in \boldsymbol{Z} \qquad (1)$$

Where $\gamma_{m,n}[k]$ is time frequency shifted version of prototype pulse $\gamma[k]$ is defined as

$$[k] = \frac{1}{\sqrt{M}}\,\gamma[k-nN]e^{j2\pi\frac{m}{M}k}, \quad \gamma[k] \in \boldsymbol{R} \qquad (2)$$

And the complex symbols can be estimated thanks to a projection over demodulation basis

$$\check{\gamma}_{m,n}[k] = \frac{1}{\sqrt{M}}\,\check{\gamma}[k-nN]e^{j2\pi\frac{m}{M}k}, \check{\gamma}[k] \in \boldsymbol{R}\textbf{:}$$

$$\hat{c}_{p,q} = \sum_{k=qN}^{(q+1)N-1} r[k]\check{\gamma}^{*}_{p,q}[k]$$

$$= \frac{1}{\sqrt{M}}\sum_{k=qN}^{(q+1)N-1} r[k]\check{\gamma}^{*}_{p,q}[k-qN]\,e^{-j2\pi\frac{p}{M}k} \qquad (3)$$

where r[k] is the received signal.

The resulting transmission scheme can be efficiently realized with the use of fast algorithm. This is the scheme depicted in Fig. 1 in which we have added an optional precoding step (Q block). Thus, this generalizes the CP-OFDM transceiver by allowing non-rectangular pulse shapes while preserving a low-complexity.

The transmission process consists in a projection of M complex symbols over an exponential basis (IDFT block) after an optional precoding step (Q block). This projection is followed by a cyclic extension of the data block (CP block) defined by the following: if we denote x[k] the entries of CP block, $0 \le k \le M-1$, and y[k], $0 \le k \le N-1$, its outputs, then we have $y[k] = x[2M - N + k]$ for $0 \le k \le M-1$ and $y[k] = x[M - N + k]$ for $N - M \le k \le N - 1$. The resulting N samples are weighted by $\gamma[k]$, $0 \le k \le N-1$. At the receiver side, the dual operation is performed in order to ensure perfect reconstruction (PR) of the transmitted symbols, that is to say $\check{c}_{m,n} = c_{m,n}$ if r[k] = s[k]. In particular, $CP^{-1}$ block is defined by the following: if we denote x[k] the entries of the $CP^{-1}$ block, $0 \le k \le N-1$ and y[k], , $0 \le k \le M-1$, its outputs, then we have $y[k] = x[N - M + k]$ for $0 \le k \le 2M - N - 1$ and $y[k] = x[k-(2M-N)]+x[p-(M-N)]$ for $2M-N \le k \le M-1$.

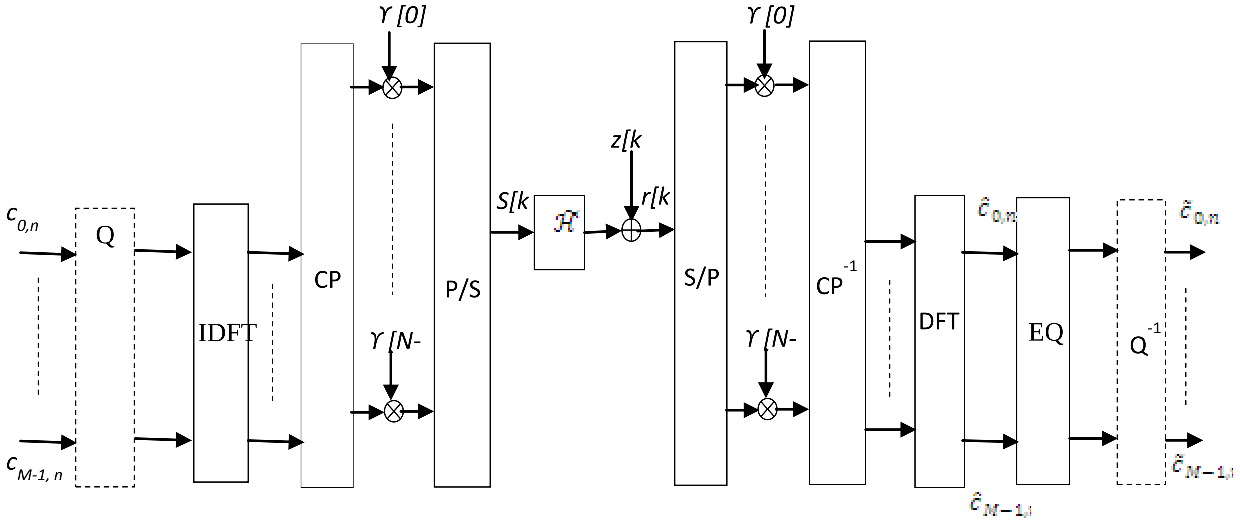


**Fig.1 Precoding WCP-OFDM Trans-multiplexer.**

If the received signal r[k] is equal to the transmitted signal s[k], then the complex symbol $\{c_{m,n}\}\ (m,n) \in \Lambda$ can be exactly reconstructed provided that the following Perfect Reconstruction (PR) conditions are fulfilled:

1. $\gamma[k]\check{\gamma}[k] + \gamma[k+M]\check{\gamma}[k+M] = 1$ for $0 \le k \le N - M - 1$
.

2. $\gamma[k]\check{\gamma}[k] = 1$ for $N - M \le k \le N - 1$.

Through this relation, one may recover the expression of rectangular filters used for CP-OFDM: if $\gamma[k] = 1$ for $0 \le k \le N-1$ and 0 otherwise then PR conditions are satisfied when $\check{\gamma}[k] = 1$ for $N-M \le k \le N-1$ and 0 otherwise. Apart from the cyclic prefix case, PR conditions may be particularized in the linear phase orthogonal case, such that $\gamma[k] = \check{\gamma}[k] = \gamma[N-1-k]$ [1, p. 160]. In this context, the work presented in [4] provides closed-form expressions for optimized prototypes filters. Optimization criteria include time-frequency localization (TFL) maximization. The TFL filter outperforms CP-OFDM in several multipath time-variant environments, using a single-tap per sub-channel equalizer. One may notice that WCP-OFDM offers a good trade-off between complexity and ICI mitigation, unlike more general filtered multitone setups [5].

## 2.2 DFT PRECODED WCP-OFDM AND PAPR ISSUE

A particular precoding technique consists in a simple discrete Fourier transform (DFT) at the transmitter side and an inverse DFT (IDFT) after the equalizer. Thus, the OFDM system becomes equivalent to the Single Carrier (SC) system because the DFT and IDFT operations virtually cancel each other [7]. In this case, the transmit signal will have the same PAPR as in a single-carrier system which results in improvement in PAPR. Multicarrier modulations are characterized by their high peak-to-average power ratio (PAPR) defined by

$$PAPR = \frac{max_{0 \leq t \leq T_0} \{|s(t)|^2\}}{\frac{1}{T_0}\int_0^{T_0} |s(t)|^2 dt} \tag{4}$$

Where $T_0 = {}^{N}/_{B}$ and s(t)= $\sum_k s[k] \mathrm{sinc}(Bt - k)$ and B is transmission bandwidth. Linear power amplification is difficult to achieve in presence of high PAPR. As a consequence, the clipping probability may be estimated thanks to the PAPR complementary cumulative distribution function CCDF = $F_c(PAPR_0) = \ P_r$ {PAPR > $PAPR_0$ }, as presented in Fig. 2. Since the TFL pulse exhibits a non-constant impulse response, the overlying transmission scheme experiences a greater PAPR than traditional rectangular filters (CP) [6].

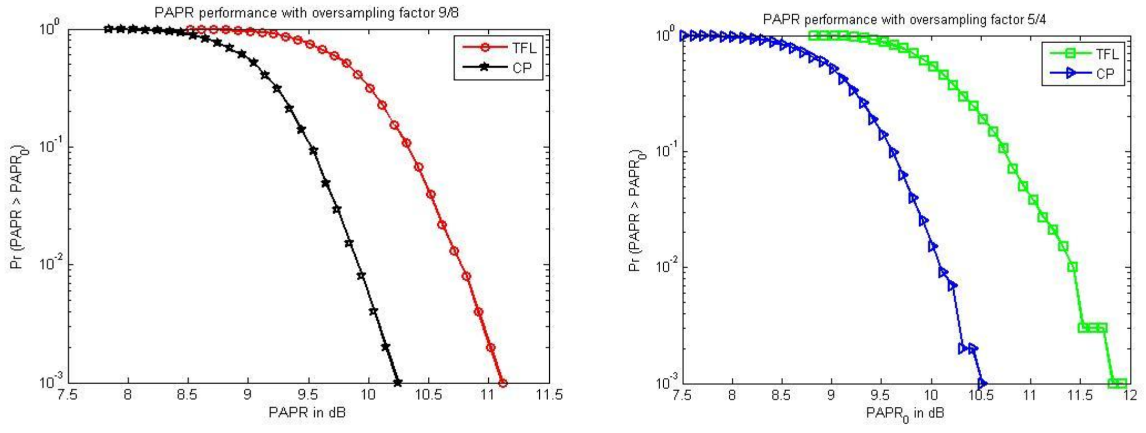
A large number of PAPR reduction techniques have been proposed in the many literatures. Among them, schemes like constellation shaping, coding schemes, phase optimization, nonlinear companding transforms, Tone Reservation (TR) and Tone Injection (TI), clipping and filtering, Partial Transmit Sequence (PTS), Precoding based Selected Mapping (PSLM), precoding based techniques and Selected Mapping (SLM) are popular. However, the techniques listed above may either distort the pulse shapes, require extra transmission power decrease the spectral efficiency and they often bring prohibitive computational complexity [8].

DFT precoding followed by IDFT leads to an equivalent SC modulation without precoding nor IDFT. CP-OFDM and SC-FDE have been compared in several studies [9]–[10]. Obviously, it turns out that SC-FDE has a lower PAPR than CP-OFDM. However, multicarrier modulations allow a per sub-channel bit-loading and power allocation, leading to better throughput than single carrier modulations for a given bit-error-rate (BER). We also notice that CP-OFDM remains sensitive to frequency offsets such as Doppler shifts.

## III SIMULATIONS

### BER PERFORMACE

In this simulation framework, we consider a land mobile transmission system, using a band B = 8 MHz, centered around a frequency fc = 1 GHz. We assume that the transmission takes place in an outdoor urban environment. Such a propagation may be fitted by a 6-path WSSUS channel model where the last path occurs at 5 s (COST 207



(a)$N/M = 9/8$

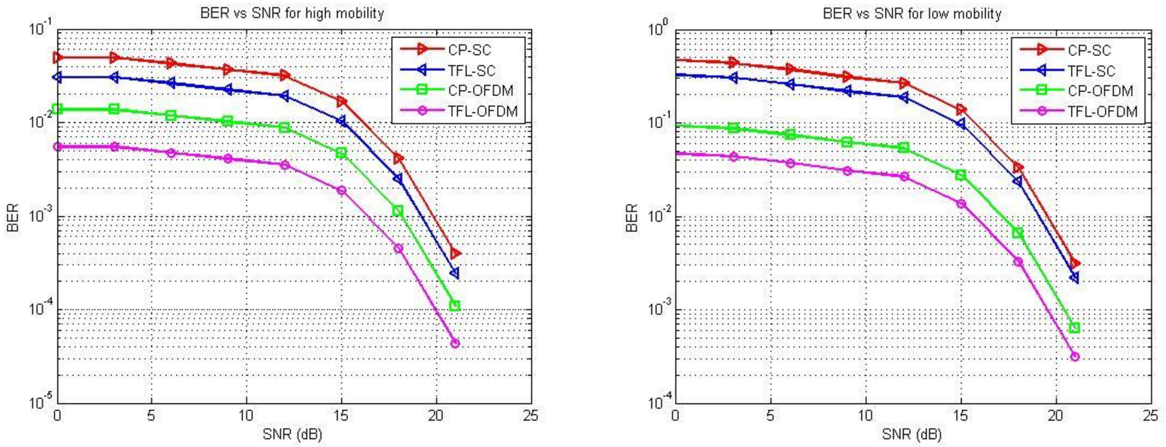
(b)$N/M = 5/4$

**Fig. 2: PAPR CCDF for M = 1024 and $N/M \in \{9/8, 5/4\}$ for cyclic prefix and time-frequency localized pulses in a multicarrier transmission scheme.**

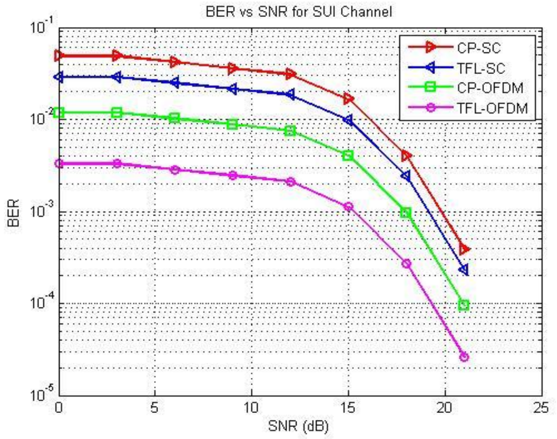
TUx6[11]) and SUI channel and whose impulse response is truncated to L = 45 coefficients. Two mobility scenarios are developed with regard to the fast fading assumption: Pedestrian, (low speed) with $v_{max} = 3km/h$ and Vehicular, (high speed) with $v_{max} = 350 km/h$.

At the transmitter side, the low-density parity check (LDPC) encoder uses 32400 bit code words and operates at coding rate $R_c = {}^3/_4$. Each code word is randomly interleaved and split into 8 data blocks of M = 2048 quadrature phase shift keying (QPSK) symbols. The oversampling factor is set to ${}^N/_M = {}^5/_4$ so that a transmitted block is made of N = 2560 symbols. We consider that each block is transmitted over independent channel realizations in order to ensure the best diversity scenario. In practice, symbols should be spaced by a period greater than the coherence time of the channel. In a similar way, sub-channels should be spaced by a band greater than the coherence bandwidth of the channel. Unfortunately, these requirements are usually difficult to achieve, considering various application constraints (e.g. spectral efficiency, interactivity, medium access control).

At the receiver side, a single-tap per sub-channel equalizer is used. After the deinterleaver, a LDPC decoder performs 10 iterations over each codeword without parity check. We compare the performances of WCP-OFDM with or without DFT-precoding. In the first case, the transmission system leads to a single carrier (SC) block scheme. In the second case, the system leads to a regular multicarrier (OFDM). For both precoding strategies the transmitter and the receiver are provided with rectangular biorthogonal prototypes (CP) and time-frequency optimized orthogonal prototypes (TFL).



(a) BER performances in high mobility scenario. (b) BER performances in low mobility scenario.



(c) BER performances in SUI channel model

**Fig. 3: BER performances for pedestrian and vehicular scenarios in a COST 207 Tux6 channel and SUI channel.**

Comparison between CP-OFDM and WCP-OFDM(with TFL pulses) for M = 2048 and ${}^{N}/_{M} = {}^{5}/_{4}$ .

Bit error- rate (BER) is plotted as a function of $E_b/N_0$, where $E_b = {}^{N\sigma_c^2}/_{2MB}$ And $N_0 = {}^{\sigma_z^2}/_{B}$ (Fig.3)

## IV CONCLUSION

we show that the time-frequency localized pulse yields better results than the rectangular pulse. Since the TFL impulse response shows smooth transitions, it justifies a low IBI term and the large number of sub-channel ensures a sufficient partitioning of the band B. For high values of $E_b/N_0$, the difference between the BER experienced by CP and TFL pulses tends to increase with the time selectivity of the channel. It confirms the interest of a time-localized pulse in such a scenario.

Even if time-frequency localized pulses yield interesting BER performances in time-frequency selective channels, they also introduce a greater PAPR than rectangular pulses, increasing with the oversampling factor. In order to mitigate the PAPR, a DFT-precoding may be used, leading to a single carrier block transmission scheme. And different channels also used like COST 207 Tux6 channel and SUI channel.

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