RESEARCH ARTICLE OPEN ACCESS

Impact of Initialization shapes on the Performance ofWaveform Optimization

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ABSTRACT
This paper aims to examine the effect of initialization for the shape of waveform that can be used in multicarrier systems such asOrthogonal Frequency-Division Multiplexing (OFDM) and Filter Bank Multi-Carrier (FBMC)for waveform optimization task.For the waveform optimization, we have investigated the recently developedPing-pong Optimized Pulse Shaping (POPS) algorithm which maximizes the outputsignal-to-interference-plus-noise ratio(SINR) by adapting both transmitter and receiver waveforms. We have examined various kinds of waveform prototypes such asPHYDYAS, Hermite, root-raised-cosine (RRC) and rectangular. The performance of these waveforms is compared in terms of SINR.

***Keywords*-**OFDM, FBMC, Optimization, Waveform, Multicarrier Systems

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Date of Submission: 01-06-2018 Date of acceptance:16-06-2018

I. INTRODUCTION

There are several blessings of the OFDM approach, many analysis studies highlighted a collection of drawbacks of the OFDM transmission, together with in the main the spectral leakage of Digital Fourier Transform (DFT)-based OFDM systems [1] which will lead to a crucial interference level through the OFDM subcarriers, awareness to carrier frequency offsets and also constrained bandwidth efficiency due to connexion of Cyclic Prefix (CP) used for the channel equalization within the frequency domain. However, the OFDM approach expeditiously solves the matter of the frequency selective weakening channel by the mean of low-complexity equalizers [2] and this will represent a vital side within the case of highly frequency selective channels [3]. Contrary to high mobility situations that are ordinarily envisaged for next Fifth Generation (5G) of mobile communication systems, the wireless propagation channel is time-frequency variant wherever the time dispersion emerges from the multipath characteristic and the time selectivity arises from the Doppler spread that damages the orthogonality iatrogenic within the OFDM signal and consequently leads to oppressive Inter-Carrier Interference (ICI). [4]

Another serious multiple radio access candidate under consideration for 5G is Filter Bank Multi-Carrier (FBMC) [5]. it's several benefits over OFDM, such as having far better management of the out-of-band radiations owing to the frequency localized shaping pulses [6]. This theme discards the conception of CP and depends on a per-subcarrier feat to combat ISI and thus improves the spectral efficiency. However, the low latency necessities aren't warranted by FBMC owing to the employment of long filter lengths [7], additionally to not guaranteed hardiness to time synchronization imperfections. Moreover, a Universal Filtered Multi-Carrier (UFMC) approach was introduced as an alternative to OFDM [8] wherever a filtering operation is applied to a bunch of consecutive subcarriers to reduce the OOB emissions. Here too, UFMC doesn't need the employment of CP which makes UFMC a lot of sensitive to tiny time placement than CPOFDM. Hence, it will not be appropriate for applications which require a relaxed time/frequency synchronization necessity.

On other hand, novel efficient algorithms focus on design of the OFDM used waveforms for multicarrier systems of the Orthogonal Frequency Division Multiplexing (OFDM) based systems. potentially reduce the system Inter-Carrier Interference (ICI)/Inter-Symbol Interference (ISI) and maximizes the received Signal to Interference plus Noise Ratio (SINR) for realistic mobile radio channels at both the Transmitter (Tx) and the Receiver (Rx) sides and waveforms are adapted to the channel propagation conditions through a maximization step of the Signal to Interference plus Noise Ratio (SINR), deduce the OFDM optimized waveforms that should be used at the transmitter and the receiver sides. flexibility to non-orthogonal multicarrier schemes its advantage plus simplicity of their implementation. [4]

Furthermore, by 2020, Internet of Things (IoT) and the Machine Type Communication (MTC) will be one of key communication which use small data packets [9] and that will result in oppressive Inter-Carrier Interference (ICI) and Inter-Symbol Interference (ISI), which leads to significant performance degradation in OFDM systems. POPS-OFDM for different Tx/Rx pulse shape durations was proposed that efficiently reduces the ISI and ICI and also minimizes the energy spreading offer a spectacular reduction in terms of out-of-band (OOB) spectrum leakage [10, 11].

An optimum waveform designed for multicarrier transmissions over rapidly time-varying and strongly delay-spread channels. and a novel optimizing algorithm for the transmitter and receiver waveforms is planned. The optimized waveforms offer a neat reduction in ICI/ISI and guarantee greatest SINRs for realistic mobile radio channels. additionally, to it, POPSOFDM waveforms offer 6 orders of magnitude reduction in out-of-band emissions and reveal an excellent strength to synchronization errors. Simulation results incontestable the wonderful performance of the planned solutions and highlighted the property of the efficient reduction of the spectral leakage obtained through the optimized waveforms. To test the robustness of the POPS algorithm, we evaluated its sensitivity to time and frequency synchronization and also to the initialization parameters. The obtained results showed the good performance of our waveforms optimization algorithm even in high mobility propagation channels. As such, the solutions can be seen as an attractive candidate for the optimization of the spectrum allocation in 5G systems. A possible challenging research axis consists in extending the optimization for the OQAM/OFDM systems [12]. Another interesting perspective can be investigated such that the design of OFDM pulse shapes optimized for partial equalization, for carrier aggregation and for a lower latency, with tolerant to bursty communications with relaxed synchronization [10, 13, 14].

Section 2 presents the system model. In Section 3, we present the SINR analysis and its optimization. Simulation results are provided in Section 4. Lastly, conclusion is drawn along with future direction in Section 5.

Notation: The boldface lower case letters denote vectors and the boldface upper case letters refer to matrices. The superscripts $.^{\mathbf{T}}$ and $.^{*}$, denote the transpose and the element-wise conjugation, respectively. In addition, **I**denotes the identity matrix with ones in the main diagonal and zeros elsewhere.

II. SYSTEM MODEL

T represents the OFDM symbol duration and F represent the frequency separation between two adjacent subcarriers. Let $a_{m,n}$, m, n ∈ Z, be the transmitted symbol at time *n*T using subcarrier *m*F and assumed to be independent identically distributed (i.i.d.) with zero mean and energy equal to E. The baseband transmitted signal is shown by the following summation:

$$e(t) = \sum_{m,n} a_{mn} \varphi_{mn}(t), \tag{1}$$

where $\varphi_{m,n}$ denotes the time and frequency shifted version of the OFDM transmitter prototype waveform.Assuming a linear time-varying multipath channel h(p,q) with q and p standing respectively for the normalized observation time and the time delay, the received signal has the following expression:

$$\begin{aligned} r_q &= \sum_{m,n} a_{mn} \sum_{p} h(p,q) [\varphi_{mn}]_{q-p} + n_q \\ &= \sum_{m,n} a_{mn} [\tilde{\varphi}_{mn}]_{q-p} + n_q, \end{aligned} \tag{2}$$

where nq is additive noise. to simplify the derivations, we presume a channel with a finite path number, K, with the following channel impulse response:

$$h(p,q) = \sum_{k=0}^{K-1} h_k e^{j2\pi\nu_k T_s q} \delta_K(p - p_k), \tag{3}$$

where h_k, ν_k and p_k are respectively the amplitude, Doppler frequency and the time delay of the kth path. The paths amplitudes h_k are assumed to be i.i.d. complex Gaussian variables with zero mean.This scattering function obeys to the Jakes model that is decoupled from the dispersion in the time domain denoted β(p) This means that scattering function S(p,v)= β(p)α(v) such that

$$\alpha(\nu) = \begin{cases} \frac{1}{\pi B_d} \frac{1}{\sqrt{1-(\frac{2\nu}{B_d})^2}} & \text{if } |\nu| < \frac{B_d}{2} \\ 0 & \text{if } \frac{B_d}{2} \le |\nu| \le \frac{1}{2T_s} \end{cases} \tag{4}$$

III. SINR ANALYSIS AND OPTIMIZATION

In this analysis we consider power as measurement of the previous system model, we can see the average power of the useful terms is represented by

$$P_S = E \boldsymbol{\Psi}^H \mathbf{K} \mathbf{S}^{\varphi}_{S(p,\nu)} \boldsymbol{\Psi} \tag{5}$$

and the mean power of interference over channel realizations is given by

$$P_I = E \boldsymbol{\Psi}^H \mathbf{K} \mathbf{I}^{\varphi}_{S(p,\nu)} \boldsymbol{\Psi} \tag{6}$$

and the noise average power is given by

$$P_N = \mathbb{E}[|\langle \boldsymbol{\Psi}_{00}, \boldsymbol{n}\rangle|^2] \\ = \boldsymbol{\Psi}_{00}^H \mathbb{E}[\mathbf{nn}^H]\boldsymbol{\Psi}_{00}^H \quad (7)$$

since the noise is assumed to be white and colored. therefore its covariance matrix is equal to $\mathbf{R}_{a,b}$=$\mathbf{E[nn^H]}$ for colored noise where $\mathbf{R}_{a,b}=\mu^{|a-b|}$ and $0 < \mu < 1$ however for white noise its covariance matrix is equal to $\mathbf{R}_{nn}$=$\mathbf{E[nn^H]}$=$N_0\mathbf{I}$. Consequently, as the prototypes are of unitary energy, then $P_N = N_0$.Using the obtained expressions of the useful power P_S, the interference power P_I and the noise power N_0 of the white noise, the SINR has the following expression:

$$SINR = \frac{P_S}{P_I + P_N} = \frac{\boldsymbol{\Psi}^H \mathbf{KS}^{\varphi}_{S(p,\nu)}\boldsymbol{\Psi}}{\boldsymbol{\Psi}^H \mathbf{KI}^{\varphi}_{S(p,\nu)}\boldsymbol{\Psi} + \frac{N_0}{E}} \quad (8)$$

The main goal of this algorithm maximizes the SINR at particular SNR value through determining the couple (φ, Ψ). Firstly, we should choose the Lagrange multiplier, we apply a derivation of the SINR that contains the transmitted or receiver prototype. Then we do the same for the auxiliary functions and we make an identification of the obtained terms. Finally, the gradient of the SINR with respect to Ψ is represented as below:

$$\frac{\partial SINR}{\partial \boldsymbol{\Psi}} = \frac{-2\boldsymbol{\Psi}^H \mathbf{KS}^{\varphi}_{S(p,\nu)}\boldsymbol{\Psi}}{(\boldsymbol{\Psi}^H \mathbf{KI}^{\varphi}_{S(p,\nu)}\boldsymbol{\Psi} + \frac{N_0}{E})^2}(\mathbf{KI}^{\varphi}_{S(p,\nu)}\boldsymbol{\Psi} - \frac{1}{SINR}\mathbf{KS}^{\varphi}_{S(p,\nu)}\boldsymbol{\Psi}). \quad (9)$$

The vector $\boldsymbol{\Psi}$ most important to the optimum SINR, i.e.

$$\mathbf{KI}^{\varphi}_{S(p,\nu)}\boldsymbol{\Psi} - \frac{1}{SINR}\mathbf{KS}^{\varphi}_{S(p,\nu)}\boldsymbol{\Psi} = 0. \quad (10)$$

Referring to expression (10), the Lagrange multiplier $\boldsymbol{\lambda}$ should be equal to the inverse of the SINR. The optimization problem could be solved by the general eigenvalue problem (GEP), since we have to solve (10). As our object is to maximize the SINR and as $1/\boldsymbol{\lambda}$ is an eigenvalue of (**KI**, **KS**) in expression (9), the optimum value $\boldsymbol{\lambda}_{opt}=1/SINR_{max}$ corresponds to its maximum eigenvalue in order to meet our expectations. It results that $\boldsymbol{\Psi}_{opt}$ is the eigenvector associated to the eigenvalue $\boldsymbol{\lambda}_{opt}$of the GEP (**KI**, **KS**). (see Algorithm 1 [4]). We are coming up with a Lagrange multiplier evaluation that can be characterized as a direct, simple and streamlined approach.

<u>*Algorithm 1 of [4]*</u>

Require: channel parameters $(K, p_k, \nu_k, h_k, T_s)$, $\varphi^{(0)}$, ϵ, $\boldsymbol{\Psi}^{(0)} = 0$, $e^{(\boldsymbol{\Psi})} = e^{(\boldsymbol{\varphi})} = 2$, $k = 0$, SNR
Compute $\mathbf{KS}^{\varphi^{(0)}}_{S(p,\nu)}$ and $\mathbf{KI}^{\varphi^{(0)}}_{S(p,\nu)}$
while $e^{(\boldsymbol{\Psi})} > \epsilon$ or $e^{(\boldsymbol{\varphi})} > \epsilon$ **do**
$\lambda = eig(\mathbf{KS}^{\varphi^{(k)}}_{S(p,\nu)}, \mathbf{KI}^{\varphi^{(k)}}_{S(p,\nu)})$
$k \leftarrow k+1$
$\boldsymbol{\Psi}^{(k)}$ eigenvector associated to λ_{max}
Evaluate $\mathbf{KI}^{\boldsymbol{\Psi}^{(k)}}_{S(-p,-\nu)}$ and $\mathbf{KS}^{\boldsymbol{\Psi}^{(k)}}_{S(-p,-\nu)}$
$\nu = eig(\mathbf{KS}^{\boldsymbol{\Psi}^{(k)}}_{S(-p,-\nu)}, \mathbf{KI}^{\boldsymbol{\Psi}^{(k)}}_{S(-p,-\nu)})$
$\varphi^{(k)}$ eigenvector associated to ν_{max}
Evaluate errors: $e^{(\boldsymbol{\Psi})} = \|\boldsymbol{\Psi}^{(k+1)} - \boldsymbol{\Psi}^{(k)}\|$ and $e^{(\boldsymbol{\varphi})} = \|\varphi^{(k+1)} - \varphi^{(k)}\|$
end while

IV. RESULTS AND DISCUSSION

We provide simulation results and study the performance of multicarrier system in terms of SINR. The performance evaluation is carried out by varying the different parameter such Q=128, SNR=30dB, BdTm=10-3 and D=1. Firstly, we examine various initial shapes of φ and Ψ included four prototypes. Case 1 uses PHYDYAS prototype whereas case 2 use RRC prototype and Hermite in case 3. However, case 4 use rectangular as shown in figure 1 and 2. It is noticeable thatrectangular shape has sharpest edge unlike another shape and its power in frequency domain has highest value compared to others. However lowest value has been reached through using PHYDYAS prototype as shown in figure 2. A dramatic increase in SINR for both conventional and optimized waveforms from 0.02 to 0.1 Bd/F after than it slightly decreasing. For given parameters, SINR reach its peak in 0.11 Bd/F under both noise effect white and colored. For instance, we gain more than 1.5 dB at 0.12 Bd/F and almost 1 dB at 0.08 Bd/F if we compare between conventional and optimized waveform as shown in figure 3. In figure 4, the plot shows the effect of colored noise on the system and we can see the performance degraded by less than 10% of performance with considering white noise.

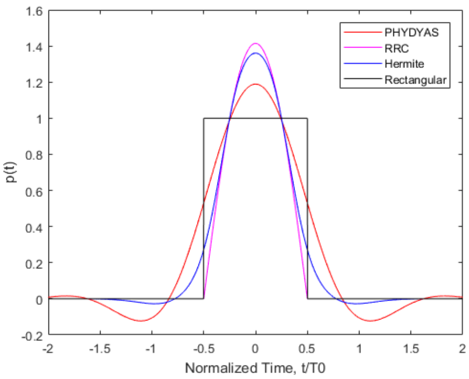

Figure 1. Shapes of initial $\boldsymbol{\varphi}$ and $\boldsymbol{\Psi}$ in time domain

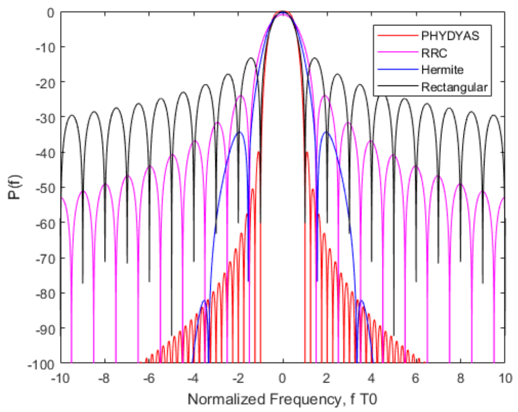

Figure 2. Shapes of initial **φ** and **Ψ** in frequency domain

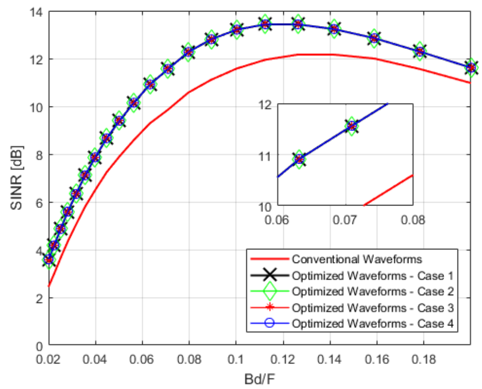

Figure 3. Optimized SINR of Bd/F with white noise effect (Q=128, SNR=30dB, BdTm=10-3 and D=1)

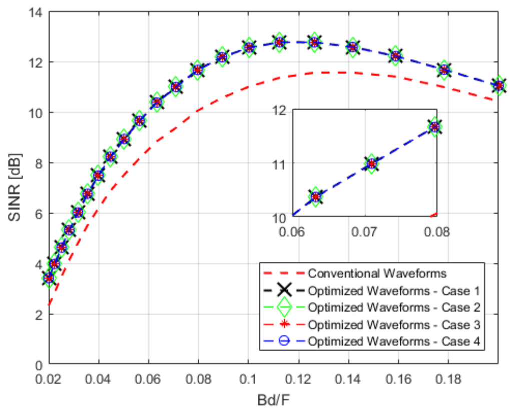

Figure 4. Optimized SINR of Bd/F with colored noise effect (Q=128, SNR=30dB, BdTm=10-3 and D=1)

V. CONCLUSION

In this paper, we have examined the performance of multicarrier systems for various kinds of waveform prototypes such as PHYDYAS, Hermite, RRC and rectangular in term of SINR through applyingPOPS algorithm. The performance is improved whatever the initial shape of waveform either under white noise or colored noise effects. All improved results are exactly same. POPS algorithm capable to optimize the performance by 1dB whatever shape of waveform to get optimum performance. A possible challenging research extends the optimization on MIMO system.

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Mohamed Alshoubaki "Impact of Initialization shapes on the Performance ofWaveform Optimization "International Journal of Engineering Research and Applications (IJERA) , vol. 8, no.6, 2018, pp.65-69