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PERFORMANCE EVALUATION OF ORTHOGONAL WAVELET DIVISION MULTIPLEX FOR 5G AND BEYOND

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Abstract:

Waveform design for 5G New Radio (NR) must meet certain requirements as defined by the International Telecommunications Union (ITU). As a result, many waveforms have been proposed. The major ingredient in these proposed waveforms is the Fourier transform. i.e. the Fourier transform based Orthogonal Frequency Division Multiplex (OFDM). On the other hand, the proposition of wavelet use in OFDM is gaining momentum. A lot of research has proposed the wavelet transform based OFDM as a better replacement for the Fourier transform due to its properties such as localization in both time and frequency. In this paper, wavelet performance is explored and weighed against three of the future wireless application systems requirements (5G and beyond). These three requirements are lower Bit Error Rate (BER), high energy efficiency and immunity to Carrier Frequency Offset (CFO). The results presented here are sufficient to serve as a guideline on wavelet use in 5G, on how to make careful trade-offs, and as well as the guide for further developments.

Keywords:

OFDM; OWDM; Wavelet; 5G; BER; CFO; PAPR

1. Introduction

The demand for more efficient wireless communication is on the increase. Therefore, there is need for continuous exploration of methods and technologies to cope with the demand. Recently, the International Telecommunications Union (ITU) has defined the expectations for 5G. These expectations are not limited to multi-Gigabit-per-second (Gbps) data rates [1], low latency, high spectral efficiency, high mobility, and high connection density. This calls for more research.

Up till now, OFDM remains the ingredient in waveform design for many multi-carrier wireless communication schemes. This is because of its resilience to selective fading, interference and multipath effects, as well as bandwidth efficiency [2]. However, the Fourier based waveform scheme suffers from low spectral efficiency due to the use of Cyclic Prefix (CP), high Peak to Average Power Ratio (PAPR), and sensitivity to carrier offset and drift. To mitigate these downsides, the Discrete Wavelet Transform (DWT) based signal coding was introduced in [3]. More of these researches are found in [4-6]. The 3rd Generation Partnership Project (3GPP) group has selected CP-OFDM (a holdover from 4G) as the signaling option for 5G for the 3GPP's Release 15. Therefore, we compared OWDM to CP-OFDM using MATLAB and propose a guideline on how to approach OWDM application in 5G and beyond.

2. Literature Review

2.1. OFDM System Model

OFDM is the most popular multicarrier modulation scheme that is currently being employed in many standards such as the downlink of 4G LTE and IEEE 802.11 family [7]. In an OFDM system, at the transmitter, data to be transmitted are mapped to constellation. Then they are split into parallel and modulated using the Inverse Fast Fourier Transform (IFFT). Guard band and Cyclic Prefix (CP) are inserted to prevent delayed version of a symbol overlapping with the adjacent symbol. The orthogonal signals are then mixed. The key process here is modulation, where signals are mapped from frequency domain to time domain and multiplexed. The multiplexed OFDM symbol is described mathematically in equation (1).

$$s_{OFDM}[k] = \sum_{n=0}^{N-1} d_n e^{j\frac{2\pi kn}{N}} \quad (1)$$

Where d_n is the complex data symbol at subcarrier n, and N is the number of subcarriers.

After modulation, the CP is added by copying the last part of the modulated IFFT signal and appending it to the beginning as a guard interval to prevent Inter-Symbol Interference (ISI). In 4G LTE system, the CP is hard-coded

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into the waveform while for 5G NR, the CP is determined by the maximum delay present in individual channel.

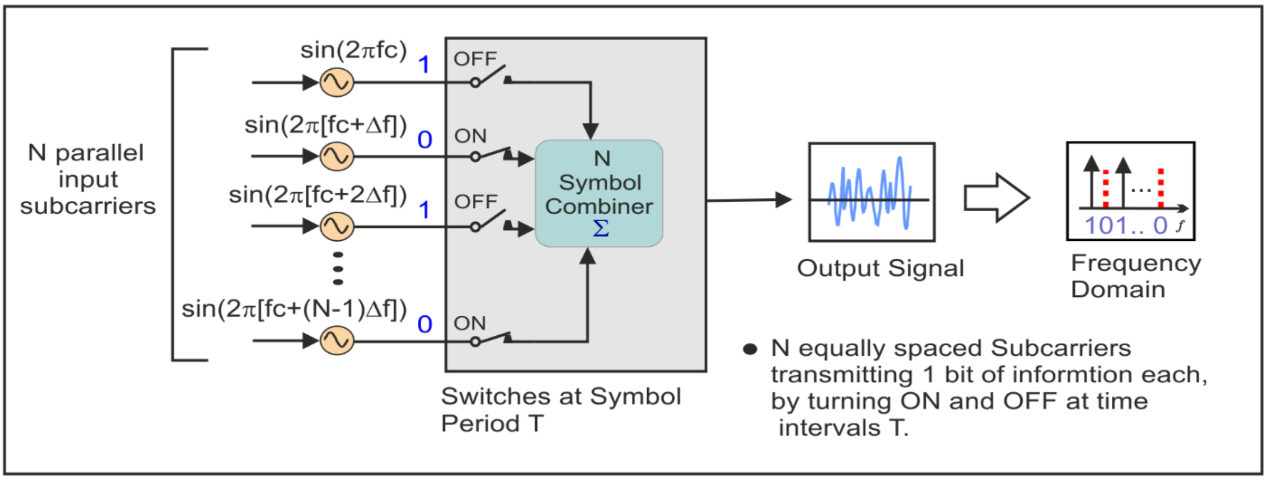

Fig.1 OFDM signal generation process model

At the receiver, the transmitting process is reversed to decode the received data. For demodulation, Fast Fourier Transform (FFT) is employed. OFDM, as opposed to a single carrier system, has the ability to cope with frequency selective fading because data are divided and transmitted in parallel streams on a modulated set of subcarriers. This approach results in an efficient use of bandwidth.

2.2. OWDM System Model

The use of wavelet as the transform replacement for Fourier in OFDM is known as Wavelet-OFDM or Orthogonal Wavelet Division Multiplexing (OWDM). This replacement is due to its properties like orthonormality, and the ability to decompose signals effectively in the time-frequencies domains by scaling and shifting. In DWT, the scaling (j) and shifting (k) results are generated by the mother wavelet denoted by Ψ(t).

$$\Psi_{J,K}(t) = 2^{-\frac{j}{2}}\Psi(2^{-j}t - k) \qquad (2)$$

Where $\Psi_{(J,\ K)}$ is the mother wavelet. Therefore, OWDM symbol can be expressed as the weighted sum of wavelet and scale carriers:

$$s(t) = \sum_{j\leq J}.\sum_{k} w_{j,k}(t).\Psi_{j,k}(t) + \sum_{k} a_{j,k}.\emptyset_{J,k}(t) \qquad (3)$$

$w_{j,k}$ is the sequence of wavelet and $a_{J,k}$ is the approximation coefficients. The OWDM transmission and reception concept is the same with the OFDM, however, the modulation process is different. It makes use of IDWT for modulation and DWT for demodulation. fig.2 highlights this.

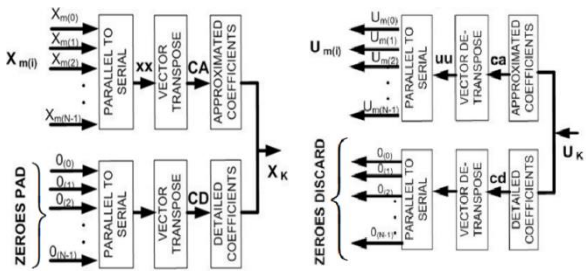

Fig.2 OWDM transmitter and receiver models

At the receiver, the modulation process is simply reversed to decode the received data. The received data is decomposed back into *ca* and *cd* using the LPF and HPF respectively. *cd* contains noise, so it is discarded while *ca* is processed for data recovery. In this paper, for our analysis, we considered Haar, Daubechies (DB2), Biorthogonal (Bior5.5) and Symlet (Sym4) wavelet transforms.

3. Simulation Results and Analysis

Here, a greyscale image of size 800 x800 of 8 bits dept is fed into the MATLAB simulator as a test data. In total, the image has 5,120,000 bits, which is enough for our simulation. The simulation parameters for the OFDM and OWDM are shown together in table 1

Table 1 Simulation parameters for OFDM and OWDM

Modulation	QPSK
FFT size	1024
Number of Subcarrier	128
CP length	16
SNR range	1db – 10db
Channel	AWGN
Frequency offset	0.1KHz
Wavelet transforms	Biorthogonal 5.5, Haar, Symlet4 and Daubechies4

3.1. BER Performance Analysis

Here we present the BER versus SNR plot for each candidate, and also images qualities at varied SNR. An AWGN channel is assumed. From the graphical result, the Fourier OFDM image output at SNR of 1 has a higher rate of distortion. Also the performance disparity between the wavelet and Fourier transforms increases with SNR.

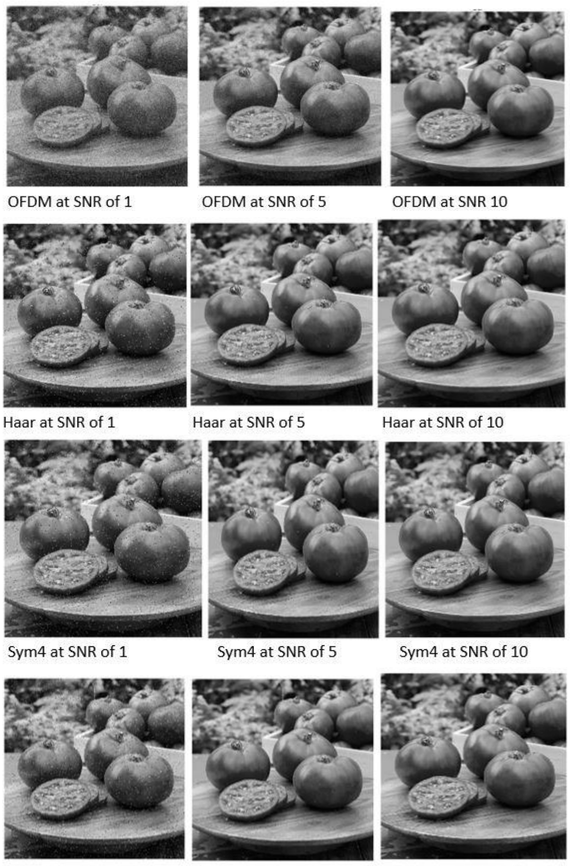

Fig.3 Received images at SNR 1dB, 5dB and 10Db

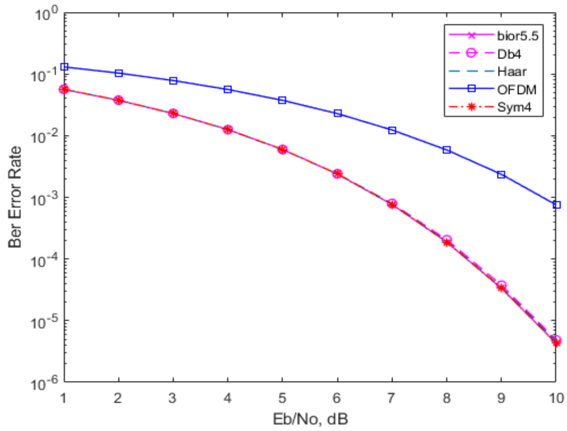

Fig.4 BER performance comparison of the various transforms in AWGN channel

3.2. PAPR Performance Analysis

The PAPR is one of the Key Performance Indicators of a wireless communication system. PAPR evaluation goes a long way in shaping the design of the power amplifier's level of linearity and therefore its cost. PAPR is evaluated by computing the Complementary Cumulative Distribution Function (CCDF) of the waveform with respect to the number of subcarriers and constellation order. The plot of the received PAPR against a varied SNR is shown in fig.5.for the Fourier-OFDM and the Wavelets OWDM. At reception, under varied SNR of 1dB to 10dB, all the wavelet variants have better and distinct PAPR performance than the OFDM with Haar wavelet having the best performance. We plotted the received PAPR at various SNR.

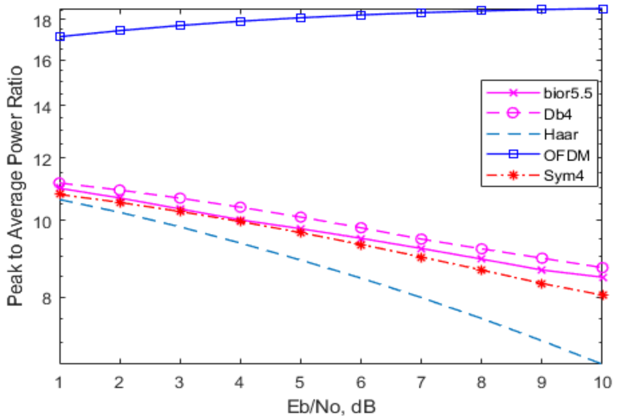

Fig.5 PAPR at reception of 1dB to 10dB

3.3. Effect of carrier Frequency Analysis

CFO is the multiplication of a signal in time domain by a time varying complex exponential function. When CFO happens, it causes the receiver signal to be shifted in frequency. Therefore, sampling of the received signal will be done at an offset point, which is not the peak point. The result is a raised InterCarrier Interference (ICI) [8].

In fig.6, we present the BER curve at CFO = 0.1KHz. The simulation result in fig.6 shows that OFDM suffers the most effect from CFO while harr incurs the least effect. Also, it is observed that the performance disparity between the transforms increases roughly with SNR.

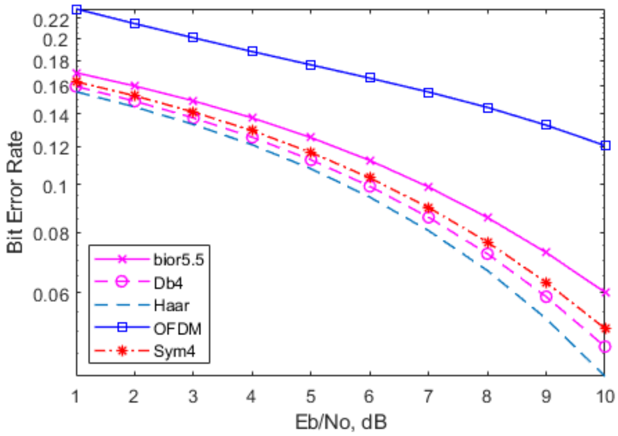

Fig.6 CFO effect on the various transforms at 1dB to 10dB.

4. OFDM and OWDM performance assessment

Here, we weigh some of the requirements needed by the future wireless system against the performance of the Fourier OFDM and the various wavelets OWDM. We take the 5G New Radio (NR) set standards into consideration. These comparisons are outlined here as discussed in [9]. Three of these requirements are:

- High Energy Efficiency: Low PAPR provides high energy efficiency. Also, low PAPR is required to operate transceivers power amplifiers efficiently. OFDM has a high PAPR compared to OWDM, this is a disadvantage and a concern to researchers.
- High Reliability: Reliability is evaluated by BER. Some applications are error sensitive and more so considerable amounts of errors might lead to an increase in latency. OWDM has a lower BER than OFDM and also does not need CP.
- Massive Asynchronous Transmission: The massive Machine Type Communications (mMTC) class of 5G NR requires a huge number of nodes to communicate over the 5G network as this will form the basis for IoT. Therefore, waveforms with strict synchronization requirements are not suitable for mMTC applications. One of OWDM properties is that it is well localized in time and frequency. fig.6 shows that it is more immune to CFO effect than OFDM. Therefore, it has a relaxed synchronization scheme and therefore preferred in this regard.

5. Conclusions

Wireless system designers understand that a good waveform design will play a key role in meeting up or exceeding the future wireless application requirements. Up until now, the waveforms proposed for the 5G NR are based on Fourier transforms, therefore, there is the need for continuous explorations of other solutions. One of those solutions is the OWDM. The results presented in this paper provides insight into the consideration of OWDM for 5G NR and beyond. This has been achieved by characterizing its pros and cons with respect to the future wireless system design criteria. Therefore, better-informed decisions and trade-offs can be made on future selection and development of the right candidate (Fourier or wavelet) for the future wireless communication system. In the future, we will extend this research to hardware implementation.

Acknowledgements

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