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Symbol Error Rate Calculation for Generalized Frequency Division Multiplexing in 5G Wireless Communication Systems

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Abstract**—***Current cellular systems of the fourth generation (4G) are not able to meet the emerging demands such as higher data rates, very low-latency transmissions and sensors with ultra-low-power consumption for future mobile communication systems. To address these requirements, Generalized frequency division multiplexing (GFDM), a novel new multi-carrier modulation technique that can be seen as a generalization of traditional Orthogonal frequency division multiplexing (OFDM) is proposed .The purpose of this paper is to study the performance of symbol error rate (SER) expressions of GFDM in some frequency selective channels. A GFDM transceiver simulation test bed with two type of receiver-zero forcing receiver and matched filter receiver show how the SER is reduced with increasing SNR for GFDM and compare to the SER of OFDM .The finding of this paper is that the performance of SER of GFDM with respect to SER is better than that of OFDM. With such performance GFDM can be a reliable technique for next generation of wireless communication*.

Keywords**—** *GFDM; SER; SNR; OFDM; FFT; ICI; ISI; ZF; MF.*

I. INTRODUCTION

Currently we are in a phase which is surrounded or going to be surrounded with 4G network. However, the trend of present time always demands high. Research on the future generation already started a few years ago. Almost every company and institutions in the sector is under the process of conceiving and studying different ideas to cope with the requisites foreseen for the fifth generation (5G), expected to come around 2020. To full fill the requirements of 5G, multicarrier modulation scheme like OFDM, GFDM are preferred. OFDM is an efficient technique widely used in wireless and many modem communications .However, it has some disadvantages like: Sensitivity in ICI and a high PAPR [1]; ISI (Inter- Symbol Interference) [2] etc. in an effort to improve these disadvantages, various techniques have been proposed. GFDM, a flexible multi-carrier modulation technique is proposed to satisfy the future needs of fifth generation technology [4]. GFDM is a non-orthogonal multi carrier scheme that provides flexible pulse shaping [5]. GFDM is a promising solution for the 5G PHY layer and real-time applications because its flexibility can address the different requirements [7] [8].

GFDM is different from OFDM in that there can be more than one time slot in a GFDM symbol, whereas there is only one in OFDM. To illustrate this, an OFDM frame consisting of three OFDM symbols and a GFDM frame consisting of M “ 3 time slots with K subcarriers is presented in Fig. 1 and Fig. 2.

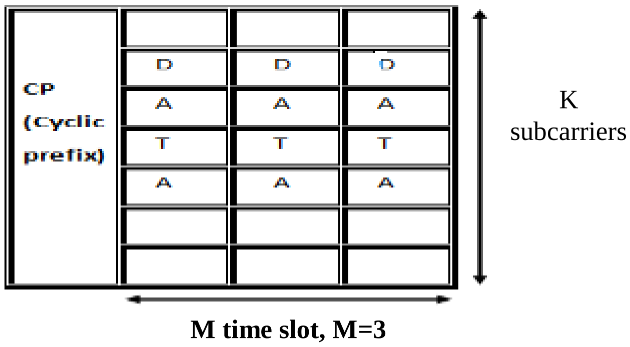

Fig. 1. GFDM frame structure (M “3 time slots, K subcarriers).

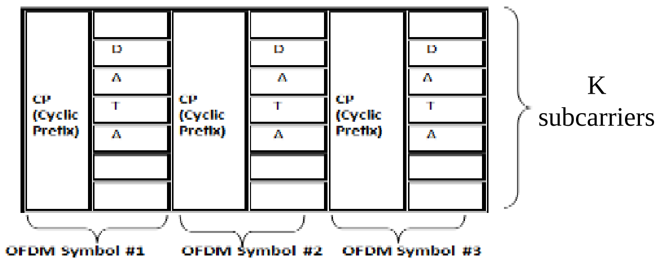

Fig. 2. Consecutive OFDM symbols with K subcarriers.

As can be defined from Fig. 1 and Fig. 2, three consecutive OFDM symbols with K subcarriers should be transmitted in order to transmit the same number of data as a single GFDM symbol (or a GFDM frame, two terms are used interchangeably in this paper) with K subcarriers and M “ 3 time-slots. Since for each OFDM symbol, there is a CP overhead, 3 CPs should be transmitted in OFDM, whereas only a single CP is enough for GFDM. From this point, GFDM seems to be spectrally more efficient than OFDM.

II. THEORETICAL ANALYSIS

This chapter provides a theoretical overview with a transceiver model of GFDM is shown to present the transmission and reception procedure of input signal. Again for analyzing the SER of GFDM an equation is derived.

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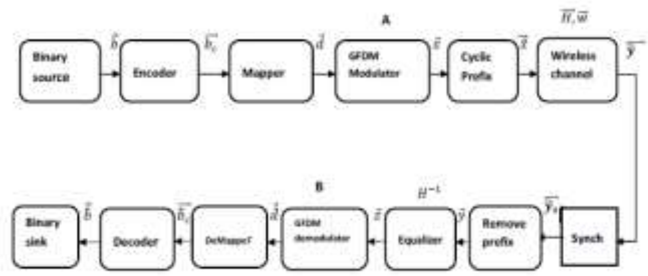

Fig. 3. Block diagram of GFDM transceiver.

Fig. 3 shows the Transceiver model of GFDM. Some important blocks of this model are discussed below:

a) Mapping

The input bits are converted into K data streams that feed K independent J-QAM mappers. Each mapper converts a block of $\log_2(J)$bits into a data symbol to be transmitted by K different subcarriers. In a GFDM, M data symbols are transmitted in the same subcarrier using M signaling windows. The data symbols are organized in a GFDM frame as follows:

$$\mathbf{S}=\begin{pmatrix} S_{0,0} & S_{0,1} & S_{0,2} & \cdots & S_{0,M-1} \\ S_{1,0} & S_{1,1} & S_{1,2} & \cdots & S_{1,M-1} \\ . & . & . & \cdots & . \\ . & . & . & \cdots & . \\ S_{K-1,0} & S_{K-1,1} & S_{K-1,2} & \cdots & S_{K-1,M-1} \end{pmatrix}$$

Where the kth row represents the symbols transmitted in the kth subcarrier and the mth column represents the symbols transmitted in the mth signaling window.

$$S_{k;m(n)} = S_{k;m}\, g(n-mN)\ ; n = 0;\ 1 \ldots . MN-1;$$

b) GFDM Modulation

The sequence$S_{k;m(n)}$is applied to a transmit filter with impulse response given by g (n) with length L = NM.

After pulse shaping, each independent signal is up-converted using a complex subcarrier defined by

$$P(k) = e^{-\frac{j2\pi k}{N}n}$$

The K modulated sub-carriers are added to form the GFDM frame

$$x(n) = \sum_{M=0}^{M-1}\sum_{K=0}^{K-1} Sk,m.\,\delta(n-mN)\oplus g(n-mN).\,pk(n)$$

Where ~ denotes a circular convolution.

c) Adding cyclic prefix (CP)

The advantage of GFDM over OFDM is that only one CP is necessary for the entire GFDM frame, while OFDM requires one CP for each time slot. The signal from the antenna is down-converted to baseband and sampled, resulting in the discrete received signal $rCP(n)$. In this paper a time-invariant multipath channel with impulse response h (n) has been considered, leading to

rCP (n) = xCP (n) ∗h (n) + w (n)

Where xCP (n) is the transmitted signal with CP and w (n) is a sequence of Gaussian noise samples with zero mean and variance _2n.

d) Zero-Forcing Receiver

The matrix representation of the GFDM signal in [9] allows one to conclude that the data symbols can be estimated by the ZF receiver as

$$\hat{} S_{ZF} = \mathbf{A}^{-1}\mathbf{req};$$

Where A−1 is the inverse of matrix A and req is the received vector after equalization.

It is important to notice that matrix A has order KM_NM, which means that A is not necessarily square. When A is not square, it is possible to use the pseudo inverse matrix of A, which is defined by

$$A+= A^{H}.(AA^{H})^{-1}$$

Where A^{H} is the Hermitian matrix of A.

e) Matched Filter Receiver

The equalized received signal is multiplied by the complex conjugate of the desired subcarrier. The resultant signal feeds the receive filter with impulse response that $\mathrm{fm(n)} = \mathrm{g}(<-n+\mathrm{mN}>_{\mathrm{NM}-1})$ matches the transmit filter of the m^{th} time slot. The matched filter reception procedure can be written as

$$\hat{} S_{MF}= A^{H}\mathbf{req}$$

Where $\hat{} S_{MF}$ is a vector containing the MK detected symbols.

f) Performance Evaluation

The symbol error rate (SER) of an OFDM system with J-QAM modulation over frequency-selective channels can be approximated by [3]

$$\mathbf{P_{fsc}} = 2\left(\frac{\mathbf{k-1}}{\mathbf{kK}}\right)\sum_{l=0}^{K-1}\mathbf{erfc}(\sqrt{\gamma_l}) \pm \frac{1}{K}\left(\frac{\mathbf{k-1}}{\mathbf{k}}\right)^2\sum_{l=0}^{K-1}\mathbf{erfc}^2(\sqrt{\gamma_l})$$

Where

$$\gamma_l = \frac{3R_T}{2(2^{\mu}-1)}\cdot\frac{E_s}{\xi_l N_0}$$

ξ = the noise enhancement factor (NEF) determines the signal-to noise ratio (SNR) reduction when using the ZF receiver.

It is defined as

$$\xi = \sum_{n=0}^{MK-1}\left|[\mathbf{B_{ZF}}]_{k,n}\right|^2$$

The zero-forcing (ZF) receiver $\mathbf{B_{ZF}} = \mathbf{A}^{-1}$where A is a KM × KM transmitter matrix [6] with a structure according to

$$A=(\vec{g}_{0,0}, \cdots \vec{g}_{K-1,0}, \vec{g}_{0,1}, \cdots \vec{g}_{K-1,M-1})$$

The performance of GFDM and OFDM over FSC considering the channel impulse response and channel delay profile as follows:

$$\vec{\mathbf{h}} = \left(10^{\frac{-i}{N_{ch}-1}}\right)^{T}$$

With N_{ch} = 16. Again, GFDM uses the CP more efficiently when compared to OFDM.

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III. RESULTS

After theoretical analysis of GFDM has defined the previous section, the symbol error rate performance of GFDM on the basis of simulation is discussed here using MATLAB.

TABLE I. Simulation parameters.

Parameter	Value
Number of sub symbol (*M*)	9
Number of subcarriers (*K*)	99
Number of overlapping subcarrier(L)	2
CP length (NCP)	16 samples
CS length (NCS)	0 samples
Number of bits per QAM symbol(μ)	4
Mapping	16-QAM
Transmit Filter (GFDM)	Root Raised Cosine
Roll-off factor	0.3

A) SER Analysis for GFDM and OFDM

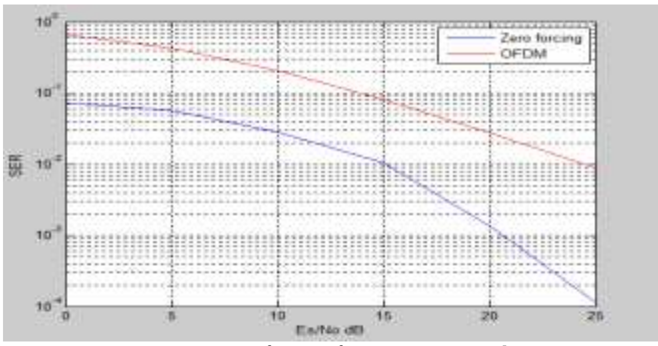

Fig. 4. SER vs. SNR for zero forcing receiver and OFDM.

The observations from the Fig. 4 are as follows that numerically SER performance is better for Zero forcing receiver of GFDM than OFDM. Again the reduction curve is also better for zero forcing receiver of GFDM.

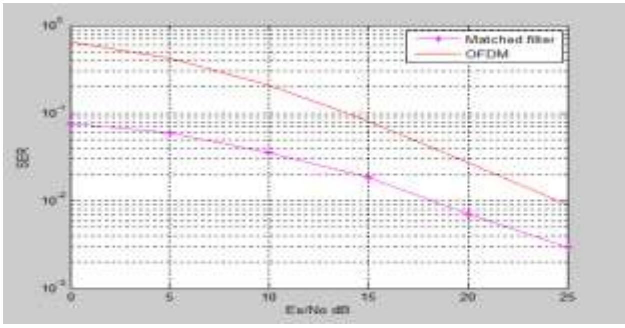

Fig. 5. SER vs. SNR for matched filter receiver and OFDM.

The observation from the Fig. 5 shows that numerically SER performance is better for matched filter receiver of GFDM than OFDM. Again the reduction curve is also better for matched filter receiver of GFDM.

The Fig. 6 shows a comparison between SER performances over SNR of GFDM and OFDM. The SER is reduced with increasing SNR for OFDM also. But the reduction curve is better for zero forcing receiver of GFDM.

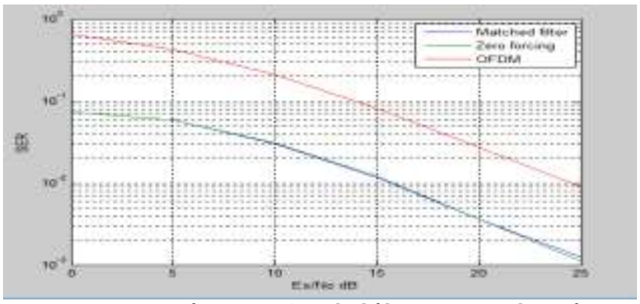

Fig. 6. SER vs. SNR for GFDM (Matched filter receiver and zero forcing receiver) and OFDM.

IV. CONCLUSION

This paper aimed at analyzing the SER of GFDM in frequency selective channels. This analyzation is based on two types of receiver-zero forcing receiver and matched filter receiver. The simulation results show (i) SER for zero forcing receiver has reduced near to zero (ii) Matched filter receiver has also provided a noticeable reduction of SER over SNR.

So, finally we can say that we have presented GFDM as a waveform modulation scheme for future 5G networks. We have analyzed the error rate performance of GFDM analytically and numerically for various receiver conditions and compared to OFDM.

Future Work

In this research work the SER performance only for frequency selective channel has shown. In further research the aim is to measure the SER performance for some other channels like AWGN channel; Time Variant channel etc. and also find out which channel provide best performance.

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