International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-7, Issue-5S4, February 2019

Performance of OQAM based GFDM under Real-time Fading Conditions

Pitchaiah Telagathoti, Ravi Sekhar Yarrabothu

ABSTRACT--- The Fifth generation cellular systems demand ultra high data speeds, ultra low power usage and lower latency. To meet these stringent requirements, Generalized Frequency Division multiplexing (GFDM) is one such waveform that is considered by researchers. At present, the 4G systems with Orthogonal Frequency division Multiplexing (OFDM) waveform have the drawbacks such as Inter Carrier Interference (ICI) and Inter Symbol Interference (ISI). To overcome the ICI/ISI and improve the spectrum efficiency, a non-orthogonal scheme of GFDM is introduced. In this paper, the performance of the Offset Quadrature Amplitude Modulation (OQAM) based GFDM, the analysis of the performance in terms of errors when passed through numerous fading channel condition for the Rayleigh channel model are discussed. The error performance is evaluated for EPA, EVA, ETU fading profiles as defined according to the 3GPP. Simulation results show that OQAM-GFDM error performance is superior to OFDM under various fading conditions and this could be more suitable wave form for 5G communications.

Keywords: Cyclic Prefix; GFDM; ISI; ICI; OFDM; Orthogonality; Rayleigh fading model.

1. INTRODUCTION

In day our day to day life, communication between us become more mobile and personal rather than fixed place and public. In a brief overview of different generation of mobile communications: 1G made the possibility of voice communication of analog nature; 2nd generation improved the voice quality by going the digital way and small message and date services along with capacity improvements in terms spectrum and battery life; 3G provided enhanced data speeds with more mobility. The revolution of smartphones with huge memory, enhanced battery technologies, miniaturization of phones and mobile broadband with 100Mbps+ data rates in the 4G cellular communications [1]. The evolution of the mobile communications is broadly driven by spectrum efficiency means more number of bits/Hz and higher data rates for data hungry applications like HD video and 3D videos. With the arrival of the 5G systems, higher data rates in the order of 100Gbps with a 1ms latency [2], [3]. Integration of Internet of Thing (IoT) devices with mobile networks and ultra low latency, and higher order data rates requirements for the individual devices are some of the daunting tasks in realizing the 5G systems [4].

The existing Orthogonal FDM systems with compelling advantages like robustness against the multipath fading channels make it widely acceptable for 4G communications. But in realising the 5G requirements such as ultra low latency, device to device communications and tactile internet, OFDM is not fully suitable due to its strict synchronization requirement [5]. In order to achieve the 5G requirements, various multicarrier based waveforms are getting considered. For realizing the 5G systems, GFDM is one such multicarrier waveform considered [6], [15]. The reason for considering GFDM systems are it is going to provide the spectral efficiency by removing the requirement of cyclic prefix (CP) for each OFDM symbol with only one cyclic prefix for the entire block [7].

Another added advantage provided by the GFDM is no strict requirement of orthogonality of the subcarriers. But this advantage comes with a cost of increase in ICI and ISI since it uses Quadrature Amplitude Modulation(QAM). In this paper, to mitigate the ICI and ISI problem of GFDM system, GFDM with OQAM is proposed [8],[19]. The performance and robustness of GFDM with OQAM modulation is analysed in the real time fading profiles namely Extended Pedestrian A (EPA), Extended Vehicular A (EVA), Extended Typical Urban (ETU) fading profiles as defined according to the 3GPP.

This paper is organized in 6 sections; section 2 explains the concepts of the GFDM system, section 3 discusses about multi pathe channel fading and especially Rayleigh fading channel model and 3GPP defined fading profiles, section 4 briefly explains the modelling of the GFDM receiver, section 5 analyses the performance of the GFDM with OQAM through the simulated results. Finally, section 6 concludes the results with future directions .

2. PRINCIPLE OF GFDM

GFDM is a loosely synchronous and non-orthogonal multicarrier modulation scheme, where each block consists of K subcarriers and M sub-symbols. Its principle is to transmit multiple symbols and multi-carrier with two-dimensional frequency/time block structure [9]. A pulse shape filter is used to get a block structure with each individual subcarrier convoluted circularly. For better control of spectral leakage, the time windowing techniques are applied. Various types of pulse shaping filters are used to remove the orthogonality right through the subcarriers. The advantages of GFDM are a simple transmitter design and less complexity in the received signal processing. In addition to the advantages mentioned, some of the signal processing can be shifted to base stations so that the power consumption at mobile handsets is minimized.

Revised Manuscript Received on February 11, 2019.

Pitchaiah Telagathoti, Department of ECE, Vignan's Foundation for Science, Technology and Research (Deem to be University), Vadlamudi, India.

Ravi Sekhar Yarrabothu, Department of ECE, Vignan's Foundation for Science, Technology and Research (Deem to be University), Vadlamudi, India. (E-mail:ykravi@gmail.com)

OFDM with QAM technique time-frequency localization is an issue for the high spectral efficient signal [10]. Offset QAM based OFDM has been identified as one such technique to overcome the time-frequency localization issue [11].For acheiving high data rates, GFDM is a better choice and in this paper GFDM/OQAM is used as instead of GFDM/QAM, to overcome the above mentioned issue.

GFDM/OQAM system is very similar to GFDM system with two changes. The first change is use the mapping of QAM, subsequently shifting the K/2 samples (offset) in the time domain between in-phase and components of QAM mapped data. The resultant OQAM mapping reduces ICI and ISI, when used with a well designed filter. The other one is achieving better spectral efficiency with pulse shaped orthogonal filters without using a cyclic prefix which is a key challenge for 5G communications. Fig 1 represents the GFDM transceiver system with OQAM.

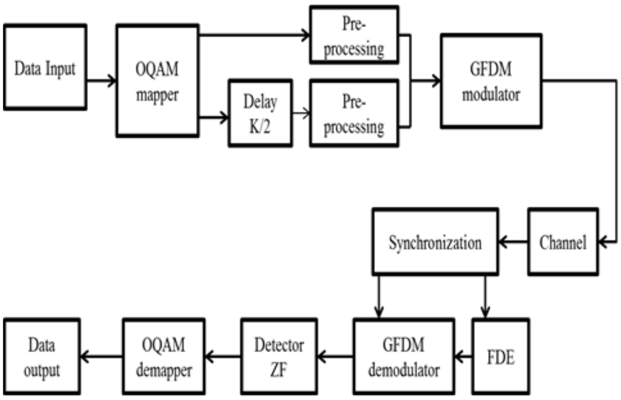

Fig. 1. GFDM transceiver System.

Complex baseband symbols are used in GFDM based QAM, where as in OQAM the modulated real valued symbols are transmitted on each sub-carrier. The prototype function for the conversion of time-frequency is,

$$g_{s,k}(q) = g[(q - \frac{kS}{2}) \bmod SK]e^{\frac{j2\pi s}{S}[q - \frac{L_p - 1}{2}]} \quad (1)$$

Where $q = 0,1,2,.....SK-1$, $g_{s,k}(n)$ is time and frequency shifted version of the prototype filter $g(k)$ and L_p is the length of the prototype filter. The discrete time baseband modulator output of the GFDM-OQAM is provided by the superposition of every symbol, which is shown below,

$$x(q) = \sum_{s=0}^{S-1}\sum_{k=0}^{K-1} a_s(k) g_{S,k}(q) e^{\phi_{k,s}} \quad (2)$$

Where $q = 0,1,2,....SK-1$, $\bar{a}_s(k)$ is real data which is part of the QAM constellation diagram. $\phi_{k,s} = \frac{(s+k)\pi}{2}$, $e^{j\phi_{k,s}}$ is phase difference of $\pi/2$ between the real data $a_s(K)$ in both frequency and time.

3. WIRELESS COMMUNICATION CHANNEL MODELS

Information transmission and reception happens through a medium which can be either a wired or wireless channel. To model the wireless communication channel, one need to consider the reflection, scattering, refraction, and diffraction, which in-turn results in to fading of propagated signals over longer distances. The received signal due to the fading gets degraded even though the AWGN is of insignificant. Sudden reduction of signal strength due to signal reception from various paths is defined as multipath fading, and is described by the channels known as the fading channels. Two fading channel models are quite frequently used and these are Rayleigh and Rician distributions and in this paper it is used Rayleigh Fading channel, since the mobile communication environment is more of Non Line Of Sight(NLOS) communication.

A. Rayleigh fading Model

Rayleigh fading model is a statistical model for the multipath propagation environment of a radio signal reception. In Rayleigh fading model, it is assumed that the magnitude of the received signal will fade or vary randomly, which has gone through the transmission medium.

$$P_{AWGN\ CHANNEL}(e) = 2\left(\frac{C-1}{C}\right) erfc(\sqrt{\beta}) - \left(\frac{C-1}{C}\right)^2 erfc^2(\sqrt{\beta}) \quad (3)$$

Here $$\beta = \frac{3R_T}{2(2^b - 1)} \frac{N_s S_e}{\xi N_0} \quad (4)$$

Here β is the signal-to-noise ratio, N_s is the multiplicative factor, ξ is the noise enhancement factor.

And $$R_T = \frac{RS}{RS + N_{cp} + N_{cs}} \quad (5)$$

Where, b is the no. of bits per symbol, N_{CS} is length of cyclic suffix and N_{CP} are length of cyclic prefix, $C = \sqrt{2^b}$, S and R are the number of sub-symbols and subcarriers respectively, N_0 is the noise power density and S_e is the average energy per symbol. For OQAM N_s is having a value of 2 [11]. SNR Probability density function in various fading channels is as follows:

$$P_{Rayleigh}(e) = \int_0^{\infty} P_{AWGNCHANNEL}(e) P_\beta(\beta) d\beta \quad (6)$$

Where $$P_\beta(\beta) = \frac{1}{\bar{\beta}_r} \exp\left(\frac{-\beta}{\bar{\beta}_r}\right) \quad (7)$$

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

By substituting equations (3), (7) in (6) then we obtained following,

$$P_{Rayleigh}(e) = 2\left(\frac{C-1}{C}\right)\left(1-\sqrt{\frac{\overline{\beta}_r}{1+\overline{\beta}_r}}\right)-\left(\frac{C-1}{C}\right)^2 \left[1-\frac{4}{\pi}\sqrt{\frac{\overline{\beta}_r}{1+\overline{\beta}_r}}\arctan\left(\sqrt{\frac{1+\overline{\beta}_r}{\overline{\beta}_r}}\right)\right] \quad (8)$$

Where

$$\overline{\beta}_r = \frac{3R_T\sigma_r^{\,2}}{(2^b-1)}\frac{N_sS_e}{\xi N_0} \quad (9)$$

and

$$\sigma^2{}_{Rayleigh} = \sigma_r^{\,2}\sum_{j=0}^{N_{chan}-1}\left|h_j\right|^2$$

Here $\overline{\beta}_r$ is the corresponding SNR under Rayleigh channel, N_{chan} is the length of channel impulse response, h is the channel impulse response and $\sigma_r^{\,2} = 1/2$ is parameter of Rayleigh taps in all fading profiles which are consider for SER performance.

B. Multipath Fading Propagation Conditions

The 3rd Generation Partnership Project (3GPP) implements a stable environment for their members produce the Specifications and other reports that defined in 3GPP technologies for all the mobile communications from 2G to 4G.

3GPP specifies the three fading profiles, by considering commonly used scenarios, like Extended Pedestrian A (EPA), Extended Vehicular A (EVA), Extended Typical Urban (ETU) [12], [13], [14]. These profiles stand for a low, medium, and high delay spread environment, respectively. Table 1, Table 2, Table 3 depicts the 3GPP defined delay profiles.

TABLE 1 Extended Pedestrian A Model (EPA)

Tap	Doppler frequency [HZ]	Excess tap delay (in µs)	Relative Power (in dB)
1	5	0	0.0
2	5	0.03	-1.0
3	5	0.07	-2.0
4	5	0.09	-3.0
5	5	0.11	-8.0
6	5	0.19	-17.2
7	5	0.41	-20.8

TABLE 2 Extended Vehicular A (EVA) Model

Tap	Doppler frequency[HZ]	Excess tap delay (in µs)	Relative Power (in dB)
1	70	0	0.0
2	70	0.03	-1.5
3	70	0.15	-1.4
4	70	0.31	-3.6
5	70	0.37	-0.6
6	70	0.71	-9.1
7	70	1.09	-7.0
8	70	1.73	-12.0
9	70	2.51	-16.9

TABLE 3 Extended Typical Urban Model (ETU)

Tap	Doppler frequency[HZ]	Excess tap delay (in µs)	Relative Power (in dB)
1	300	0	-1.0
2	300	0.05	-1.0
3	300	0.12	-1.0
4	300	0.2	0.0
5	300	0.23	0.0
6	300	0.5	0.0
7	300	1.6	-3.0
8	300	2.3	-5.0
9	300	5.0	-7.0

The difference between the channel tap values from one another depends on the Doppler frequency, which is relative to the velocity of the mobile equipment. Higher speed of a device leads to larger the Doppler frequency f_d and bigger variations in the channel conditions. The Doppler frequency is described as below:

$$f_d = v * \cos(\theta)/\lambda \quad (10)$$

Here, v is the receiver speed. λ is the wave length of the signal. θ is the angle between the direction of approaching signal and the direction of mobile device motion.

In addition to the delay profiles, each of the multi path propagation has the maximum Doppler frequency defined. Those maximum Doppler frequencies are 5Hz for EPA, 70Hz for EVA, 300Hz for ETU [16],[17],[18].

4. RECEIVER CHANNEL MODELING

At receiver, the channel is modelled in frequency domain as shown below.

$y = IFFT\{\frac{FFT(r)}{FFT(h)}\}$, Here FFT (.) is Fast Fourier Transform and IFFT(.) is Inverse FFT, which are more efficient than IDFT and DFT. The received matrix B with Zero Forcing (ZF) receivers is,

$$\text{ZF: } B_{ZF} = (A^H A)^{-1} A^H \quad (11)$$

The ZF Receiver is chosen to reduce the self-interference under noiseless conditions. In this paper for all the fading models, we use the ZF receiver in the GFDM receiver systems, so that the self interference is well controlled.

5. SIMULATION RESULTS

As defined in the above section, OQAM based GFDM and OFDM transceiver systems coupled with the fading channel models of 3GPP has been simulated and the table 4 depicts the values of the system parameters.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

TABLE 4. GFDM System Simulation Parameters

Sl No	Parameter	Value
1	Signal Bandwidth	20 MHz
2	Sampling period	50 ns
3	Filter type	RRC Filter
4	Number of Active subcarriers	99
5	Block Size	15
6	FFT size	Active subcarriers *Block Size
7	Filter Roll-off - factor	0.3
8	Filter Oversampling (frequency domain)	2

The simulated results depicted in the figures 2, 3, 4, shows the SER performance for GFDM with QAM and OFDM system under different 3GPP fading profiles namely EPA, EVA and ETU.

From Figure 2, it can inferred that for the GFDM/OQAM system with extended pedestrian A model (EPA) case, to get the zero errors, the minimum value of SNR is 25 dB, where as for the OFDM case to get zero errors, the minimum SNR value required is greater than 45 dB. We can infer from figure 2 that even under extremely noisy filled channel conditions, GFDM-OQAM system is better in terms of lower SER when weighed against the OFDM systems.

From Figure 3 it is noticed that for the GFDM system with extended Vehicular A model (EVA) case, to get the zero errors, the minimum value of SNR is 40 dB, where as for the OFDM case to get zero errors, the minimum SNR value required is greater than 50 dB.

From Figure 4 it can be understood that for the GFDM system with extended Typical Urban model (ETU) case, to get the zero errors, the minimum value of SNR is 40 dB, where as for the OFDM case to get zero errors, the minimum SNR value required is greater than 50 dB.

From the figures 2, 3 and 4, one more observation that can be derived is GFDM/OQAM systems have very few errors when compared to OFDM systems at lower SNR values, which proves the superiority of GFDM/OQAM over OFDM systems.

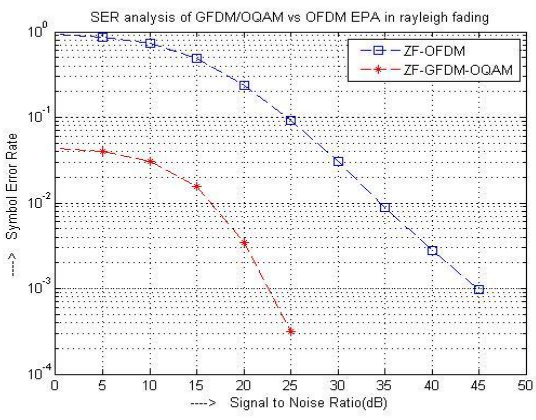

Fig. 2. SER Performance under Rayleigh channel based on EPA

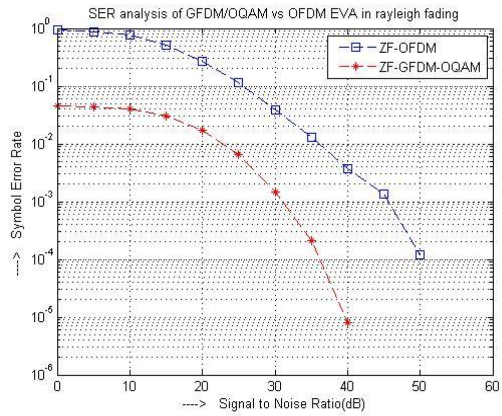

Fig. 3. SER Performance under Rayleigh channel based on EVA

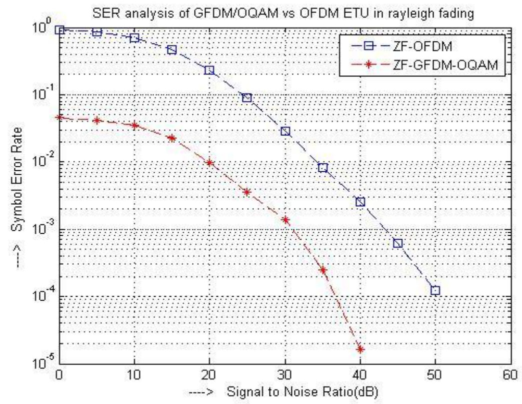

Fig. 4. SER Performance under Rayleigh channel based on ETU.

6. CONCLUSION

In this paper, it has been observed that GFDM system with OQAM is superior to OFDM systems under noisy and fading conditions such as urban, vehicular and pedestrian profiles. The current work can be extended to other profiles such as high ways, rural fading conditions, since 5G communications includes a wider area of coverage with ubiquitous communication environment. In addition, the suitability of the GFDM systems for ultra low latency applications also can be verified through the simulations

REFERENCES

1. N. Michailow, M. Matthe, I. Gaspar, A. Caldevilla, L. Mendes, A. Festag, and G. Fettweis, “Generalized Frequency Division Multiplexing for 5th generation cellular networks,” Communications, IEEE Transactions on, vol. 62, no. 9, pp. 3045–3061, Sept 2014.
2. G. Fettweis and S. Alamouti, “5G: Personal mobile Internet beyond what cellular did to telephony,” IEEE Commun. Mag., vol. 52, no. 2, pp. 140–145, Feb. 2014.
3. G. Wunder et al., “5GNOW: Non-orthogonal, asynchronous waveforms for future mobile applications,” IEEE Commun. Mag., vol. 52, no. 2, pp. 97–105, Feb. 2014.
4. J. G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, A. Lozano, A. C. Soong,and J. C. Zhang, “What will 5g be?” Selected Areas in Communications, IEEE Journal on, vol. 32, no. 6, pp. 1065–1082, 2014.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

5. M. Nekovee, “Quantifying performance requirements of vehicle-to vehicle communication protocols for rear-end collision avoidance,” in Proc. IEEE 69th Veh. Technol. Conf., Barcelona, Spain, Apr. 2009, vol. 1, pp. 1–5.
6. Sklar, Digital Communications: Fundamentals and Applications, 2nd ed. New York, NY, USA: Prentice-Hall, 2001.
7. N. Michailow, S. Krone, M. Lentmaier, and G. Fettweis, “Bit error rate performance of Generalized Frequency Division Multiplexing,” in Vehicular Technology Conference (VTC Fall), 2012 IEEE, Sept 2012, pp. 1–5.
8. P. Siohan, C. Siclet, and N. Lacaille, “Analysis and design of ofdm/oqam systems based on filterbank theory,” Signal Processing, IEEE Transactionson, vol. 50, no. 5, pp. 1170–1183, 2002.
9. G. Fettweis, M. Krondorf, S. Bittner, “GFDM – Generalized Frequency Division Multiplexing”, Proceedings of the 69th IEEE Vehicular Technology Conference, Barcelona, Spain, 26-29 April 2009, pp. 1-4.
10. B.LeFloch, M.Alard, and C.Berrou, “Coded orthogonal frequency division multiplex,”proc.of IEEE,vol.83,PP.982-996,June 1995.
11. Shravan Kumar Bandari, V.V Mani and A.Drosopoulos, “OQAM Implementaion of GFDM,” in 2016 23rd International Conference on Telecommunications (ICT)
12. Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (3GPP TS 36.104 version 11.2.0 Release 11) (www.3GPP.org)
13. Clerckx B, Lozano A, Sesia S, van Rensburg C and Papadis B. 3GPP LTE and LTE Advanced. EURASIP J. Wireless Commun. Netw. Sep 2009;1: 472-124.
14. Maddah-Ali M, Motahari A, Khandari A. Communication over MIMO X channels: Interderence alighnment, decomposition, Performance analysis. IEEE Trans. Inf. Theory;Aug 2008;54:3457-3470.
15. Rappaport T.S. et al. Millimeter wave mobile communications for 5G cellular: It will work!. IEEE Access, Aug 2013;1:335-349.
16. Jindal N and Lozano A. Aunified treatment of optimum pilot overhead in multipath fading channels. IEEE Trans. Commun; Oct 2010;58:2939:2948
17. Li C, Zhang J, Letaief K.B. Throughput and energy efficiency analysis of small cell networks with multi-antenna base stations, IEEE Trans. Wireless Commun; May 2014;13:2505-2517.
18. Buzzi S, Colavolpe G, Saturnino D, Zappone A. Potential games for energy-efficient power control and subcarrier allocation in uplink multicell OFDMA systems, IEEE se. Topics Signal Process, Apr 2012;6:89-103
19. S. K. Bandari, V. V. Mani and A. Drosopoulos, "OQAM implementation of GFDM," *2016 23rd International Conference on Telecommunications (ICT)*, Thessaloniki, 2016, pp. 1-5.