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Research paper



Performance Analysis of 5G Waveform – Bi-Orthogonal Frequency Division Multiplexing under Real Fading Condition Simulations

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Abstract

4G LTE communication system uses OFDM and for resource allocation control channels like PRACH is used. Around 6% bandwidth is getting used for this PRACH procedure and due to OFDM requirement of strict synchronization, short messaging become tedious and cause power wastage due to the control traffic for every message. The main challenge for 5G communications is to handle the transmission of extremely asynchronous data and control traffic in one go. Existing OFDM based systems have the drawback of very sensitive to the time and frequency offsets and in turn results in synchronization errors. To overcome this challenge, it has been adopted a new waveform based on Bi-orthogonal Frequency Division multiplexing (BFDM) which supports the Internet of Things (IoT) sporadic traffic. In this paper, BFDM principles, behaviour of BFDM under various channel conditions, Matlab simulation results pertaining to the performance of BFDM against the existing OFDM are discussed. The simulation results shows that the Symbol Error Rate of the BFDM system is less than the OFDM under time varying fading conditions such as Extended Pedestrian A (EPA), Extended Vehicular A (EVA), Extended Typical Urban(ETU) models.

***Keywords*:** *5G; BFDM; LTE; OFDM; SER*

1. Introduction

Cellular communication has evolved from 1G to 4G cater to various service offerings since its inception. 1G introduced analogue voice services, 2G incorporated digital wireless technologies with increased voice capacity and 3G enabled mobile broadband services. Now 4G cellular communications providing high performance streaming of multimedia content along with the voice, video and messaging services. Discussions are shaping up for the fifth-generation (5G) cellular access which is to be introduced around 2020 frame and Internet of Things (IoT) concept paves a way for 5G communications. IoT devices generate sporadic traffic which needs an efficient access from the 5G networks. Such IoT devices will be inactive for larger time periods and the internet is accessed periodically for minor or incremental update without manual intervention and such communication is known as machine-type communication (MTC). The current 4G random access procedures are not sufficient for this kind of sporadic traffic [1].

In this paper a new approach [2] is used to efficiently handle sporadic traffic of 5G by using an enhanced physical layer random access channel (PRACH), which achieves device acquisition and transmission of small data payloads simultaneously. By doing so, without maintaining a continuous connection, PRACH is used to transmit smaller data packets like in UMTS. In LTE the user data is carried only by using the physical uplink shared channel (PUSCH) and due to this scalable sporadic traffic is not possible. 5G Now [2] proposed a design of arranging a data access section in between the synchronization PUSCH and normal PRACH, which is called as Data PRACH (D-PRACH) to support transmission of asynchronous data. The guard band between PRACH and PUSCH is used by D-PRACH and in this way the sporadic traffic is removed from the uplink data channel PUSCH, which results in to a very significant reduction in signalling overhead and reduction in power consumption of the devices. Sacrificing the guard bands for data transmission, normally leads to augmented interference for PUSCH users, which can be taken care by newer waveform designs.

In Bi-Orthogonal Frequency Division Multiplexing (BFDM), normal orthogonality is replaced with a set of pair wise orthogonal transmit and receives pulses. Consequently, more flexibility is obtained for the design of transmit prototypes with suppression of side lobes. Matched filter is not suitable for BFDM and in this paper a mismatched ZF filter is used [3]. The PRACH symbol transmission is very much immune to time offsets due to the long symbol duration and so the BFDM design is well suited for transmission of sporadic traffic. BFDM shows exceptional and controllable performance degradation trade-off between the time and frequency offsets in comparison with conventional OFDM.

This paper is presented in four sections. The section II, describes BFDM system design, Section III talks about the system setup for simulation, Section IV shows the simulation results and finally conclusions are made in section V.

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2. BFDM System Design

Pulse shaping method is used by Bi-orthogonal frequency division multiplexing (BFDM) for PRACH transmissions. Like in OFDM, the symbols are transmitted as per a group of pulses shifted on time-frequency lattice points (kT,lF),where T is time shift and F is the Frequency shift period and $k,l\in\mathbb{Z}$.As mentioned in [2], the exact reconstruction of symbol is possible only if bi-orthogonal Riesz bases is formed by transmit pulses$\{g_{k;l}\}$ and the receive pulses $\{\gamma_{k;l}\}$. Two factors namely pulse properties and the time-frequency product TF (>1) will determine the possibility of perfect symbol reconstruction. In this paper we chose the TF=1.25.

Transmitter

As shown in the Figure 1, an additional process is done for the pulse shaped PRACH [4],compared to normal OFDM. Unlike in LTE, whereZadoff-Chu sequences are used for PRACH, BFDM transmitter uses a single-tone PRACH transmission [5].

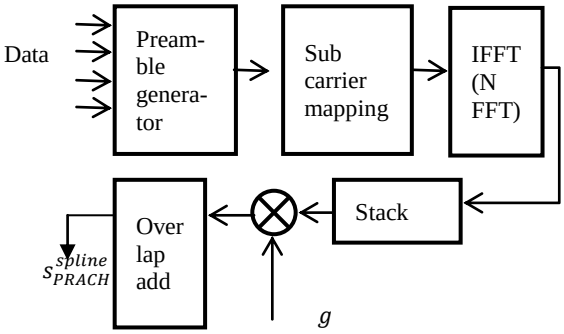


Figure 1: BFDM PRACH transmitter

Shaping of the PRACH signal spectrum is done by using a pulse g. Let 'P' be the length of pulse g. The output signal s[n]generated after the inverse FFT (IFFT) stage by iterating and taking modulo P, which is of same length P.

Given k symbols, each symbol $s_k[n]$is stacked as row matrix.

$$S=\begin{pmatrix} s_0[n] \\ s_1[n] \\ \vdots \\ s_{K-1[n]} \end{pmatrix},\text{S}\in \mathbb{C}^{KxP} \quad (1)$$

Each$s_k\ [n]$is point wise multiplied with the shifted pulse g and superimposed by overlap and add.

Then, the base band pulse shaped PRACH transmit signal is

$$s_{pr}^{ps}[n]=\sum_{k=0}^{K-1} s_k\,[n]g[n-kN] \quad (2)$$

Receiver

Pulse shaped PRACH receiver is a shown in the Figure 2. First an inversion operation is carried out on the transmitter side pulse. Here the first K symbols of the received signal $r_{PR}[n]$are arranged in a row vector matrix

$$\text{R}=\begin{pmatrix} r_0[n] \\ r_1[n] \\ \vdots \\ r[n] \end{pmatrix},\text{R}\in \mathbb{C}^{KxP} \quad (3)$$

Then each row is point wise multiplied by the shifted bi-orthogonal pulse γ , so the received signal become

$$r_k^{\gamma}[n]=r_k[n]\gamma[n-kN] \quad (4)$$

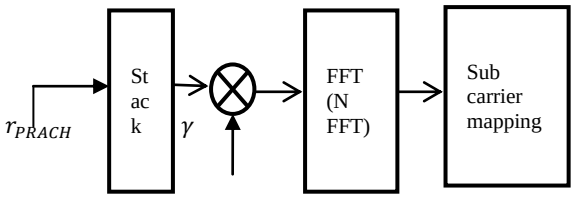


Figure 2: BFDM PRACH receiver

Pulse design

As discussed before the transmit pulse g and received pulse γ play a key role and so they should be designed carefully. In the BFDM approach, the transmitpulse g is generated according to the system requirement and the received pulse γ is computed from g, as a canonical dual (bi-orthogonal). The computation methods used in this paper are as proposed in [6]. In summary, the bi-orthogonality means transmit pulse g generates a Gabor Riesz basis and equivalent dual Riesz basis is generated by receive pulse γ. As shown in [7] this can be achieved with the S^{-1} method.While calculating the bi orthogonal pulses, side effects such as spectral re-growth due to periodic settings are negligible.

The ratio of the time and frequency pulse widths (variances) σt and σf should be almost matched to the time-frequency grid ratio.

$$\frac{T}{F}\approx\sqrt{\frac{\sigma_t}{\sigma_f}} \quad (5)$$

Pulse g is constructed based on the B-spline in the frequency domain. B-Splines were studied thoroughly in the Gabor (Weyl-Heisenberg) setting[8]. The prime reason for the usage of B-Spline pulses is due to the excellent tail properties of convolution of such pulses.

The second order B-spline (the tent) function decays faster in time domain and the same in frequency domain is stated as

$$B2(f)=B1(f)*B1\,(f) \quad (6)$$

Where

$$B1(f)\text{: }=\text{Ϫ}[-1/2,1/2]\,(f) \quad (7)$$

However in practice, the transmit pulse has to be of finite duration so g(t) can be given as

$$\text{g}(t)=\left(\frac{\sin(B\pi t)}{B\pi t}\right)^2\text{Ϫ}(t) \quad (8)$$

3. System Set Up For Simulation

A typical wireless system can be modeled as shown in the Figure (refer fig 3.) In the current work, BFDM transmitter, receiver and channels are modeled using MATLAB software.

The block diagram consists of

- Data Source: A random generator is used
- Encoding of data: QAM modulator is used
- BFDM Modulator: BFDM Transmitter is implemented as explained in Section II.
- Decoding of data: QAM demodulator is used
- BFDM Demodulator: BFDM Receiver is implemented as explained in Section II

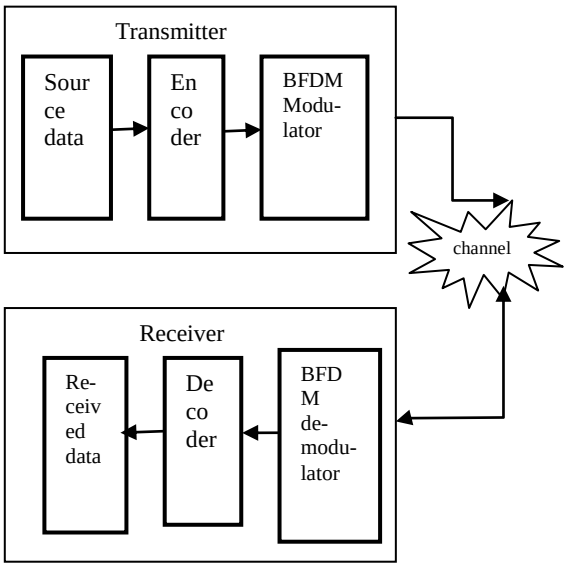


Figure 3:. Communication block diagram for BFDM

A. Channel

In digital communication channel means a medium to send and receive the signal. In wireless channel modeling we consider reflection, refraction, and scattering, these results in fading of signal. Above the large distances, the signal quality degrades even without the presence of large quantities of AWGN. Degradation is also called as fading and this is denoted as channel or fading channels. In general, fading channels Rayleigh and Rician distributions are most commonly used. In this paper, Rayleigh distribution is used, since the cellular communication is always non-Line of Sight.

B. Rayleigh distribution

Since the Line of sight (LOS) is not considered, the Rayleigh Distribution fading represents the worst case fading conditions. **As**the power is distributed quickly, the phase is evenly distributed and is independent of amplitude, mostly uses in wireless communication signal model.

C. Multipath Fading Propagation Conditions

When a signal propagates from transmitter to receiver it faces multipath. Perhaps there is Line of Sight in between a transmitter and a receiver or it can reflect to ground and then it may reach to receiver. While this reflected copy of same signal reaches to receiver they may have delay and attenuation based upon path length. There are three known LTE channel models of multipath profiles are defined by 3GPP [9] namely Extended Pedestrian A (EPA), Extended Vehicular A (EVA) and Extended Typical Urban (ETU) and is given in following Tables (refer with table 1, 2, 3). These three fading profiles characterize a low, medium, and high delay spread environment, respectively. The Doppler shifts for EPA, EVA, and ETU are 5Hz, 70 Hz, 300Hz respectively.

Table 1:.EPA Delay Profile

Tap	**Excess Tap Delay in Nano seconds**	**Relative Power in dB**
1	0	0.0
2	30	-1.0
3	70	-2.0
4	90	-3.0
5	110	-8.0
6	190	-172
7	410	-20.8

Table 2:.EVA Delay Profile

Tap	**Excess Tap Delay in Nano seconds**	**Relative Power in dB**
1	0	0.0
2	30	-1.5
3	150	-1.4
4	310	-3.6
5	370	-0.6
6	710	-9.1
7	1090	-7.0
8	1730	-12.0
9	2510	-16.9

Table 3:.ETU Delay Profile

Tap	**Excess Tap Delay in Nano seconds**	**Relative Power in dB**
1	0	0.0
2	50	-1.5
3	150	-1.4
4	310	-3.6
5	370	-0.6
6	710	-9.1
7	1090	-7.0
8	1730	-12.0
9	2510	-16.9

4. Simulation Results

The BFDM and OFDM systems are simulated using Matlab software along with the 3GPP fading profiles and the input parameters used for the results are as shown in Table 4

Table 4:. Input parameters with values

Parameter	**Standard PRACH**	**Pulse shaped PRACH**
Bandwidth	1.08MHz	1.08MHz
OFDM symbol duration	$800\mu s$	-
Subcarrier spacing (F)	1.25kHz	1.25kHz
Sampling Frequency (fs)	30.72MHZ	30.72MHZ
Length of FFT (NFFT)	24576	24576
Number of Subcarrier (L)	839	839
Cyclic Prefix length (Tcp)	3168Ts	0
Guard time (Tg)	2976Ts	0
Pulse length (P)	-	4ms
Number of symbol (K)	1	1
Time-frequency product (TF)	1.25	1.25

The standard carrier spacing 15 KHz of OFDM is reduced to 1.25 KHz. The simulation result of the Power spectral density (PSD) of both BFDM and OFDM is shown in Figure 4. From the figure 4, it is observed that the BFDM has more side lobe suppression when compared to the OFDM.

The SER analysis of the BFDM and OFDM under various 3GPP fading profiles - EPA, EVA and ETU and the results are depicted in figure 5,6,7 respectively.

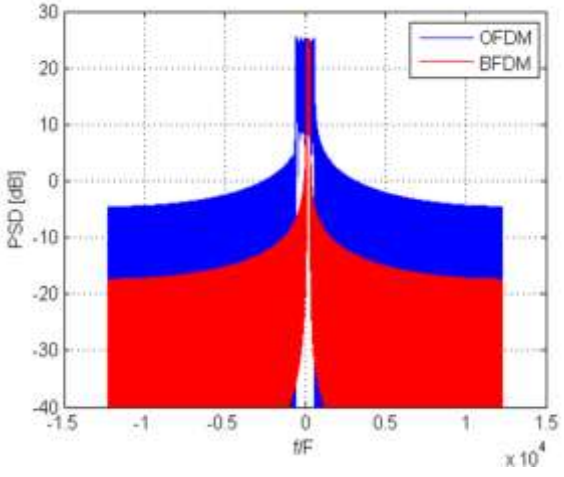


Figure 4:. PSD of BFDM and OFDM systems

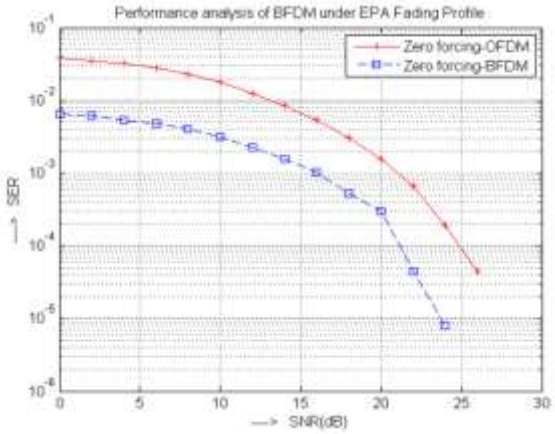


Figure 5: SER analysis of BFDM under EPA fading profile

From Figure 5 it is observed that for the BFDM system after the SNR value of 24 dB the SER value reaches to zero for extended pedestrian A model (EPA) case, where as OFDM case to get SER value of 0, the SNR value is greater than 28 dB. That means under noisy environment BFDM performs better in terms of lesser erroneous symbols received compared to OFDM based LTE systems.

From Figure 6 it is observed that for the BFDM system after the SNR value of 26 dB the SER value reaches to zero for extended Vehicular A model (EVA) case, where as OFDM case to get SER value of 0, the SNR value is greater than 36 dB.

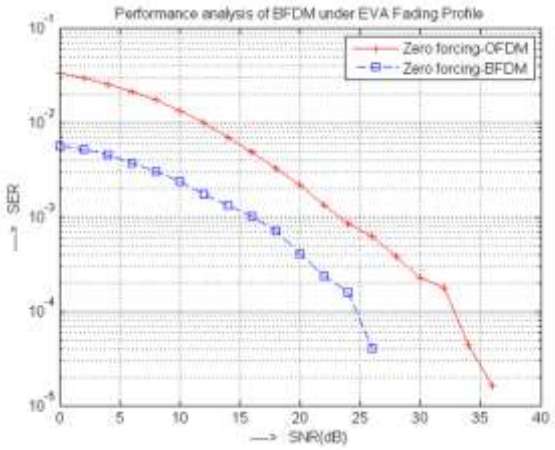


Figure 6:.SER analysis of BFDM under EVA fading profile

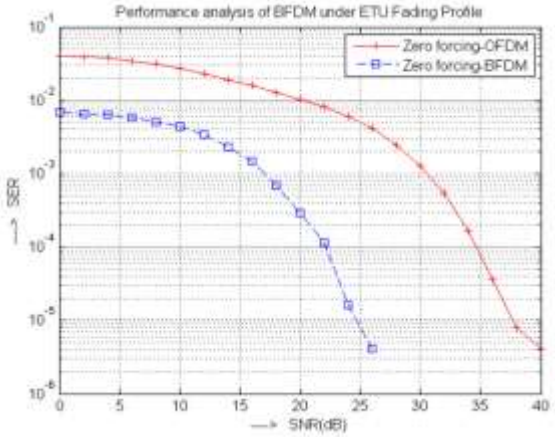


Figure 7:.SER analysis of BFDM under ETU fading profile

From Figure 7 it is observed that for the BFDM system after the SNR value of 26 dB the SER value reaches to zero for extended Typical Urban model (ETU) case, where as OFDM case to get SER value of 0, the SNR value is greater than 40 dB.

From the figure 5, 6 and 7 it is noticed that BFDM shows better SER compared to OFDM, when frequency offset is more means in ETU case, where the maximum Doppler shift occurs. For these simulations the carrier spacing used is reduced to 1.25 KHz instead of 15 KHz. This implies that BFDM waveform is suitable for short message communication; since it has fewer errors than OFDM signal at the receiver for all 3GPP defined fading conditions namely Extended Pedestrian A (EPA), Extended Vehicular A (EVA) and Extended Typical Urban (ETU).

5. Conclusions

In this paper, it is proven that BFDM performed well compared to OFDM under various real time fading conditions. BFDM is immune to frequency offsets that are common for cellular communications and also suitable for short message communications. The current work can be further tested using Offset QAM (OQAM) instead of QAM.

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