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Doubly-Selective Channel Estimation in Fbmc-Oqam and Ofdm Systems

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Abstract: *The Spectrum efficiency for 5G networks can be achieved by Filter Bank Multi Carrier / Orthogonal Quadrature Amplitude Modulation (FBMC / OQAM) that avoids the usage of guard band. FBMC is very sensitive to Carrier Frequency Offset (CFO) and Timing Offset (TO). This paper proposes Zadoff-chu sequence based preamble or pilot is used to design the FBMC frame for synchronize more with receiver to achieve sufficient channel estimation and phase tracking which reduces the carrier frequency and timing synchronization. This method helps to control the out of band emissions and create non-orthogonal waveforms to investigate the overall system performance such as Bit Error Rate (BER) over AWGN channels. The performance metrics such as Complementary Cumulative Distribution Curve (CCDF) for FBMC signal with different multicarrier to analyze the Peak to Average Power Ratio (PAPR) is obtained by simulation. The simulation result proves that FBMC outperforms well when compared with other multicarrier systems.*

Keywords: FBMC, CFO, TO, BER, CCDF, PAPR.

1. Introduction:

OFDM [1] has a fundamental problem making it unattractive for future wireless communication services. The demerits of OFDM systems are its large out - of - band emissions (OOBE), which affects the spectrum utilization, Doppler frequency shift, BER and large PAPR. In order for OFDM systems to meet the strict requirements of time and frequency synchronization, guard interval, guard band and to reduce OOBE in the real-world applications at the cost of spectral and/or power efficiency, large PAPR values and reduced bit error rate (BER) performance are studied.

Fifth generation (5G) radio access technology is expected to take a huge advantages [2] over previous radio generations by supporting cognitive radio and machine type communication. Different Access techniques for 5G are Filter Bank Multicarrier (FBMC) [3], Universal Filter Multicarrier (UFMC) [4], and Generalized Frequency-Division Multiplexing (GFDM) [5]. Among these techniques, FBMC is more suitable waveform candidate for 5G because of its high spectrum utilization and reduced out of band emissions. Though FBMC has the drawback of CFO and TO synchronization, but this system is very sensitive to the carrier parameters at the receiver side.

Frequency localized prototype filters, such as the PHYDYAS filters, with linear multi-tap equalizers and BER performances are better for FBMC compared with OFDM [6] and with other 5G radio access technologies. Meanwhile, this access method attains high spectral efficiency by removing the guard band. The channel estimation becomes difficult because of the real field Orthogonality for FBMC [7]. This paper proposes new Zadoff-chu sequence [8] based preamble design with FBMC/OQAM to study the performances of PAPR, CCDF and BER.

The organization of the paper is as follows: Section 2 reviews the Related Work, Section 3 discusses problem statement and the System Architecture of proposed System. Section 4 gives the Simulation Results. The Conclusion is presented in Section 5.

2. Related Work

Recent discussions on the 5G wireless communications have initiated a much stronger wave other than OFDM systems. A number of proposals have been made to adopt new waveforms with improved spectral containment. The 5GNOW project started in Europe, encounters challenges in LTE and LTE-Advanced [9] in coping with the dynamic needs of 5G. The 5GNOW have identified some alternative choices of waveforms to better serve 5G needs. These waveforms are built based on different types of filtering, among this FBMC method suits different needs of various applications. But it is also have some drawbacks in frequency and timing synchronization at the receiver.

In the past, number of authors have looked into the problem of CFO and TO in FBMC [10]. However, the approaches taken in those studies are different from the work presented in this paper. While here preambles and pilots for carrier and timing acquisitions are used, most of the past works operate based on the statistical properties of the FBMC signals, i.e., they are blind methods. Blind synchronization of carrier offset and timing estimation method for the FBMC method [11] have been proposed without knowledge of channel. The work presented in [12-14] does not mention the short preamble, but assumptions are made that CFO must be in the range of half symbol spacing. The long preamble proposed are based on a set of complex-valued pilot symbols that occupy all subcarriers. There are lot of difference in the long preamble proposed in [15-16] and the one proposed in [17- 18] is real-valued and only occupies the alternate subcarriers, the remaining subcarriers are left empty. This modification of the long preamble as demonstrated through numerical results in [1] improves the accuracy of the CFO estimates significantly but it consumes the spectrum, it remains major drawback.

3. Problem statement:

In OFDM, Orthogonality between subcarriers allows controlling ICI by ensuring time and frequency synchronization at the receiver. OFDM has very large side lobes, rectangular pulse shaping exhibit poor stop band attenuation and requires guard band at spectrum in order to control out-of-band emissions. OFDM uses cyclic prefix to reduce ISI, which limits the spectral efficiency. These problems are overcome by FBMC/OQAM which adopts Zadoff-chu sequence based preamble to reduce the carrier frequency and timing synchronization. The proposed method does not transmit a cyclic prefix or guard band and shapes subcarriers using well frequency-localized waveforms that suppress signals side lobes, thus providing larger spectral efficiencies.

The system complexity has been reduced by preamble based (or pilot based) synchronization. Zadoff-Chu sequence based preamble is proposed to reduce the CFO and STO estimation that avoids intrinsic interference and has been used for channel estimation. In this paper, a periodic Zadoff–Chu sequence preamble is considered; both STO and CFO estimators are designed based on a least-square approach. This is a time domain approach which exhibits a stable performance independently of the actual TO. This method also provides good robustness against multipath channels but has rather moderate complexity. By using Zadoff–Chu sequence preamble, accurate CFO has been obtained to see the reduced PAPR results and improved BER performance.

3.1 System Architecture

The focus of the proposed architecture is to obtain better spectral efficiency using Zadoff-chu sequence based preamble design with FBMC/OQAM to minimize the BER. The proposed system architecture is shown in the Figure 1.

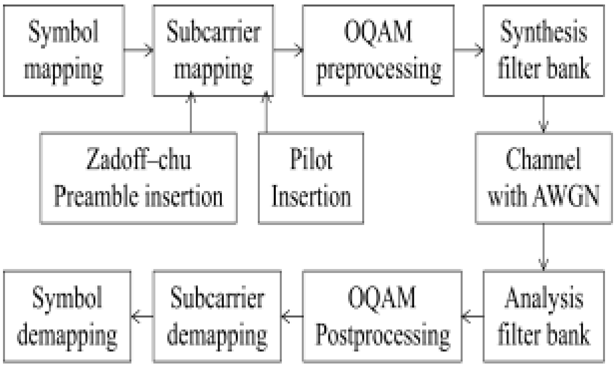

Fig 1. Proposed block diagram for FBMC

The block diagram consist of transmitter, receiver and channel with additive white Gaussian noise. The Transmitter consists of Symbol mapping, where the digital data is modulated using the any one of digital technique namely QPSK, 4-QAM or 64-QAM and BER [19] of the system mainly depends on this block. The need of subcarrier mapping would be useful for the FBMC frame creation that consists of preambles, data pilots and data subcarriers. Each FBMC frame is equipped with a preamble that is specially designed for fast tuning of carrier frequency and timing synchronization at the receiver, upon the receipt of each packet. Pilots [20] are used for the efficient channel estimation and equalization that is needed in order to realize spectral efficiency, spectrum sharing approaches or high mobility scenarios. OQAM processing scheme simultaneously employs an improved pulse shaping, and interpolation by factor 2 for transmit at the Nyquist rate. The additional filtering [21], together with the IFFT/FFT operation and serial to parallel conversion forms a synthesis filter-bank structure, where the prototype filter is designed to significantly suppress ISI.

The ideal receiver performs the exact opposite operation to that of transmitter. The parameters (time, frequency and phase) of transmitted FBMC signal must be observed exactly across the receiver. They are timing and frequency synchronization, channel estimation, channel equalization [22] and phase tracking. In FBMC, Timing Offset (TO) and Carrier Frequency Offset (CFO) results in ISI (Inter-Symbol Interference) and ICI (Inter-Carrier Interference). Pilot aided and blind synchronization methods are used to provide the synchronization**.** FBMC only satisfies the Orthogonality in the real domain, which causes it suffering from intrinsic interference even if perfect Timing and frequency synchronization is achieved. However, to avoid the intrinsic interference originated from neighboring symbols in the time domain, more than a couple of FBMC symbols either pilots or preambles must be allocated only for channel estimation purpose. Generally the pilots are used to cancel the interference. By doing so, the received main pilots become interference-free, and channel estimation can be performed.

3.2 Zadoff-chu sequence based preamble design

Fig.4.1.FBMC data packet with short and long preambles

The short preamble consists 10 cycles of a periodic signal. The short preamble consists of a summation of multiple tones of subcarrier with wider separation than the subcarrier spacing to allow detection of large CFO values. It is used to find a coarse estimation of CFO, so that the CFO will be within the range of half symbol spacing. The payload contains information such as the length of the frame, the data rate and the channel code. As in OFDM, the long preamble does not start with a guard interval. By the end of long preamble, all synchronization steps have to be completed and the receiver should be ready to correctly detect payload part of the packet. The long preamble in FBMC frame is positioned such that the underlying filters do not overlap with the short preamble and the payload part of the frame.

The design consideration is made in the proposed work to achieve this, the length of the long training should be at least equal to the length of the prototype filter (K) plus by a factor 2. Hence, efficient prototype filter leads to a shorter preamble and thus bandwidth efficient system is more. This is analyzed by using wider subcarrier that increases the bandwidth of each subcarrier, accordingly reduce the symbol period and the length of the corresponding prototype filter. The proposed preamble makes an attempt to control the length of the preamble that improves the bandwidth efficiency. This results in improvement of BER and reduction in PAPR values. A longer preamble allows a more accurate estimate of CFO and the key parameter for preamble design is FBMC that satisfies both conditions.

The proposed Zadoff–Chu (ZC) sequence is efficiently utilized for generating a long preamble that achieves superimposed ZC sequences used for preamble symbols.

Zadoff–Chu sequences are currently using in the 3GPP LTE Long Term Evolution air interface in the Primary Synchronization Signal, uplink control channel, uplink traffic channel and sounding reference signals. Thus the proposed zadoff chu sequences will be useful for random accessing of preamble in 5G evaluation. The proposed Zadoff–Chu sequences are an improvement over the Walsh Hadamard precoding [18] used in universal mobile telecommunication because they result in a constant-amplitude output signal, reducing the cost and complexity of the radio's power amplifier.

ZC sequence is generated by

$$x_u(k) = e^{-\frac{j\pi uk(k+N\mathrm{mod}2)}{N}}, k = 0,1,\ldots.N-1.$$

where, u is the root index, there are two root indexes considered in this paper “ZC_RootIndex1” and “ZC_RootIndex2”. The two root indexes are used to generate two different sets of preamble that generates a repeated structure of preamble. The repeated structure of preamble are also useful for carrier frequency, timing synchronization and channel estimation. N is the length of the sequence, which is obtained by the number of subcarriers used in the FBMC.The preamble is generated and FBMC frame is created by using the Zadoff chu sequence preamble. Now, this frame is transmitted over the channel with additive white Gaussian noise. The parameters of frame gets affected due to the noise, the receiver must be able to detect the noise and generate the accurate results. Thus, the Zadoff- chu preamble is useful in receiver section.

3.3 Carrier frequency offset and Timing offset synchronization

The carrier frequency offset is achieved by angle of the correlation peak and the timing offset synchronization is achieved by the cross-correlation between local proposed ZC sequences and received preamble sequences. The searching range is one frame length, so the maximum delay of the input signal should not exceed one frame length. The peaks selected for estimation is chosen by filter coefficients and the number of preamble symbols per frame and the interval between two filter tap is the time that a preamble symbol last.

3.4 Channel estimation

The proposed preamble symbol is chosen to do channel estimation as it can be used to generate pilot sequence. The value of preamble symbols in transmitter is known and the repeated structure formed cyclic prefix in preamble that make it robust to multipath. The least-squares channel response estimate at subcarrier i can be obtained as: Hi=Yi/Xi, where Yi is the received symbol and Xi is the transmitted preamble symbol on the i^{th} subcarrier.

3.5 Phase Tracking

The compensated phase is estimated by pairs of pilots and zc sequence preambles in frame. The tracking aims at computing a channel estimate by using transmitter and receiver data on the pilots at two different time instants. The phase is calculated as mean value of the angles of pilots and preambles.

4. Simulation Results

The Proposed work uses the following simulation parameters for the performance metrics such as Complementary Cumulative Distribution Curve (CCDF) for FBMC signal with different multicarrier to analyze the Peak to Average Power Ratio (PAPR) and BER, MSE for spectral analysis. The frequency offset and timing offset with respect to MSE is also considered.

Simulation Parameters

Modulation Type	QPSK or 4-QAM
Number of Sub Carriers	128 (120 for Data carriers, 8 for Pilot carriers
Sampling Rate	20MHz
Carrier Signal Power (1GHz)	0.01w
Prototype Filter	PHYDYAS
Filter Overlapping Factor	4 (P[0] =1, P[1]=0.9715983, P[2]=1/√2,P[3]

	=0.235)
FBMC Root Index 1	7
FBMC Root Index 2	3

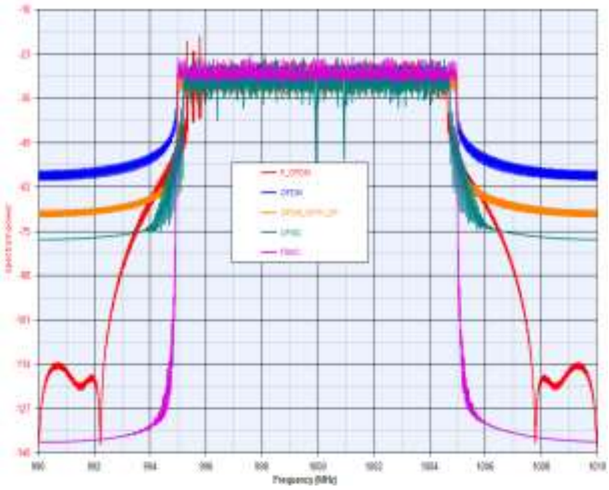

Fig 2. Frequency Vs Spectrum Power

The performance of Frequency over Spectrum power is shown in Fig.2. The OFDM utilizes the frequency spectrum of 10MHz bandwidth out of which 9MHz is utilized for subcarrier transmission and remaining 1MHz is utilized for guard band which wastes the spectrum. To overcome this issue, different multi carrier techniques such as F-OFDM, GFDM, UFMC and FBMC for 5G spectrum is analyzed. The observation shows that the FBMC technique is much better than the other multi carrier techniques due to the efficient usage of spectrum. The proposed FBMC method efficiently suppresses the side lobes and reduces out – of – band emission. It is observed that FBMC with well-designed preambles and prototype filters helps to improve the spectrum of each sub carriers within limited bandwidth.

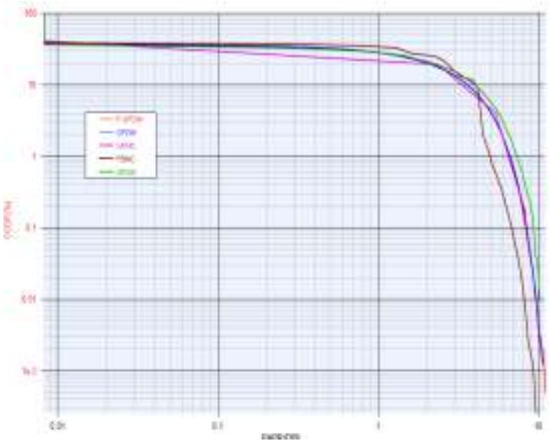

Fig 3. PAPR Vs CCDF

The performance of PAPR over CCDF is shown in Fig.3. PAPR is the common metric to characterize the amplitude fluctuations of the signal. These amplitude fluctuations results in out of band emissions, spectrum re-growth, causing ICI and ISI. The CCDF curve shows how much time the signal spends at or above a given power level. The PAPR value of FBMC is reduced to 2dB for 1% of CCDF while compared with other access techniques of 5G. The F-OFDM and UFMC has the same PAPR values of OFDM but GFDM has more PAPR values than OFDM which becomes a drawback for GFDM.

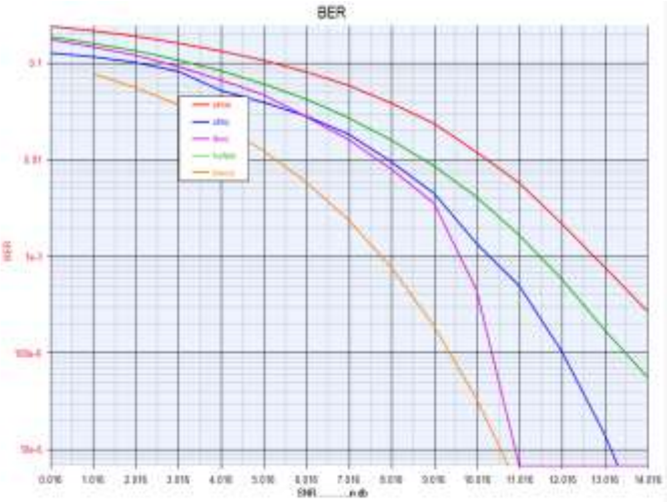

Fig 4. SNR Vs BER

The performance of SNR over BER is shown in Fig.4. The BER response of FBMC is much better than OFDM and UFMC. At 1e^{-4} of BER, the SNR of FBMC is decreased by an amount of 1.6 dB to UFMC, 3dB to F-OFDM and 5.5 dB to OFDM. It is observed that the FBMC BER response is nearer to the theoretical response such as QPSK BER.

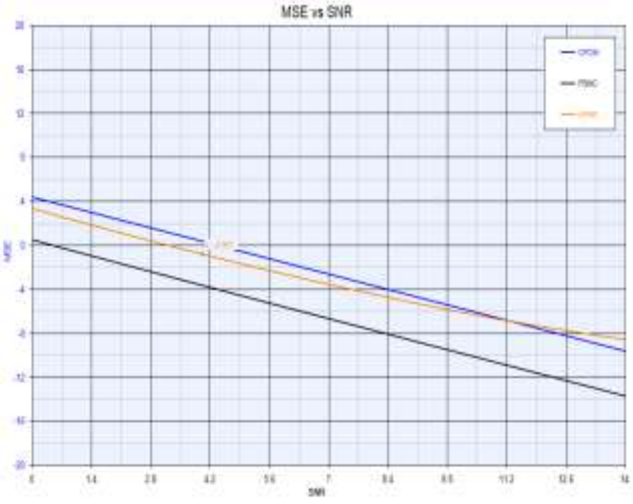

Fig 5. SNR Vs MSE

The performance of SNR over MSE is shown in Fig.5. The intrinsic interference originated from neighboring symbols in time domain severely damages the pilot signal in the channel estimation stage leads to poor estimation accuracy. So to analyze the channel estimation, the Mean Square Error (MSE) as a function of SNR founds to be useful. The FBMC scheme has almost no loss in most SNR ranges while OFDM scheme has a very big loss at all SNR points. Approximately, 6dB gain could be achieved by FBMC over the OFDM. Such improvement is due to the efficient interference utilization property.

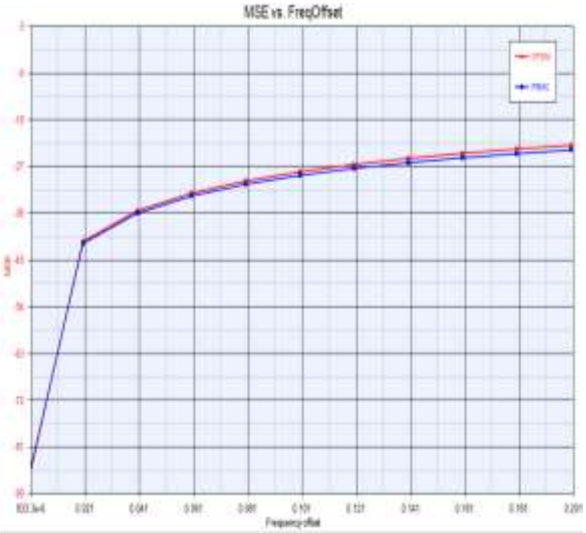

Fig 6. Frequency offset Vs MSE

The performance of Frequency offset over MSE is shown in Fig.6. In OFDM, imperfect frequency domain synchronization among different uplink users leads to MSE caused by inter-carrier interference (ICI). In FBMC, even a small CFO causes loss of Orthogonality among the different subcarriers and thus introduces ICI. Furthermore, carrier frequency offset (CFO) results in ISI in a multi carrier OQAM system. The graph presents mean square error (MSE) or distortion in terms of ICI, ISI at the receiver. Based on the observation, FBMC has 1.2 dB less distortion than OFDM during the normalized carrier offset. As a result, if a system requires high SNR, FBMC outperforms than OFDM in terms of CFO immunity. This indeed is an important gain in a system with high data rate when higher order modulations are required.

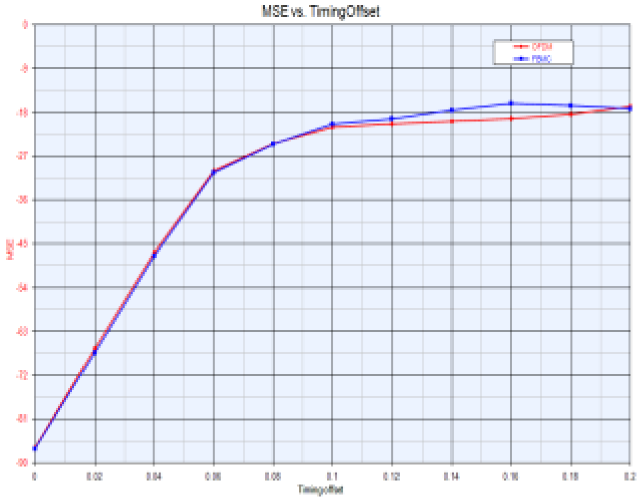

Fig 7. Timing offset Vs MSE

The performance of Timing offset over MSE is shown in Fig.7. The amount of multiuser spectral leakage due to STO for any multicarrier waveform is closely related to the discontinuities in the observation window at the receiver. Moreover, filtering at both transmitter and receiver sides helps to mitigate the performance loss caused by the timing offset. It is observed that FBMC has 0.2 dB less distortion than OFDM at the timing offset. The proposed preamble base FBMC scheme has performed better than conventional multicarrier scheme .Therefore, it is crucial to have accurate timing offset estimation methods when higher SNRs are required.

5. Conclusion

This paper proposes a new preamble design and corresponding channel estimation algorithm for FBMC/OQAM system. The Zadoff chu sequence used to generate the long preamble structure for the frame. The performance results show that the proposed preamble based method performs well than the conventional preamble structure in the following attributes of spectral efficiency, and reduced PAPR values. Moreover, the proposed algorithm has low complexity which makes efficient BER performance with respect to SNR and MSE for corresponding frequency offset and timing offset. Hence it can be directly applied to advanced mobile systems like 5G. This work can be extended to MIMO FBMC in future because it offers many exciting problems for research.

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