Spectrum Sensing of FBMC Signal Based on Auto Correlation

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Abstract - The focus of this paper is on a feature detector for filter bank multicarrier (FBMC) signal in cognitive radio. In this paper, we first prove that the FBMC signal samples are uncorrelated with each other. However, if the FBMC signal is processed by our proposed method, then the autocorrelation function (ACF) of FBMC signal becomes non-zero at the lag equal to number of subcarriers. On the other hand, additive white Gaussian noise (AWGN) samples after the same proposed processing remain uncorrelated. Using this feature, an autocorrelation based feature detector is proposed to detect FBMC signal in noise. The main advantage of the proposed detector is that, unlike blind detectors, this detector can distinguish between FBMC signal and noise (or interference). Next, the distribution of the test statistic of the proposed detector is derived under noise-only scenario so that the threshold of the Neyman-Pearson detector can be designed to maintain constant false alarm rate while maximizing the probability of detection. Simulation results demonstrate the efficacy of the proposed detector

Index Terms - Autocorrelation, cognitive radio, FBMC signal, feature detector.

I.INTRODUCTION :

Orthogonal Frequency Division Multiplexing (OFDM) has been a dominant technology in 4G LTE-Advanced. However, OFDM might be a misfit for future generation cellular technologies such as 5G and cognitive radios due to some disadvantages such as loss in spectral efficiency due to cyclic prefix (CP) insertion, high out-of-band radiation and sensitivity to narrowband interferers. As shown in main outcomes of EU research projects 5GNOW and PHYDYAS, filter bank multicarrier (FBMC) is a promising alternative to OFDM for 5G and cognitive radios, respectively. FBMC uses well designed bank of filters with minimum out-of-band radiation and no use of CP means significant improvement in the spectral efficiency. Spectrum sensing is one of the most important tasks in cognitive radios. In the traditional cognitive radio standards, the main problem has been to detect the presence of primary (licensed or legacy) user using incumbent geolocation databases and spectrum sensing techniques. However, the challenging problem of heterogeneous secondary coexistence has garnered very less attention in the cognitive radio standards and related literature. Since 5G will involve multitier heterogeneous networks in heterogeneous bands (licensed as well as unlicensed), acquiring spectrum awareness regarding the secondary users is equally important.Moreover, the use of new waveforms in 5G PHY will necessitate design of the spectrum sensing algorithms for the new candidate waveforms. As FBMC is one of the few most potential candidates for 5G waveform, sensing and distinguishing FBMC signal is a very relevant problem. As such, the focus of this paper is on proposing spectrum sensing scheme for FBMC signal. In spectrum sensing literature, most of the detection schemes have been designed for OFDM signal and there is a dearth of research on spectrum sensing of FBMC signal.Although blind detection techniques such as energy detection can be used to detect any waveform, they cannot distinguish between noise and interfering signal. In addition they have serious issues such as SNR walls, a feature detector was proposed based on the induced repeating patterns in the transmitted FBMC signal. Thus there is a dearth of feature detectors for FBMC signal in the spectrum sensing literature. With this as motivation, a feature detector is proposed in this paper which can distinguish between FBMC-plus-noise and noise-only scenarios. Also unlike, no attempt is being made to induce patterns in the basic FBMC transmission.

The specific contributions of this paper are:

- It is shown that the autocorrelation function (ACF) of the FBMC signal is zero for non-zero lags.
- After proper study of FBMC signal generation, a method is proposed to process the FBMC signal at the receiver so that the processed FBMC signal has non-zero ACF value at a certain lag value other than zero. On the other hand, if the same processing is applied to AWGN samples, the processed noise samples remain uncorrelated.
- A spectrum sensing scheme is proposed to detect the differences in ACF behavior of the processed (or modified) data in the two scenarios of FBMC-plus-noise and noise only.
- The conditional distribution of the proposed test statistic, conditioned on the received signal being only noise, is derived so that the threshold for Neyman-Pearson detector can be evaluated analytically

OFDM has been researched and deployed for broadband wired and wireless communications for the past two decades. OFDM is widely adopted because of a number of advantages that it offers: Orthogonality of subcarrier signals that allows

- Trivial generation of transmit signal through an inverse fast Fourier transform (IFFT) block
- Trivial separation of the transmitted data symbols at the receiver through a fast Fourier transform (FFT) block
- Trivial equalization through a scalar gain per subcarrier

- Trivial adoption to multiple-input multiple-output (MIMO) channels.

II.LITERATURE SURVEY

[1] G. Wunder, P. Jung, M. Kasparick, T. Wild, F. Schaich: This article provides some fundamental indications about wireless communications beyond LTE/LTE-A (5G), representing the key findings of the European research project 5GNOW. We start with identifying the drivers for making the transition to 5G networks. Just to name one, the advent of the Internet of Things and its integration with conventional human-initiated transmissions creates a need for a fundamental system redesign. Then we make clear that the strict paradigm of synchronism and orthogonality as applied in LTE prevents efficiency and scalability. We challenge this paradigm and propose new key PHY layer technology components such as a unified frame structure, multicarrier waveform design including a filtering functionality, sparse signal processing mechanisms, a robustness framework, and transmissions with very short latency. These components enable indeed an efficient and scalable air interface supporting the highly varying set of requirements originating from the 5G drivers

[2] B. Farhang-Boroujeny: Recent discussions on viable technologies for 5G emphasize on the need for waveforms with better spectral containment per subcarrier than the celebrated orthogonal frequency division multiplexing (OFDM). Filter bank multicarrier (FBMC) is an alternative technology that can serve this need. Subcarrier waveforms are built based on a prototype filter that is designed with this emphasis in mind. This paper presents a broad review of the research work done in the wireless laboratory of the University of Utah in the past 15 years. It also relates this research to the works done by other researchers. The theoretical basis based on which FBMC waveforms are constructed is discussed. Also, various methods of designing effective prototype filters are presented. For completeness, polyphase structures that are used for computationally efficient implementation of FBMC systems are introduced and their complexity is contrasted with that of OFDM. The problems of channel equalization as well as synchronization and tracking methods in FBMC systems are given a special consideration and a few outstanding research problems are identified. Moreover, this paper brings up a number of appealing features of FBMC waveforms that make them an ideal choice in the emerging areas of multiuser and massive MIMO networks.

[3] B. Sujitha Gowri, Dr. P. Ramana Reddy: OFDM is the basic multi carrier modulation technique for both wireless and cellular communications. OFDM is a perfect choice for point-to-point communication, which offers minimum complexity and achieves very high bandwidth. However, it has several challenges such as, limited spectral efficiency and large out of band emissions. In order to overcome these challenges, there are several modulation techniques being developed in these days, among these Filter Bank Multi Carrier (FBMC) is one of the techniques.This paper describes about Power Spectral Density (PSD) and Bit Error Rate (BER) of the FBMC and conventional Cyclic Prefix (CP) based Orthogonal Frequency Division Multiplexing (OFDM) systems under Additive White Gaussian Noise (AWGN) channel. FBMC technique has less out of band emissions as a result of less number of side lobes. Meanwhile, the omission of CP improves the bandwidth efficiency of the system.

III.FBMC SIGNAL STRUCTURE

FBMC is a multicarrier transmission technique that is an attractive alternative to the OFDM technique. In OFDM, FFT acts like a filter using rectangular window in time domain which amounts to frequency response at each subcarrier (or subchannel) being a sinc function. The sinc function has high side-lobes resulting in out-of-band ripples. In FBMC, in order to reduce the out-of-band ripples, the main-lobe of filter-frequency-response at each subcarrier is spreaded while side-lobes are reduced so that only adjacent subchannels are overlaping as shown in Fig. 1. In the figure, the even (or odd) indexed subchannels are separated and there is overlap between adjacent subcarriers. As a result of spreading the main-lobe in frequency, the subcarriers are no longer orthogonal in FBMC as they were in OFDM. However, there are several advantages of this design: side-lobes are significantly lesser as compared to OFDM, no inter-channel-interference from all subcarriers (except from the immediate neighbour's) as in OFDM in the presence of carrier frequency offset. The orthogonality between adjacent subchannels in FBMC can be achieved using offset quadrature amplitude modulation (OQAM) modulation technique. In this paper, we consider OQAM-FBMC implementation employed in [5], [11].

As overall frequency spread of the response has significantly reduced in FBMC, the impulse response of the filter spreads in time beyond one symbol period and the symbols overlap in time domain. The number of symbols that overlap in time domain is given by the parameter K, known as overlapping factor. In this paper, the overlapping factor considered is K = 3. The design of the prototype filter (or the first filter in the filter-bank) is based on Nyquist criterion as explained in [5]. Next, the filter bank is obtained by multiplying the prototype filter coefficients by e j2πln N where l is the index of l th filter in the bank and n is the index of input data element given to IFFT.

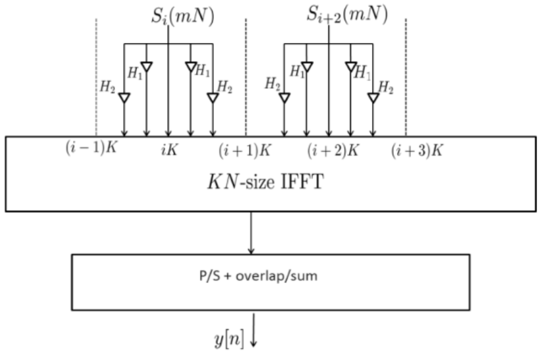

Fig. 1: Weighted frequency spreading and extended IFFT for $K = 3$. Here, i is subcarrier index, m is symbol index and N is number of subcarriers [5].

In OFDM, each data element given to the subcarrier of the N−size IFFT block modulates a single carrier whereas in filter-bank, each data element applied to KN−size IFFT modulates $(2K - 1)$ sub-carriers due to the overlapping factor K. Thus, single data element is spread over many IFFT inputs. This operation is known as *weighted frequency spreading* [5]. As shown in Fig. 2, input element $S_i[mN]$, with $0 \leq i \leq (N-1)$ and m as the symbol index, modulates $(2K - 1)$ carriers centered at iK subcarrier. The Prototype filter frequency coefficients are chosen in such a way that they satisfy Nyquist criterion for zero ISI [12]. These filter coefficients are obtained as [13]:

$$\begin{aligned} H_0 &= 1 &&; H_k^2 + H_{K-k}^2 = 1 \quad ; \\ H_{KN-k} &= H_k &&; \quad 1 \leq k \leq K-1 \qquad (1) \\ H_k &= 0 &&; K \leq k \leq KN-K, \end{aligned}$$

where N is number of subcarriers. Hence, using (1), the weights for $K = 3$ are obtained as $H_0 = 1$, $H_1 = H_{-1} = 0.911438$ and $H_2 = H_{-2} = 0.411438$. The corresponding impulse response **h** of length $KN = 192$ samples is shown

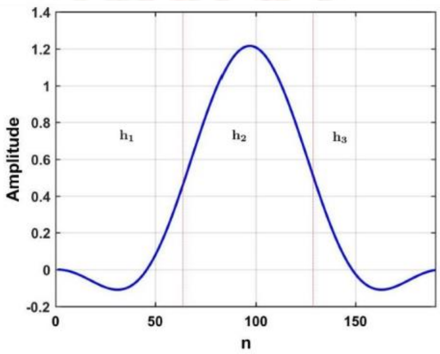

Fig. 2: Impulse response of prototype filter for $K = 3$ and $N = 64$ subcarriers. Here, n is discrete time index.

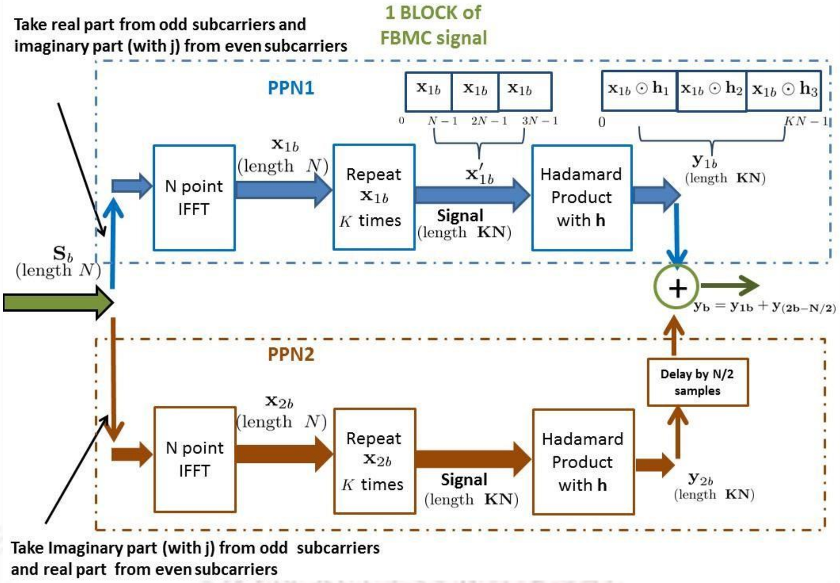

Fig. 3: FBMC block diagram

In OQAM technique, the real and imaginary parts of a complex symbol are delayed by half the symbol time and are not transmitted simultaneously, thus making the subcarriers orthogonal. The delay of half the symbol time introduced here reduces the capacity of the system. Hence, to achieve full capacity the symbol rate is doubled and two poly-phase networks (PPNs) are employed for low-complexity implementation of OQAM-FBMC so that the size of IFFT block reduces from KN to N [5]. As the focus of this paper is not to explain the efficient OQAM-FBMC implementation using PPNs, we direct interested readers to [5], [11] for discussion on actual efficient implementations of OQAM-FBMC using PPNs.

Next, we explain the FBMC signal generation described and implemented in [11], which is helpful in finding the structure in the FBMC signal, which in turn can be detected using a feature detector. Note that the implementation of weighted frequency spreading shown in Fig. 2 can be achieved by first loading every K^{th} subcarrier with data and then convolving with frequency response $H(k)$ of prototype filter, where k is subcarrier index. In time domain, this is equivalent to repeating the time-domain data-block K times and then multiplying the resultant data vector of length KN with **h**. This approach is used in this paper to generate the FBMC signal and is shown in Fig. 4. The FBMC transmitter section is shown in Fig. 4. Complex QAM/PSK symbols, $S[i]$, are fed to N-IFFT block of both PPN1 and PPN2 sections. In PPN1, real part of data is loaded on to sub-carriers of odd indices and imaginary part of data is loaded on to sub carriers of even indices. The PPN1 data vector corresponding to b^{th} block is represented by $\mathbf{x}_{1b}$. On the other hand, in PPN2, imaginary part of data is loaded on to odd subcarriers and real part of data is loaded on to even subcarriers. Each output block of KN samples of

PPN1 and PPN2 overlap by $\frac{N}{2}$ samples and the samples are added to give the transmitted FBMC signal $y[n]$. Here, $y[n] = y_1[n] + y_2[n - N/2]$ where $y_1[n]$ and $y_2[n]$ are the outputs of PPN1 and PPN2 sections, respectively.

IV.RESULTS:

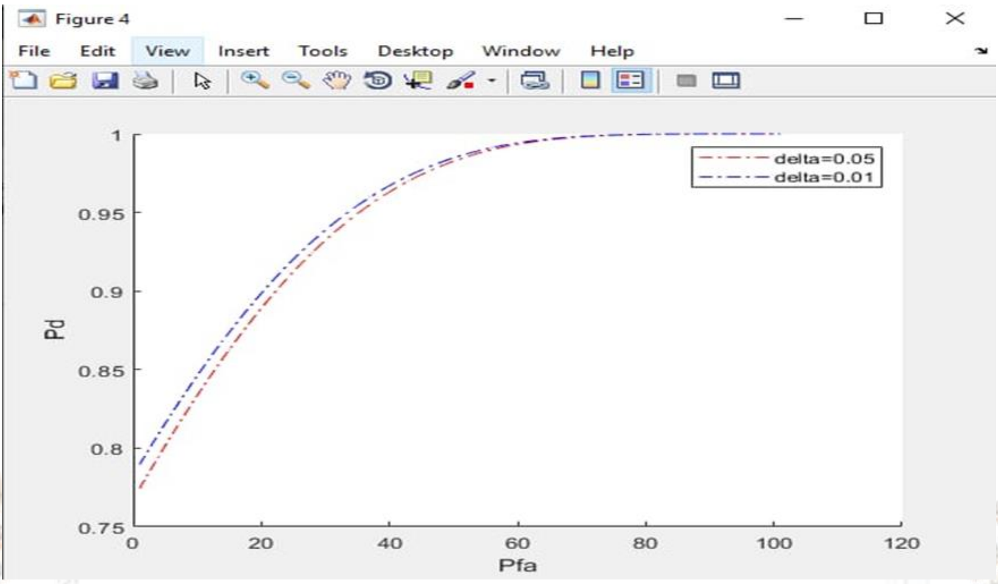

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Fig.4 Reciver operating characterstic (ROC) curves for FBMC signal for SNR = -10 Db With N=64.The number of Monte-Carbo relization

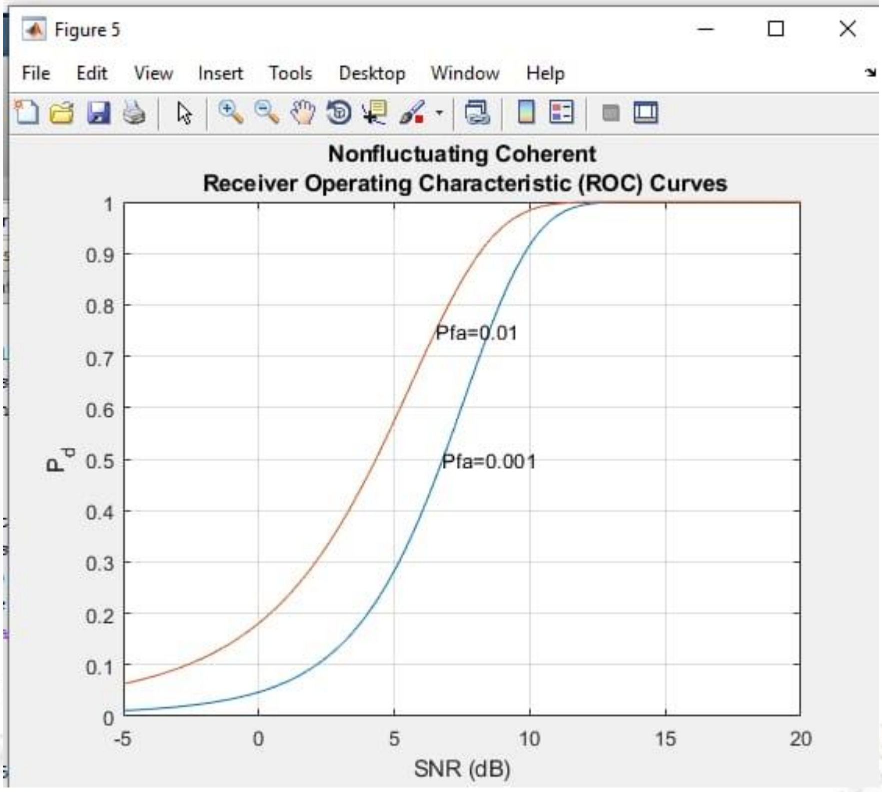

Fig.5:PD Vs SNR [dB] plot for FBMC signal for PFA =0.1 WITH N=64 and the Number of Monte-Carlo realizations=1000

V.CONCLUSION:

In this paper, we have demonstrated that FBMC signal does not have any autocorrelation property. However, after suitably modifying the received signal, the autocorrelation property is clearly visible. This property is used to differentiate between noise-only and FBMC-plus-noise scenarios. A detector is proposed and distribution of test statistic under the noiseonly scenario is derived so that the threshold for the NeymanPearson detector can be designed. It is demonstrated that the proposed autocorrelation detector has good performance. Further research would be carried out to analyze the performance of the detector under unknown noise variance scenario

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