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Non-Uniform Polyphase DFT Filter Bank for Cognitive Radio Sensing

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Abstract—For simultaneous multiple bands width sensing, a Non-Uniform Polyphase Discrete Fourier Transform Filter Bank introduced using two uniform Polyphase Discrete Fourier Transform Filter Banks. This proposal can be used for cognitive radio sensing in unlicensed Bands, A design example for the simultaneous extraction of three variable width channels (No. 42,58, and 114) related to the Bands U-NII-2A, U-NII-1, and U-NII-2C of the 5 GHz wireless communication Band IEEE 802.11ac is discussed. A computational cost reduction in the number of multiplication and addition operations was accomplished using the Non-Uniform Polyphase Discrete Fourier Transform Filter Bank, down to 78.3% and 85% compared to the needed operations to implement three pass band filters in the direct form. These examples expand the cognitive radio idea further to highlight the possibility of using this technology to detect active users transmitting in unlicensed, to avoid interference, collisions, and other good quality transmission constraints.

Index Terms— Non-Uniform filter bank, DFT filter Bank, Cognitive radio sensing, Polyphase filter bank, Filter bank

1. INTRODUCTION

The wireless application are increasing day after day. The static spectrum allocation and the inflexible spectrum management ,where each wireless operator has an exclusive license, made the spectrum crowded whereas most of the useful part of the spectrum are already booked ,there comes the need for dynamic access to the spectrum and hence developing the Cognitive Radio (CR)technology[1].

Spectrum sensing computational complexity performance depends on the of the sampling rate.

Polyphase DFT filter bank is computationally efficient scheme as compared to existing strategies, as it reduces the sampling rate by a factor M due to the use of decimation.

A prototype Low Pass Filter LPF has been employed as window sequence to form the polyphase components in the polyphase filter bank structure which has conventional frequency domain advantage in sensing the spectrum since (a) it reduced spectral leakage ,hence a better sensing performance is achieved (b) the reduced sampling frequency by factor M reduced the FFT computation [2].

2. SPECTRUM SENSING :

Cognitive radio application major element is the spectrum sensing. Sensing indicates detecting the spectrum holes (unused spectrum) and use it without causing interference with other users. Cognitive radio aims to manage the unutilized spectrum bands by the primary user and share it with secondary users.[1]

2.1. Cognitive Radio Receivers

The proposed Non-Uniform polyphase Discrete Fourier Transform DFT filter bank can be used in the cognitive radio system shown in the Fig.1 similar to the proposed in [3]and [2] where the analysis Filter bank is used as a channelizer then followed by one of the spectrum sensing techniques .

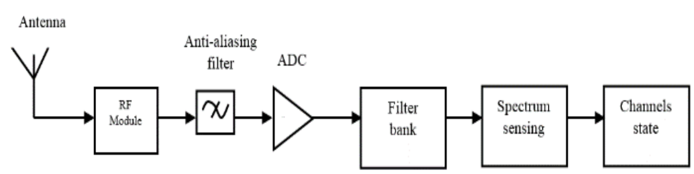

Figure 1: cognitive radio receiver

2.2. Cognitive Radio Sensing Technique

Cognitive radio non-cooperative sensing technique widely known are

a) Energy Detection , most common Method of spectrum sensing due to its minimal computational complexity and implementation cost [4].

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b) Cyclostationary Feature Detection It exploits the periodicity in the received primary signal to identify the presence of primary users (PU), the signal characteristics priori knowledge is required.

c) Matched Filter The optimum detection method when the transmitted primary user signal is known , the limitation this method , It needs a dedicated receiver for each type of primary user [1].

3. Uniform Polyphase DFT filter Bank

A computationally efficient structure that enables the implementation of i filters at the cost of just one prototype filter as shown in Fig.2. The prototype filter type must be FIR (Finite Impulse Response) LPF (Low pass Filter) Polyphase decomposition made an important advancement in Multirate signal processing [Bellanger , et al., 1976], [Vary, 1979],as it reduces computational complexity by a factor of M[5].

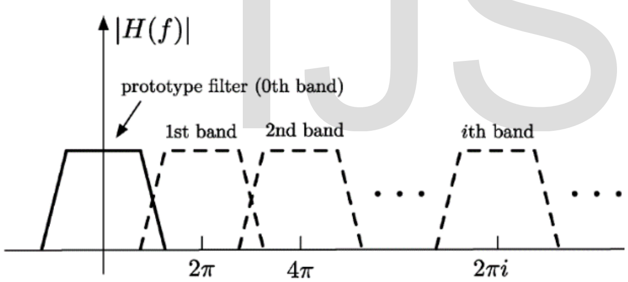

Figure 2 : The prototype LPF and the Obtained Sub-bands

3.1. The Structure

The polyphase DFT filter Bank represented in the Fig.3 , can extract the desired sub-bands number of any input signal Bandwidth by providing the suitable design requirement.

3.2. The Operation

The polyphase DFT filter Bank operation illustrated in the flow chart in Fig. 4 and it can be listed as follows:

- Delaying the signal by M-1.
- Parallel Decimation the delayed signal using Decimation factor equal to M.
- Parallel Filtering by the Decimated signal polyphase components originated from the LPF coefficients.
- Taken the Fast Fourier transform (FFT) of the parallel filtered signal, MATLAB uses the FFT algorithm to implement the DFT .

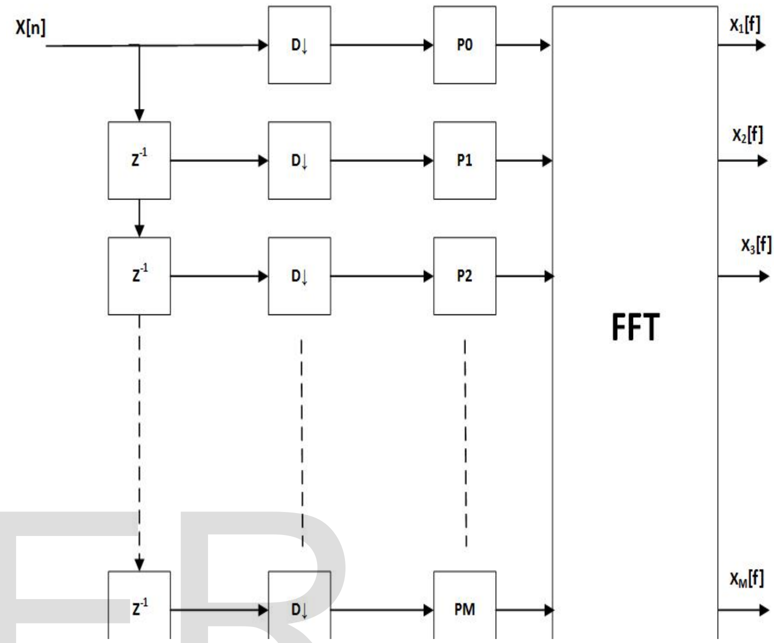

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Figure 3: The Polyphase DFT filter bank

3.3. Design Requirements

- Specify the number of Sub-Bands Needed.
- The number of polyphase branches, M need to be calculated.

$$M = \frac{\text{Sub\_bands number} - 1}{2} \quad (1)$$

- Suitable LPF designed to be used in the polyphase structure.
- Adjusting LPF coefficients to suit the polyphase structure.
- A decimation Factor, D↓ value must be specified.
- Choose suitable FFT block points.

3.4. Design Constrains

- The obtained Sub-Bands are uniform, if non-uniformity is needed, Manipulation of the design are made to achieve that purpose.
- To avoid Sub-Bands overlapping, the value of prototype LPF Passband width must be =1/M.
- The FFT blocked number of point value must to be a power of 2. for example, 2-point FFT ,4-Point and so on.

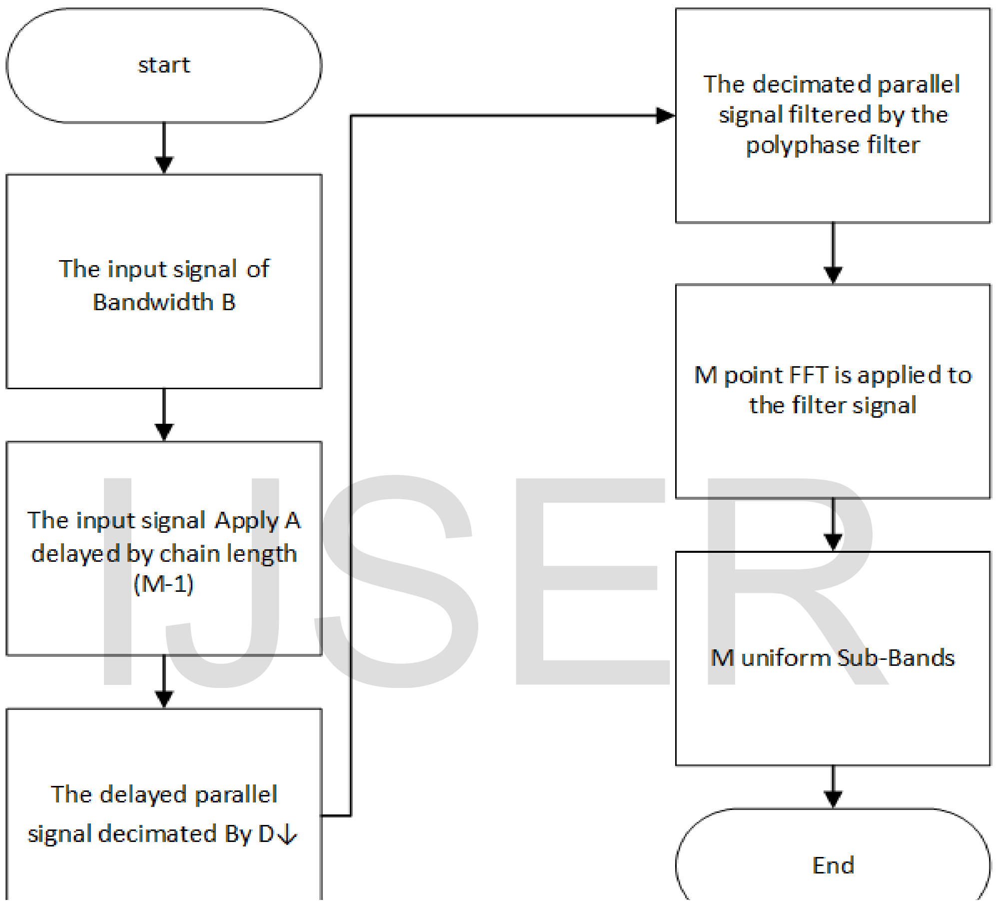

Figure 4: The polyphase DFT filter bank operation flow chart

3.5. Polyphase Components Design

The design steps:

- Specify M, the number of polyphase branches .
- Design Finite Impulse Response FIR Low Pass Filter LPF . The FIR LPF design method is the window method ,the filter specifications: The passband and the stopband frequencies, passband and stopband ripples to be chosen upon the design needs. The coefficients (h[0] ,h[1], ..h[L]) obtained will be rearranged in the polyphase branches
- Number of tabs N per polyphase branch is calculated by dividing the number of FIR Coefficient by M.
- The number of LPF Coefficients adjusted either by
- Zero padding or eliminating some of Coefficients to meet matrix dimension requirement.
- The polyphase filter components (P0,P1,…PM-1) will be created by arranging the FIR Coefficient in M branches and each branch will contain N Coefficients, the arrangement will be done as follows:

P0 = h[0] , h[M] , h[2M] - - h[NM]
P1 = h[1] , h[M+1] , h[2M+1] - - h[NM+1]

P2 = h[2] , h[M+2] , h[2M+2] - - h[NM+2]

PM-1 = h[M-1] , h[2M-1] , h[3M-1] - - h[NM+M]

4. The proposed Non-Uniform filter Bank

A MATLAB script was written to design the Non-Uniform polyphase discrete fourier transform filter bank, the design example will highlight all the design parameters used.

Design Example :

The proposed filter Bank shown in Fig.5 .This example was designed to detect three channels (No. 42,58 ,and 114) of width (80 ,80 ,and 160) MHz located in the Bands U-NII-2A ,U-NII-1 ,and U-NII-2C the cutoff frequencies are (5170–5250 , 5250–5330 , and 5490–5650) GHz with central frequencies (5210, 5290 ,and 5570) GHz respectively[6].Assuming the scanned spectrum Bandwidth 65 MHz .

The proposed filter bank structure is divided into two main parts each with different specification:

1. The first part :

The decimation factor used was 64 , the LPF pass band width of 0.1 ,as shown in Fig.6.a contain 160 coefficients (H`0 ..H`159) and only 128 coefficients was needed to implement the polyphase structure (H`0 ..H`127) ,the filter was designed by hamming window method using MATLAB the M chosen = 64 which represents the number of branches and the number of tabs in each branch N = 2, arranged in a matrix and each row contained the following coefficients :

P`0 = H`0 , H`63 , P`1=H`1 , H`64 , P`2 = H`2 , H`65 ,…… P`63 = H`1 , H`127 .

A 64 points FFT was used and it produces 64 output (X`1 ,X`2,…X`64) . The output in this part was taken from X`27 .

2. The second part:

The decimation factor used was 16 , the LPF pass band width of 0.045 ,as shown in Fig.6.b, contain 160 coefficients =(H0 ..H159) designed with hamming window method using MATLAB the M chosen = 16 which represents the number of branches and the number of tabs in each branch N =10 .

arranged in a matrix and each row contained the following coefficients:

Po = H0, H16, H32, H48, H64, H80, H96, H112, H128, H144.

P1= H1, H17, H33, H49, H65, H81, H97, H113, H129, H145.

:

P15 = H15, H31, H47, H63, H79, H95, H111, H127, H143, H159.

A 16 points FFT was used and it produces 64 output (X1 ,X2,…X16) The output in this part was taken from X3 and X4 .

5. Results and Analysis

Fig.7 shows the obtained Multiple bands width Channels from the proposed Non-uniform filter bank. Three sub-bands of different Bandwidths can be used as channels to sense three spectrum bands simultaneous. The implementation cost was of the proposed Non-uniform filter bank structure was calculated in Table 1. A good reduction in additions and multiplications operations required to implement the polyphase Non-uniform filter bank when compared to the ordinary direct form filter, as we will need to design three different passband filters to get the same channels.

The implementation cost needed to implement the an equivalent three bandpass filters are 6621 additions, and 3552 multiplications using the same filter order 159 for each filter , the high cost is due to the need of using an 256 point FFT as shown in Table 2 ,while the implementation cost for the proposed polyphase Non-uniform DFT filter bank is 656 additions, and 512 multiplications due to the polyphase structure and the use of the 16-points and 32-points FFT separately.

The example was designed to sense unlicensed bands, further we can use the same approach to sense licensed bands, since technically there is no difference between the these bands, but they were mainly a spectrum allocation according to global standards .

6. Conclusion

One Non-uniform configuration introduced as a design example to simultaneously extract multiple sub-bands of different bandwidths in which can be used as multiple channels to sense three different spectrum bands, using two Uniform Polyphase DFT filter banks. It can be used for reconfigurable multiple Bands sensing by developing another configuration. The polyphase representation was utilized to achieve lower cost and less complicated implementation. Since the Non-uniform DFT filter bank reduced number of operations, multiplications and additions needed down to 78.3% and 85%, respectively, when compared to direct form of pass band filters implantation to form a channelizer to sense the same three spectrum band.

The simultaneous extraction will minimize the sensing time; hence a faster detection of the sub-bands can be gained.

The example is about the unlicensed spectrum bands, which can expand the idea of cognitive radio to further approach to detect active users of these unlicensed bands to avoid interference and collusions , instead of focusing on detecting a primary users of the licensed band.

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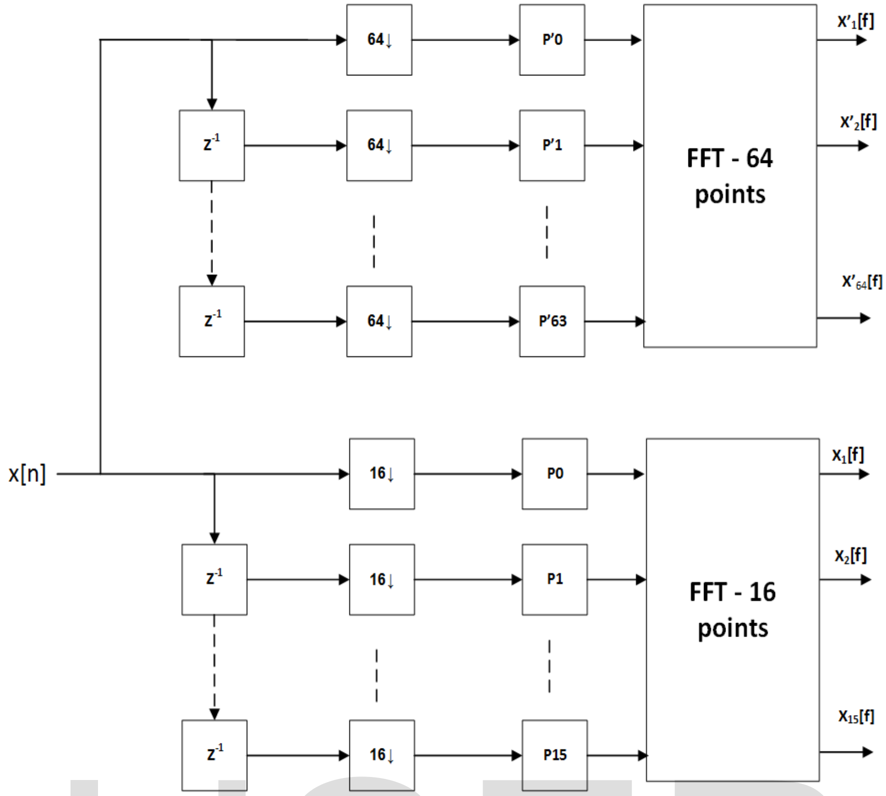

Figure 5: The proposed Non-Uniform polyphase DFT filter Bank

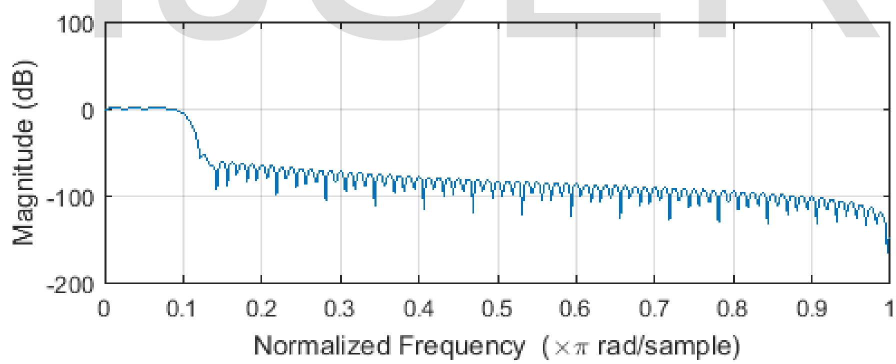

Figure 6.a : The magnitude and phase response of the LPF used in the first part

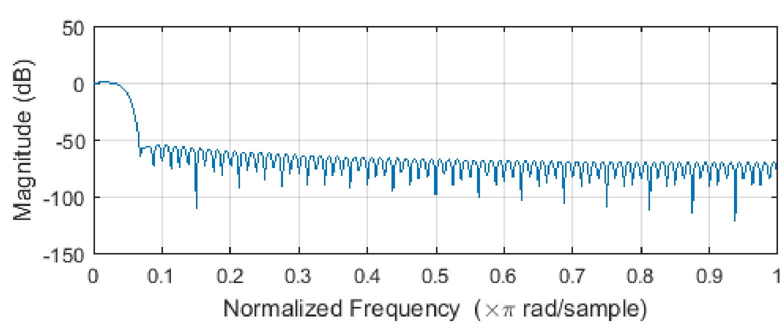

Figure 6.b : The magnitude and phase response of the LPF used in the second part

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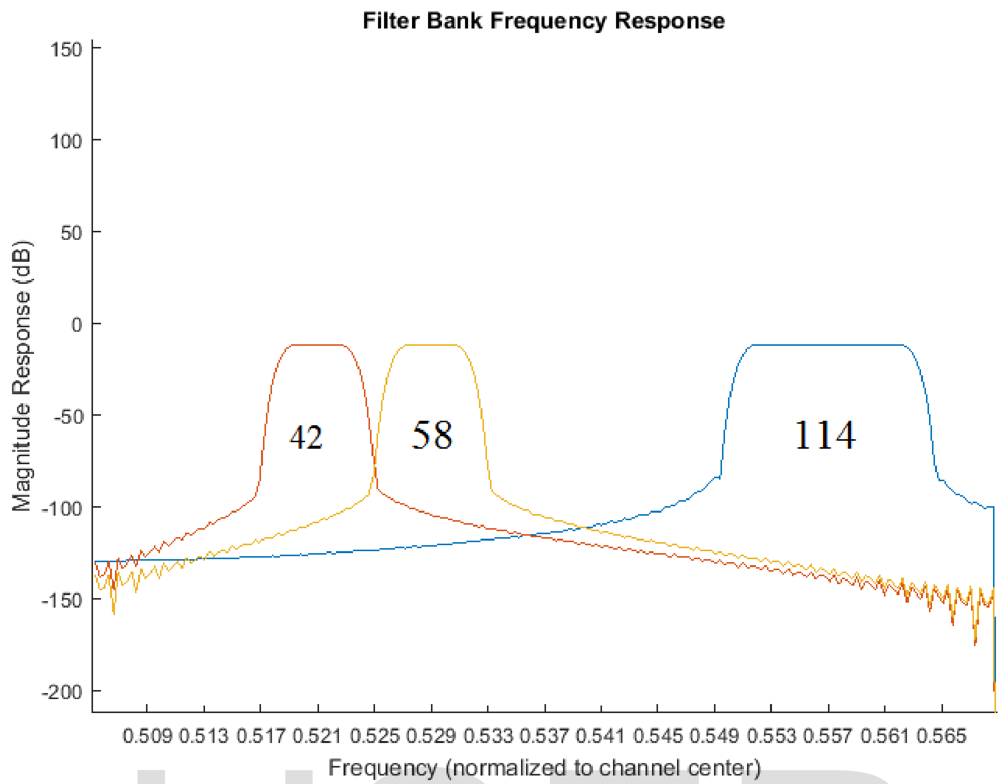

Figure 7: The channels obtained from Non-Uniform polyphase DFT filter Bank

Table 1: Non-uniform polyphase DFT filter bank implementation cost

Part	Polyphase filter Bank				M point FFT [7]		Total	
	No. of taps N	No. of branches M	Addition (n-M+1)	Multiplication (n+1)	Addition	Multiplication	Addition	Multiplication
1	2	64	64	128	384	192	448	320
2	10	16	144	160	64	32	208	192
							656	512

where n is filter order .

Table 2: Three filters implementation cost

	Filter cost in the direct form		256 points FFT cost[7]		Total	
Filter	Addition n+1	Multiplication n+1/M	Addition	Multiplication n	Addition	Multiplication
1	159	160	2048	1024	2207	1184
2	159	160	2048	1024	2207	1184
3	159	160	2048	1024	2207	1184
					6621	3552

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