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Low complexity reconfigurable channelizers using non-uniform filter banks☆

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ABSTRACT

A Software Defined Radio (SDR) channelizer needs reconfigurable sharp filter banks with low implementation complexity. In this paper, the design of non-uniform Modified Discrete Fourier Transform filter bank (MDFT FB) is proposed to be used in SDR channelizer. The frequency response masking technique is used to design the prototype filter which gives sharp filters with lower hardware complexity, compared to the finite impulse response filters. The canonic signed digit (CSD) representation is used in the design, to convert the continuous filter coefficients into discrete coefficients. Multi-objective artificial bee colony algorithm is utilized to improve the performance degradation when the CSD represented filter coefficients are used. Further, the shift inclusive differential technique with common sub-expression elimination is used to reduce the number of adders. Xilinx ISE is used to verify the hardware requirement, for the implementation of the non-uniform MDFT FB. Hence low complexity reconfigurable SDR channelizers using non-uniform MDFT FB is proposed in this paper.

1. Introduction

A digital Software Defined Radio (SDR) channelizer has to select a particular channel from a wide bandwidth signal. There are different kinds of wireless standards with different bands of frequencies. Hence a filter bank (FB) with non-uniform (NU) subbands is needed. The SDR channelizer requires a sharp filter to select a desired channel. The order of the sharp filter will be high when finite impulse response (FIR) filters are deployed. Hence, to design a prototype filter, the frequency response masking (FRM) technique is needed to reduce the hardware complexity [1]. In the literature various types of filter banks are proposed for the design of SDR channelizer [2–4]. In [5], the SDR channelizer is implemented for multiple IS-95 Code Division Multiple Access (CDMA) signals using a polyphase filter bank and uniform Modified Discrete Fourier Transform (MDFT) FB. Variable bandwidth filters are used in [2] for the design of the SDR channelizers. However, the design complexity is high due to the presence of two interpolators with high hardware complexity. A dynamic channelizer is designed in [3], using NU cosine modulated filter bank (CMFB). However, it does not have linear phase in the individual filters. In [4], NUCMFB is used for the design of the SDR channelizer. This gives lower hardware complexity when compared to the SDR channelizer proposed in [2]. However, the individual filters of the CMFB, do not have linear phase. Several other works related to SDR are available in the literature [6–8]. In [7], the SDR receiver is designed by utilizing the Field programmable gate array (FPGA) implementation of coefficient decimated polyphase FIR filter bank structure. In [8], a flexible channel extractor for wideband system based on polyphase filter bank is proposed. However, the hardware implementation complexity is seen to be high in [7,8].

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Due to the simple design procedure, the modulated FBs are the most preferred type of FBs. Among the modulated FBs, the CMFB and Discrete Fourier Transform (DFT) FB are the commonly used FBs. Here, only the prototype filter is needed to be designed [9]. If the prototype filter has linear phase, the whole FB will have linear phase. In DFT filter banks, no inherent aliasing cancellation structure is available whereas in MDFT FB an in-built structure is available to remove almost all aliasing, in order to give near perfect reconstruction (NPR) filter bank [10]. NPR filter bank design can be done with very low distortion as well as low aliasing. This leads to low computational as well as hardware complexities, compared to those of PR filter banks [9,11,12].

A technique to design non-uniform and reconfigurable MDFT filter banks which have near perfect reconstruction had been proposed by the authors in [13]. This NU NPR MDFT filter bank is utilized in the design of digital hearing aids in [14]. In this paper, the reconfigurable non-uniform MDFT FB is proposed to be used for designing a reconfigurable SDR digital channelizer with low hardware complexity. Here, the appropriate adjacent subbands of a uniform FB are merged to obtain non-uniform sub-bands. Hence, the properties of the NU MDFT FB such as aliasing, amplitude distortion and linear phase do not change from those of the corresponding uniform FB [13]. In this paper, to design a narrow bandwidth prototype filter, the FRM technique is utilized, which leads to low order sharp filters required for the SDR channelizer. To reduce the implementation complexity, the coefficients of the FRM prototype filter are expressed as discrete coefficients utilizing canonic signed digit (CSD) representation, which results in a multiplier-less filter.

The performance of the prototype filter and hence the non-uniform MDFT FB is degraded, when the CSD representation is used. Hence, the coefficients of the prototype filter have to be optimized using some optimization technique which gives a global optimal solution. Since the search space is discrete, meta-heuristic algorithms can be deployed [15]. In all the meta-heuristic algorithms, the various objective functions are weighted and combined to get a single solution. In order to get multiple solutions in a single run, the Pareto optimization method such as multi-objective artificial bee colony (MOABC), is a good option for multi-objective optimization problems [16,17]. By removing the adders which are utilized in the multiple constant multiplications (MCM) in the filter implementation, the complexity can be further reduced in the realization of the filters. There are various methods to optimize the MCM, which can decrease the complexity [16,18,19]. In [16], a modified shift-inclusive differential technique with common sub-expression elimination (SID-CSE) method is proposed, which reduces the number of adders in the discrete filter. By utilizing the FRM, CSD, modified MOABC and modified SID-CSE, the hardware complexity is made very low in the proposed SDR channelizer, when compared to the existing techniques. To supplement the theoretical data for low hardware complexity, the non-uniform MDFT FB is implemented using Xilinx ISE using Kintex7 FPGA.

The paper is organized as follows: the design of SDR channelizer using non-uniform MDFT FBs is proposed in Section 2 where the design of uniform MDFT FBs and non-uniform MDFT FBs are also included. The design examples are given in Section 3. Hardware complexity reduction techniques are detailed in Section 4. The results and discussions are given in Section 5. Hardware implementation using FPGA is shown in Section 6 and the conclusions are presented in Section 7.

2. The proposed design of a SDR channelizer using non-uniform MDFT FB

2.1. Uniform MDFT FB

The difference between the DFT FB and MDFT FB is that in the latter, the decimation is a two-step process. Instead of a decimation by M, the sub-band signals are initially decimated by $M/2$ in the first step. In the second step, each channel after decimation by $M/2$, is split into two sub-bands. Both the sub-bands are decimated by a factor of 2, with one sample delay in the second sub-band. Then the real and imaginary parts are separated in the alternate sub-bands. This is shown in Fig. 1 [10,12]. $Y_k^{(R)}(z)$ in Fig. 1 represents the real part and $Y_k^{(I)}(z)$ represents the imaginary part of the output of the k-th analysis filter, where $k = 0, 1, ...,M - 1$. The alias spectra in the adjacent channels is proven to be canceled in [10,12]. The alias spectra in the non-adjacent channels can be almost removed, provided the prototype filter has a high stop-band attenuation. In order to reduce the amplitude distortion error, the condition given in Eq. (1) must be satisfied [13].

$$\left|H\left(e^{j\omega}\right)\right|^2 + \left|H\left(e^{j\left(\omega-\frac{2\pi}{M}\right)}\right)\right|^2 = 1, \quad for \quad 0 \le \omega \le \frac{2\pi}{M} \tag{1}$$

At $\omega = \frac{\pi}{M}$,

$$\left|H\left(e^{\frac{j\pi}{M}}\right)\right| \approx 0.707 \tag{2}$$

This leads to NPR in the MDFT filter bank. Since down-sampling of $M/2$ is essential, M has to be even.

2.2. Design of the MDFT FB using FIR filters

The uniform MDFT FB is obtained by using the design of the prototype filter [13]. The specifications for a FIR prototype filter with sharp transition bandwidth are selected as shown in Table 1.