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Efficient design of multiplier-less digital channelizers using recombination non-uniform filter banks

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Abstract A novel approach for the efficient realization of digital channelizers in software defined radios using recombination filter banks is proposed in this paper. Digital channelizer is the core of software defined radio. Computationally efficient design supporting multiple channels with different bandwidths and low complexity are inevitable requirements for the digital channelizers. Recombination filter banks method is used to obtain non-uniform filter banks with rational sampling factors, using a two stage structure. It consists of a uniform filter bank and trans-multiplexer. In this work, the uniform filter bank and trans-multiplexer are designed using cosine modulated filter banks. The prototype filter design is made simple, efficient and fast, using window method. The multiplier-less realization of recombination filter banks in the canonic signed digit space using nature inspired optimization algorithms, results in reduced implementation complexity.

1. Introduction

Software defined radios (SDRs) were initially developed for military applications, but later on, the potential advantages of SDRs are explored and much attention was given for improving their performances. The digital channelizer in an SDR is used to select the desired narrow band channel from the wideband signal. The different wireless standards have different channel spacing or bandwidths. Hence non-uniform filter banks are highly suitable in such applications. The equal bandwidth channels can be efficiently extracted using polyphase DFT filter banks (Zangi and Koilpillai, 1999). Only the prototype filter is designed and all other filters are obtained from this filter by modulation. Channels with unequal bandwidths are not efficiently extracted with uniform DFT filter banks.

The non-uniform filter bank channelizer using tree structured filter banks is given in Fung and Chan (2002). The tree structured filter bank has a long system delay and the non-uniform decomposition has constraints on bandwidths. The channelizer proposed in Li et al. (2008) obtains the non-uniform subbands by merging the adjacent channels of a uniform cosine modulated filter bank. The number of adjacent channels merged should be an integer multiple of the upper

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bandedge frequency. However, this method is suitable only for non-uniform channels with integer decimation factors.

The non-uniform filter bank design by merging the adjacent channels of a uniform filter bank result in integer sampling factors (Kumar et al., 2013). A method to design non-uniform filter banks with rational sampling factors was proposed by Cox (1986). It consists of a two stage structure, in which some of the channels of the analysis filters of a uniform filter bank are combined using the synthesis filters of a transmultiplexer (TMUX) with less number of channels. The non-uniform filter banks, thus obtained are called recombination filter banks. Later Xie, Chan and Yuk had extensively analysed the topic and suggested different modifications (Xie, 2004; Chan and Xie, 2006).

In this paper, we propose a new approach for the design of the digital channelizers of software defined radio using recombination filter banks. The uniform filter bank and trans-multiplexer are designed as near perfect reconstruction (NPR) cosine modulated filter banks (CMFBs). Only the prototype filter is required to be designed and all the other analysis and synthesis filters are obtained from this filter by cosine modulation. Compared to perfect reconstruction filter banks, NPR CMFB gives high stopband attenuation and the design requires less number of constraints. The amplitude and aliasing distortions should be within the tolerable limits for the application in hand. Therefore, in this work, a simplified, efficient and fast design technique is given, as the prototype filter is designed using Kaiser window approach (KWA). KWA results in high stopband attenuation. The constraints for spectral inversion and protrusion cancellation of recombination non-uniform filter bank (Chan and Xie, 2006) are satisfied by this method. The coefficients of the prototype filter are represented using minimal signed power of two (SPT) form called canonic signed digit (CSD) representation. The coefficients are synthesized into the CSD representation using different modified meta-heuristic algorithms. The performances are further improved with less number of adders using modified hybrid meta-heuristic algorithm. This results in digital channelizers which are computationally efficient, support multiple channels with different bandwidths and have low implementation complexity.

The remaining part of the paper is organized as follows: Section 2 gives an introduction of recombination filter bank and briefly illustrates the design of near perfect reconstruction CMFB. Section 3 explains the design of the proposed digital channelizers for the SDR receivers. Section 4 explains the multiplier-less design of the recombination filter banks using hybrid meta-heuristic algorithm. Section 6 outlines the design and optimization of the CSD coefficient filter bank using various modified meta-heuristic algorithms. Result analysis is given in Section 5 and the conclusion in Section 6.

2. Overview of re-combination filter banks

Recombination non-uniform filter banks (RNUFBs) realize the non-uniform subband decomposition with rational decimation factors. The method involves a uniform filter bank in one stage followed by a uniform transmultiplexer in the required channels. The number of channels of the uniform TMUX will always be less than that of the uniform filter bank. The generic structure of the recombination filter bank is shown in Fig. 1 (Chan and Xie, 2006).

From Fig. 1, it can be seen that m_l subbands of the uniform filter bank are combined using the synthesis filters of a m_l channel trans-multiplexer. The lth combined channel has a decimation ratio of M/m_l. The analysis and synthesis filters will be LTI systems or a cascade of LTI systems with modulation sequence $(-1)^n$, provided M and m_l are chosen to be co-prime to each other. The co-prime condition enables the interchange of decimators and interpolators. When l is an odd value, the output spectrum will be inverted. The modulation sequence $(-1)^n$ eliminates the spectral inversion and also enables to realize a wide range of sampling factors. The frequency shifted versions of $H_{r_l+i}(z)$ and $G_{l,i}(z)$ may overlap and that will result in undesirable or spurious responses. In order to eliminate the spurious responses at the output, the H_{r_l+i} and $G_{l,i}(z)$ should satisfy the matching conditions as given below (Chan and Xie, 2006).

$$\frac{N_M}{M} = \frac{N_{m_l}}{m_l} \tag{1}$$

$$H(e^{jm_l\omega}) = G_l(e^{jM\omega}) \quad \omega \, \epsilon \left[-\frac{\pi}{m_l M}, \frac{\pi}{m_l M}\right]$$

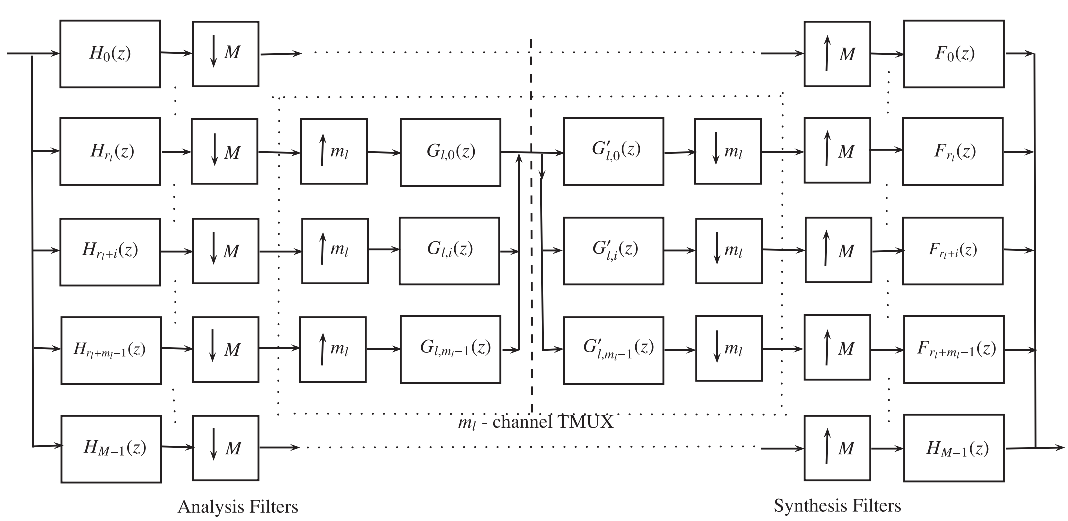

Figure 1 Generic structure of recombination filter bank (Chan and Xie, 2006).