Int. J. Electron. Commun. (AEÜ) 69 (2015) 655–665

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

Design of totally multiplier-less sharp transition width tree structured filter banks for non-uniform discrete multitone system

T.S. Bindiya *, Elizabeth Elias

Department of Electronics and Communication Engineering, National Institute of Technology, Calicut 673601, India

ARTICLE INFO

Article history:
Received 4 October 2013
Accepted 8 December 2014

Keywords:
Tree structured filter banks
Frequency response masking
Canonic signed digit
Meta-heuristic algorithms

ABSTRACT

In this paper, a multiplier-less near perfect reconstruction tree structured non-uniform filter bank for discrete multitone (DMT) system is proposed. In DMT systems, filters with sharp transition width are required to reduce the inter-channel interference. When sharp transition width filter banks are to be implemented, the order of the filters will become very high. Frequency response masking technique is known to result in filters with sharp transition width with less complexity. To further reduce the complexity and power consumption, the filter bank is made totally multiplier-less by converting the continuous filter coefficients to finite precision coefficients in the canonic signed digit space. This may lead to performance degradation and calls for the use of suitable optimization techniques. Here, the search space consists of only integers. Hence, meta-heuristic algorithms are preferred as they can be tailor made to suit the problem under consideration. In this work, meta-heuristic algorithms such as, artificial bee colony, harmony search and gravitational search are deployed to improve the performance of the tree structured filter bank. Thus, the proposed method results in tree structured non-uniform filter banks which are simple, multiplier-less and have linear phase, sharp transition width, very low aliasing and reduced amplitude distortion.

1. Introduction

During the past few years, multirate filter banks are used in many applications like speech processing, transmultiplexers, image compression, adaptive signal processing and biomedical signal processing. They are used in such applications due to their ability to decompose the signal into a set of sub-band signals which occupy different portions of the original frequency band and to combine a set of sub-band signals belonging to different frequency bands into one signal. The most basic type of filter banks are two channel uniform filter banks named as quadrature mirror filter banks (QMF) [1]. The method is extended to get M-channel uniform filter banks [1]. In many applications such as image coding, discrete multitone (DMT) modulation etc., non-uniform filter banks (NUFB) have to be used which divide the frequency spectrum of the input signal into non-uniform sub-bands. Besides being non-uniform, the filter banks should be free of aliasing and should possess linear phase property.

Discrete multitone (DMT) modulation is the wireline counterpart of the orthogonal frequency division multiplexing (OFDM). The structure of a non-uniform DMT system is shown in Fig. 1 [2,3]. The input binary stream is first partitioned into sub-streams with different spacing using a non-uniform delay chain. These sub-streams are processed by DMT modulation blocks which perform inverse discrete Fourier transform (IDFT) and cyclic prefixing operations on the input signal [2]. The outputs of the DMT modulation blocks are passed through a non-uniform synthesis filter bank and transmitted through the channel. In Fig. 1, $F_i(z)$ and $H_i(z)$ indicate the filter in the ith channel of the synthesis and analysis filter bank respectively. The channel output $r(n)$ is separated by the non-uniform analysis filter bank in the receiver side and passed through the DMT demodulation blocks, which do the inverse operation of that of the DMT modulation blocks. The output of the DMT demodulation blocks are interleaved using the non-uniform delay chain to obtain the received signal $y(n)$ [2,3].

The non-uniform transmultiplexer can be realized using a tree structured filter bank as discussed in [2]. Many design methods are proposed in the literature to implement the non-uniform filter banks [1,4–6]. The tree-structured method proposed in [1] is a good method which results in alias-free linear phase octave band non-uniform filter banks, in which the bandwidths of the analysis filters are spaced in octaves via cascading perfect reconstruction (PR) two-channel uniform filter banks. The design of the tree structured filter banks using constrained equiripple technique is discussed in [5]. In

* Corresponding author. Tel.: +91 9496818039.
E-mail addresses: elizabeth@nitc.ac.in, bindiyajayakumar@nitc.ac.in (E. Elias).

http://dx.doi.org/10.1016/j.aeue.2014.12.004
1434-8411/

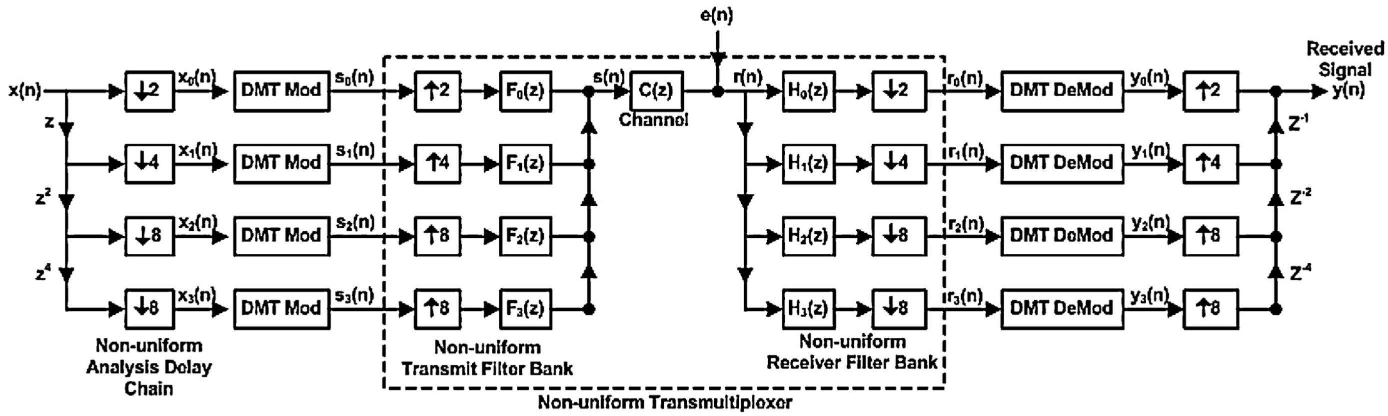

Fig. 1. Block diagram of non-uniform DMT system.

[6], an optimized design of the tree structured filter banks using variable combinational window function is proposed.

Due to the non-ideal filters in the filter banks and non-ideal behaviour of the channel, inter channel crosstalk can occur in the non-uniform DMT system as reported in [3]. The inter channel crosstalk introduced by the filters is due to their non-zero transition widths. This is reduced by designing sharp transition width filter banks. Since the order of the finite impulse response (FIR) filter is inversely proportional to the transition width, filters with sharp transition width will have high orders. This increases the implementation complexity of the filter banks. The FRM method is proved to be a very good method to get sharp transition width filters [7] with less complexity. Tree structured sharp transition width non-uniform filter banks based on FRM are not reported in the literature so far.

The multipliers in the digital filters occupy large area and consume more power than adder circuits. If the filter coefficients are represented in the signed power two (SPT) space, the multipliers can be replaced with less complex and less power consuming adders and shifters [8]. Canonic signed digit (CSD) representation [9] is a special case of the SPT space, which uses minimum number of non-zero SPT terms to represent a decimal number. CSD representation of the filter coefficients is a popular method to reduce the number of SPT terms in the filter coefficients [10–15].

When the continuous coefficients are rounded to finite precision values using restricted number of SPT terms, the prototype filter and hence the filter bank performance may degrade. This calls for efficient optimization techniques in the discrete space. Classical gradient based optimization techniques cannot be deployed in the discrete space, since here the search space contains integers. Metaheuristic algorithms are good alternatives for this type of optimization problem since these finally can reach a global solution if the parameters are properly selected with respect to a particular design problem [16].

The design of multiplier-less FRM based channel filters using ternary coded genetic algorithm (GA) is reported in [17]. In [18], the optimization of the transmultiplexer in the CSD space is done using integer coded GA, in which the integer indices of a look up table entries are used to get the solution. Integer coded artificial bee colony (ABC) algorithm is used in [19] for the design of non-uniform filter bank transmultiplexers in the CSD space. Design of multiplier-less FRM filter using modified integer coded ABC algorithm and modified integer coded differential evolution (DE) algorithm are presented in [20]. Modified harmony search algorithm (HSA) and modified gravitational search algorithm (GSA) for the optimization of multiplier-less reconfigurable channel filters are proposed in [21]. Design of multiplier-less tree structured sharp transition width filter bank using metaheuristic algorithms is not reported in the literature so far. So, in this paper, various metaheuristic algorithms like ABC, DE, HSA and GSA are used for the design of multiplier-less sharp transition width non-uniform tree structured filter banks and the performances are compared. The design method proposed in this paper gives filter banks with the following features:

- Non-uniform
- Linear phase
- Very small aliasing errors
- Sharp transition width
- Multiplier-less
- Optimized amplitude distortion and frequency response characteristics

This paper is organized as follows. Section 2 gives an overview of the tree structured filter banks. In Section 3, the proposed methodology using FRM prototype filter and its multiplier-less implementation using metaheuristic algorithms are discussed. Section 4 gives the design example of multiplier-less five channel tree structured filter bank with decimation factors {16, 16, 8, 4, 2} and with decimation factors {2, 8, 16, 16, 4} using various metaheuristic algorithms. This section also illustrates a design example of a multiplier-less ten channel filter bank with decimation factors {16, 16, 8, 8, 8, 8, 8, 8, 16, 16}. Section 5 summarizes the results and Section 6 concludes the paper.

2. Overview of tree structured filter banks

The non-uniform transmultiplexer in the DMT system can be realized using a tree structured filter bank as discussed in [2]. An overview of two channel quadrature mirror filter banks and tree structured filter banks is given in this section.

2.1. Two channel quadrature mirror filter banks (QMF)

The structure of a QMF bank is given in Fig. 2 where $H_L(z)$ and $H_H(z)$ represent the analysis filters and $G_L(z)$ and $G_H(z)$ represent the

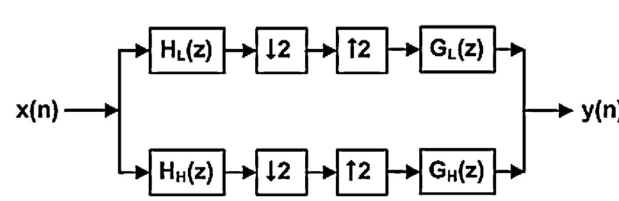

Fig. 2. Block diagram of two channel QMF bank.