CD Equalization with Non-maximally Decimated DFT Filter Bank

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***Abstract*— We perform CD compensation in the frequency domain through non-maximally decimated DFT filter bank with one-tap per sub-channel equalizer. Larger CD values are tolerated at the cost of slightly increased complexity compared to overlap-and-discard method.**

I. Introduction

In optical communications, intersymbol interference (ISI) or the channel memory increases quadratically with the signal bandwidth, where ISI is caused by dispersion. In non-dispersive managed or uncompensated links, significant values of residual chromatic dispersion (CD) can accumulate. Recently, significant efforts has been made extend the reach of optical long-haul transmission links by enhanced digital signal processing.

Recently, a number of efforts have come out to bring digital signal processing into optical communication links specially for longer reach applications. Orthogonal frequency division multiplexing (OFDM) has been employed for CD compensation [1] but has the disadvantage that a decrease in spectral efficiency is incurred since a prefix is needed. Single carrier (SC) with either time domain equalization (TDE) [2] or frequency domain equalization (FDE) [3] approaches have been as well investigated. SC FDE is very attractive because it has much lower calculation complexity than TDE when the equalizer has many taps [4]. Filter banks (FBs) are digital signal processing systems that find applications in various fields in wireless communications as 3G-LTE systems. An important class of FBs is the discrete Fourier transform (DFT) FBs, which can be efficiently implemented based on the use of polyphase filters, FFT and inverse FFT.

Our main interest is in the application of FBs in optical fiber communications. The efficient structure of the non-maximally decimated DFT FB with non trivial prototype filter is applied for SC FD CD compensation. A FB based FDE with trivial prototype filters commonly called overlap-and-discard implementation of linear convolution for CD compensation serves as a benchmark. The performance of both FB based (i.e. with trivial and nontrivial prototype filters) equalization techniques are discussed from the point of their ability to compensate for different CD values.

II. Efficient Non-maximally Decimated FB

Fig. 1 illustrates the general framework of a filter bank. We use the definition $z = e^{sT}$, where $s = \sigma + jw$ is the complex frequency variable. $H_k(z)$ and $F_k(z)$ are the analysis and the synthesis filters, respectively, of the kth subchannel. M is the number of subchannels and L represents the rate changing factor. In general, $L \leq M$. Throughout this paper, we will consider the case of non-maximally decimated FB i.e. $L < M$ and we choose $L = M/2$.

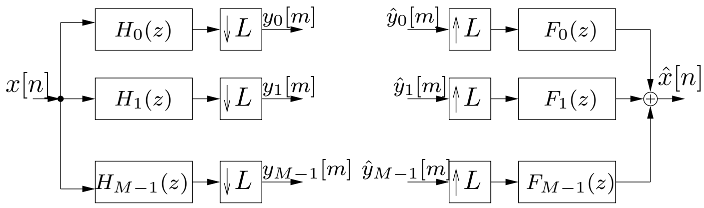

Fig. 1. Filter Bank: Basic Structure

For complex modulated (i.e. DFT) FB, the transfer functions of $H_k(z)$ and $F_k(z)$ are obtained by complex modulating one low-pass prototype filter $H(z)$ i.e. $H_k(z) = F_k(z) = H(ze^{j\frac{2\pi k}{M}})$, $\forall k = 0, \cdots, M-1$.

Both analysis and synthesis FBs can be efficiently implemented [5] by first using polyphase decomposition of $H(z) = \sum_{m=0}^{M-1} z^{-m} G_m(z^M)$, where $G_m(z), m = 0, \cdots, M-1$ will be used to denote the polyphase components of length K of $H(z)$. Then some important identities for multirate processing are applied and finally the complex modulation by means of DFT and IDFT of size M is performed.

III. FB based CD Compensation

Our approach for FD CD compensation is based on an efficient non-maximally decimated DFT FB presented in Sec. II. We show that the so far applied overlap-and-discard method with 50% overlap for CD compensation, which will act as a benchmark, is a special DFT FB structure of that introduced in Sec. II.

A. Non-trivial Prototype Filter FB Based CD Compensation

Fig. 2 shows the efficient non-maximally decimated DFT FB with non-trivial prototype filter for CD equalization. The equalizer is given by $\underline{e} = [e_0, e_1, \cdots, e_{M-1}]$, where each element e_m is a single tap coefficient per subchannel and $d = e^{-j\pi(KM-1)/M}$.

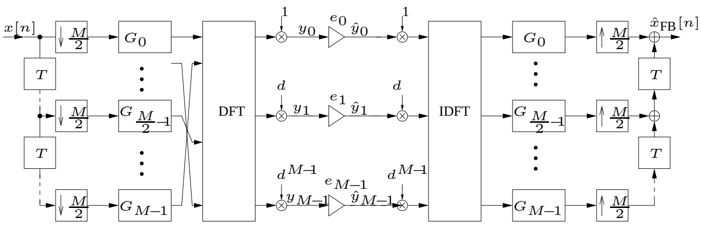

Fig. 2. Efficient Non-maximally Decimated with non-trivial Prototype Filter DFT FB CD compensation

B. Trivial Prototype Filter FB Based CD Compensation

The overlap-and-save FFT method also known as overlap-and-discrad FFT method for FD CD compensation with 50% overlap as benchmark [3] can be realized as a special non-maximally decimated DFT FB structure. In order to realize this benchmark, the analysis and the synthesis prototype filters are restricted to be trivial filters (i.e. rectangular window) of length M and $M/2$ respectively.

Fig. 3 shows OLD FFT method implemented as an DFT FB structure which is a non-maximally decimated DFT FB.

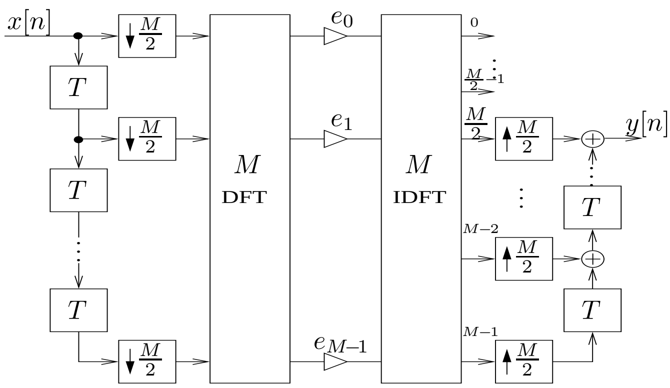

Fig. 3. Non-maximally Decimated with trivial Prototype Filter DFT FB CD compensation

Since all M degrees of freedom are used in the design of the equalizer $\underline{e} = [e_0, e_1, \cdots, e_{M-1}]$, it is no longer strictly the overlap-and-discard method to implement linear convolution with the aid of FFT and IFFT, but it is a FB based CD equalization with a trivial prototype filter.

IV. Results

For an oversampled 28 GBaud RZ-PDM-QPSK coherent optical transmission system, our method and the benchmark for CD compensation have been compared by evaluating their applicability for different FFT sizes and for compensating different CD values. For performance analysis, the required optical signal to noise ratio (OSNR) to tolerate different CD values (accordingly different fiber lengths) at a bit error ratio (BER) of 10^{-3} is chosen to be the figure of merit. In the simulations, the prototype filter is a real coefficient linear phase FIR low pass extended lapped transform (ELT) filter with $K = 2$. M is chosen as power of 2 so that the DFT and IDFT are efficiently implemented with FFT and IFFT, respectively.

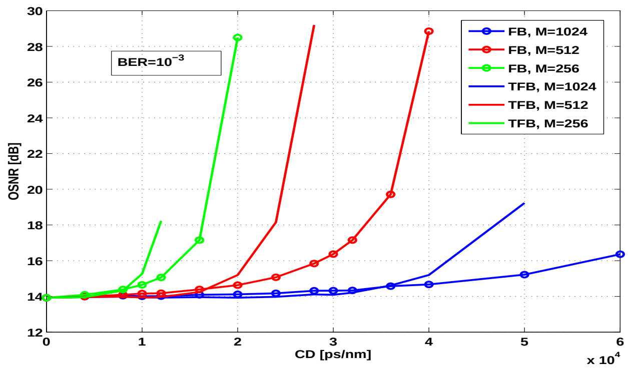

Fig. 4. Required OSNR for different CD values and different FFT size M: Non-maximally decimated DFT FB with trivial and non-trivial prototype filter based CD compensation

The simulations shown in Fig. 4 reveal that for the same OSNR, higher CD values are compensated for the same FFT size with our method at the cost of slightly increased complexity. For the same CD tolerance a lower OSNR is required with our FB based FDE with non trivial prototype filter. In contrast to the structure with TFB, the structure with non-trivial prototype filters allows to extend the reach even further for acceptable OSNR penalties up to 3 dB. Morevoer, this benefit increases for large FFTs.

V. Conclusion

In this work, FD CD compensation was proposed based on a non-maximally decimated DFT FB with non-trivial prototype filter and with single tap equalizer per subchannel. The well known overlap-and-discard with 50% overlap applied so far for CD compensation can be as well interpreted as non-maximally decimated FB but with trivial prototype filters. With our method, we believe that CD compensation can be realized with less complexity for a given CD requirement. Our method allows to achieve a larger CD tolerance for a given FFT size with only minor penalty as compared to the benchmark.

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