MULIPLIERLESS IMPLEMENTATION OF FILTERED MULTITONE MODULATION FOR VERY-HIGH-RATE DIGITAL SUBSCRIBER LINES

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ABSTRACT

The system structure of discrete multitone modulation is analyzed using a filter-bank approach, which leads naturally to the recently proposed filtered multitone (FMT) modulation scheme. An efficient multiplierless implementation for FMT modulation is then investigated.

1. INTRODUCTION

Digital subscriber line (DSL) technology enables high-speed digital transmission on conventional telephone lines. Following the development of high-bit-rate DSL (HDSL) and asymmetric DSL (ADSL) technologies, very-high-bit-rate DSL (VDSL) technology has recently emerged as an extension of ADSL technology to achieve higher bit rates for loops between optical network units (ONUs) and customers [1]. A typical VDSL architecture is shown in Fig. 1. Transmission rates that can be achieved by a VDSL with respect to the distance from ONU to a customer are listed in Table 1.

Table 1 Transmission Rates With Respect to Distance

Downstream rate (Mb/s)	Upstream rate (MB/s)	Distance (m)
52	6.4	300
26	3.2	800
13	1.6	1200

Very recently, filtered multitone (FMT) modulation has been proposed as a promising alternative for VDSL transmission for improved spectrum management [2][3]. FMT also offers filtering-based implementation alternatives to time-domain prefixing and suffixing that characterize typical discrete multitone (DMT) implementations. In this paper, the DMT and FMT modulation methods are explained from a filter-bank perspective and an efficient multiplierless implementation scheme for FMT modulation is investigated.

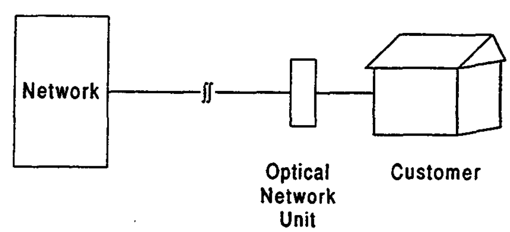

Fig. 1: A VDSL architecture.

2. REVIEW OF ADSL: A FILTER-BANK PERSPECTIVE

A typical discrete-Fourier-transform (DFT) based ADSL system is illustrated in Fig. 2. The inverse discrete Fourier transform (IDFT) and DFT blocks in Fig. 2 can be regarded as a synthesis filter bank and an analysis filter bank [4], respectively. This filter-bank

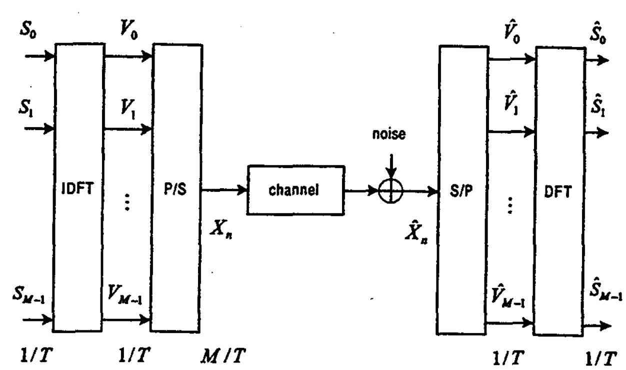

Fig. 2: A typical DMT ADSL system.

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interpretation of the IDFT and DFT blocks is illustrated in Fig. 3, where $H_{(}z)$ and $F_k(z)$ are the transfer functions of the synthesis and analysis filter banks and are given by

$$H_k(z) = \frac{1}{\sqrt{M}} \sum_{n=0}^{M-1} W^{-nk} z^{-n}, \; W = e^{-j2\pi/M} \tag{1}$$

and

$$F_k(z) = \frac{1}{\sqrt{M}} \sum_{n=0}^{M-1} W^{nk} z^{n}, \; 0 \le k \le M-1 \tag{2}$$

respectively, where $0 \le k \le M-1$.

The frequency responses of the synthesis filters are obtained as

$$H_0(f) = \frac{1}{\sqrt{M}} \sum_{n=0}^{M-1} e^{-j2\pi n f} \tag{3a}$$

and

$$H_k(f) = \frac{1}{\sqrt{M}} \sum_{n=0}^{M-1} 1 - e^{-j2\pi n (f-k/M)}$$

$$= H_0(f - \frac{k}{M}) \tag{3b}$$

for $k = 0, 1, \ldots, M-1$ and from (2), we get

$$F_k(f) = H_0(f + \frac{k}{M}) \quad \text{for } k = 0, 1, \ldots, M-1$$

Hence the filter banks in Fig. 3 can be simplified to yield a structure shown in Fig. 4.

3. FILTERED MULTITONE MODULATION FOR VDSL

Although DFT-based filter banks can be implemented efficiently, each filter in the filter banks has relatively low stopband attenuation and large passband overlaps with its neighboring filters. Consequently, the use of DFT-based modulation in VDSL systems will introduce significant interchannel interference (ICI). As an example, Fig. 5(a) depicts the frequency responses of a 64-channel DFT filter bank where low stopband attenuation and large passband overlaps between neighboring filters can be observed.

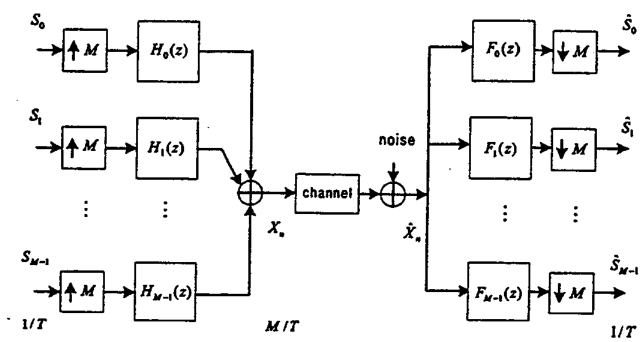

Fig. 3: A filter-bank interpretation of an ADSL system.

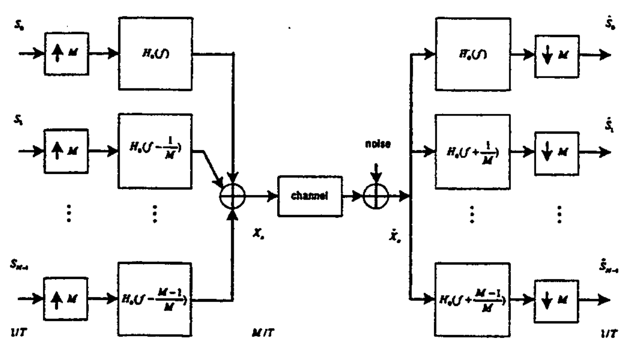

Fig. 4: An equivalent filter bank interpretation of an ADSL system.

Recently, the use of the filtered multitone (FMT) modulation structure shown in Fig. 4 with a more sophisticated prototype filter was proposed for VDSL systems [2][3]. Compared with the DFT-based DMT modulation, the FMT modulation offers reduced ICI and intersymbol interference (ISI) without using cyclic suffixing; furthermore, it entails more efficient spectral utilization that leads to increased transmission bit rate. As an example, Fig. 5(b) shows the frequency responses of a 64-channel FMT receiver where the prototype filter is a linear-phase FIR filter of length N = 640.

From the theory of multirate systems and filter banks [4] it is known that efficient implementation of the synthesis and analysis filter banks can be achieved using the polyphase decomposition [4] as illustrated in Fig. 6 where $G_k(z)$ for $k = 0, 1, \ldots, M-1$ represent FIR filters of length N/M with $N-1$ being the order of $H_0(z)$ and can be obtained as

$$H_0(z) = \sum_{k=0}^{M-1} z^{-k} G_k(z^M) \tag{4}$$

For example, if $H_0(z)$ represents a 640-tap linear-phase FIR filter, then G_k for $k = 0, 1, \ldots, M-1$ are FIR filters of length 10. The impulse responses and amplitude responses of the polyphase filters represented by $G_k(z)$ for $k = 0, 8, 16, \ldots, 56$ are shown in Figs. 7(a) and (b), respectively.

4. MULTIPLIERLESS IMPLEMENTATION OF FIR FILTERED MULTITONE MODULATION

It is advantageous to implement the prototype filter represented by $H_0(z)$ without multiplications. A commonly used approach is to represent the filter by coefficients that can be expressed as sums of a small number of power-of-two terms (SP2). Since the polyphase filters G_k have low orders, exhaustive search can be readily applied to obtain $G_{qk}(\omega)$ with SP2 coefficients such that

$$E_k(G_k) = \max ||G_{qk}(\omega) - G_k(\omega)|| \tag{5}$$

where

$$k = 0, 1, \ldots, M-1 \quad \text{and} \quad \omega \in [0, \pi]$$

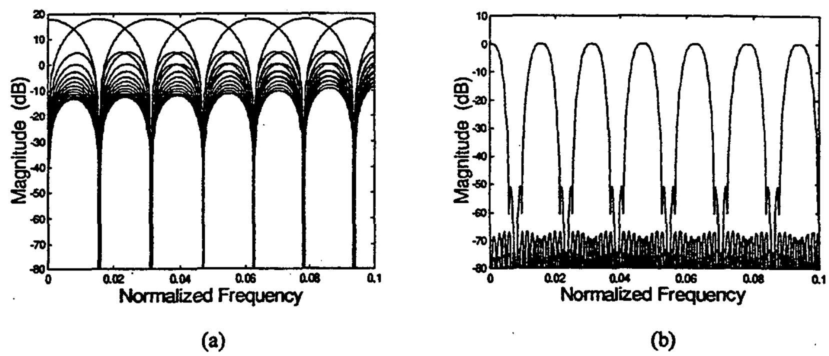

Fig. 5: (a) Frequency responses of a 64-channel DFT-based filter bank.
(b) Frequency responses of a 64-channel FMT filter bank.

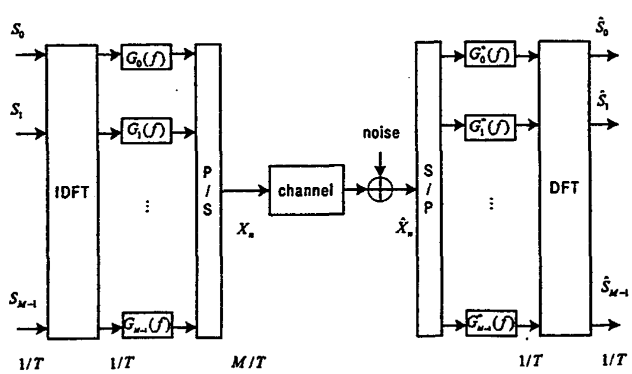

Fig. 6: Fast implementation of FMT for VDSL system.

is minimized. Fig. 8(a) depicts the amplitude responses of polyphase filters G_{qk} for $k = 0, 8, 16, \ldots, 56$. The amplitude response of the prototype filter H_{q0} obtained using the quantized polyphase filters is shown in Fig. 8(b).

5. CONCLUSIONS

We have reviewed the system structure of DMT modulation from a filter-bank perspective. This point of view relates the conventional DMT modulation approach to the recently proposed FMT modulation approach for VDSL systems in a natural manner. A multiplierless implementation scheme for FMT modulation has been proposed, which offers reduced computational complexity with tolerable performance degradation.

ACKNOWLEDGEMENT

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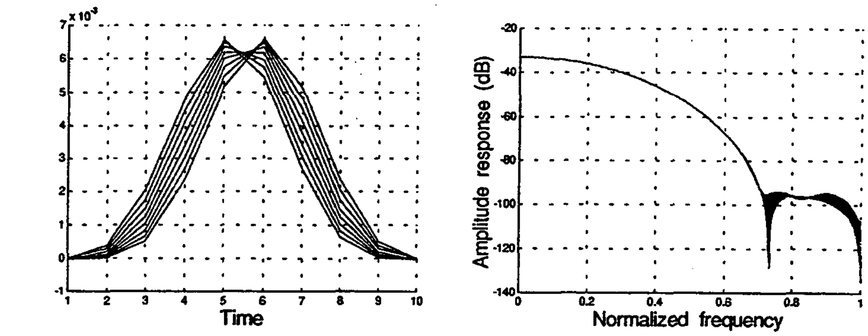
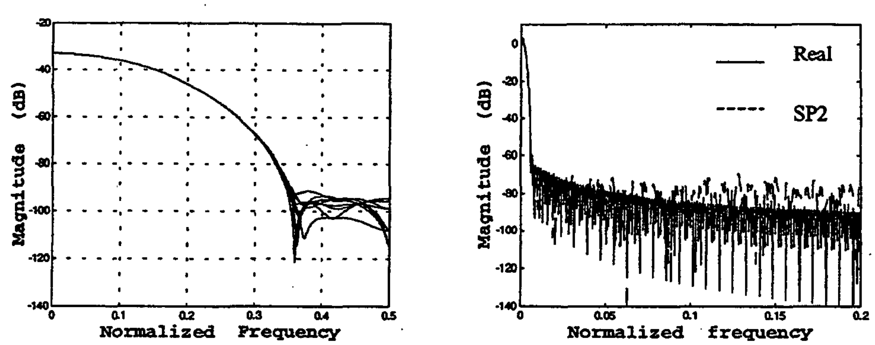


(a) (b)

Fig. 7: (a) Impulse responses. (b) Amplitude responses of filters G_k for $k = 0, 8, 16, \ldots, 56$.



(a) (b)

Fig. 8: Amplitude responses of (a) SP2 for filter G_k for $k = 0 : 8 : 63$.
(b) Prototype filter with SP2 coefficients (dashed line) and that with real coefficients (solid line).