行政院國家科學委員會專題研究計畫　成果報告

用戶線路之頻域等化器技術設計與研究

計畫類別：個別型計畫
計畫編號：NSC92-2622-E-002-012-CC3
執行期間：92 年 06 月 01 日至 93 年 05 月 31 日
執行單位：國立臺灣大學電子工程學研究所

計畫主持人：吳安宇

計畫參與人員：林志修　賴永元

報告類型：精簡報告

處理方式：本計畫為提升產業技術及人才培育研究計畫，不提供公開查詢

中　華　民　國 93 年 8 月 27 日

用戶線路之頻域等化器技術設計與研究

Study of Per Tone Equalization Technique and its implementation for xDSL system

計畫編號：NSC 92-2622-E-002-012-CC3
執行期限：92/06/01 ~ 93/05/31
主持人：吳安宇 副教授 Email: andywu@cc.ee.ntu.edu.tw
執行機構：國立台灣大學電機工程學系

一、 中文摘要

多載波調變系統近年在有線及無線網路通訊中引起相當廣泛討論與應用，其中正交頻率分頻多工(OFDM/DMT)調變最為廣泛採用，如802.11a 和數位式用戶線路(xDSL)。正交頻率分頻多工調變技術的概念是在頻譜上將傳輸通道的頻寬細分為更小且相互正交的頻帶通道。由於每一個小通道的頻寬較窄，固每個通道上的頻譜將較為平坦。再者，通道間的相互正交性，使的在不同通道上的訊號彼此互相獨立。如此，我們可充分的利用正交頻率分頻多工天生擁有的優點，在不同的通道上，依據當時各子通道的品質動態調整所傳的資料量，以達到頻寬最大使用率。

正交頻率分頻多工調變技術中，不同傳輸訊號(Symbol)間相互的干擾，將降低接收訊號正確性的能力，進而影響到所能傳輸的速率。在數位式用戶線路中，時域等化器(TEQ)常被使用來消除或減少不同傳輸訊號間相互的干擾效應。但是，當通道脈衝響應相當長時，所需要的時域等化器的長度也相對的增加，這使的時域等化器的硬體成本及複雜度都大大的提高。另一方面，在實際的應用為了在不同系統的規格下使用相同的硬體，我們必須考量最差的情況。由於不同的數位式用戶線路系統間所需要的時域等化器的長度差異很大，這讓時域等化器在此使用效率無法相對應所需花費的硬體成本。在目前新的研究[1]，等化器可在頻率上各別針對每一個子通道做等化，如此可以提高整個等化器的效能。在這個計劃中，我們先探討數位式用戶線路系統，然後依據最新的研究 [1], 將整個研究重點放在研發更新、更低成本、低功率且更高效能的正交分頻多工系統頻域等化器。

關鍵詞：
多載波調變、正交頻率分頻多工、數位式用戶線路、時域等化器(TEQ)、頻域等化器(FEQ)

二、 英文摘要

Orthogonal Frequency Division Multiplexer (OFDM) and Discrete Multi-Tone (DMT) are these of the multi-carrier modulation techniques, which have been extensively adopted both in wire and wireless communication, such as 802.11a standard, and xDSL systems. In OFDM/DMT modulation scheme, the communication channel is divided into a bank of orthogonal sub-channels in the frequency domain. The primary advantage of the multi-carrier modulation is that the bits allocation for each sub-channels can be dynamic based on the quality of each channel. In high SNR sub-channels, we can allocate more bits to transfer. On the contrast, fewer bits are allocated in these channels with low SNR. As the result, we can make full use of the bandwidth with a

sophisticated adaptive-bits-allocation approach.

One major disadvantage of the OFDM/DMT scheme is that it is very sensitive to Inter Symbol Interference (ISI). In the xDSL systems, time domain equalization (TEQ) is often implemented to eliminate the impairment of ISI. The hardware cost of TEQ, however, is very high; especially, when the channel impulse response is very longer. On the other hand, to operate in different systems with one hardware-module, such as in xDSL systems, we must implement TEQ in the worst case. This is not desired when the tap-delay line of TEQ is very different among the xDSL systems. In the updated research [1], the equalization is performed for each sub-carrier. This will improve the overall performance. In the project, based on [1], we will focus on the study and implementation of xDSL equalizer in frequency domain to achieve low cost, low power, and high performance (high SINR).

Keywords：

OFDM/DMT, TEQ, Per Tone FEQ, XDSL

三、 計畫緣由與目的

Market demand for high data rates plays an important role in advanced communications. With the development of DSP and VLSI technology, the demand for video/audio services, consumer services, Internet, and Word Wide Web (WWW) grows exponentially. An advanced communication technology is needed to satisfy the requirement. Besides, it is very important to take advantage of existing infrastructure to transfer the data, but not to building new ones. Since both servers and clients can save the cost for building the network. This is a significant factor for ADSL to become a popular application.

In the ADSL and next-generation xDSL system, the adopted modulation approach is DMT technology, which is multi-carrier modulation scheme. The idea of DMT scheme is to divide the channel into sub-channels. The frequency response of channel becomes flat, and the sub-channel is orthogonal to each others. We can utilize the property to dynamically allocate different bits to each sub-channel based on the equality of each channel. This will improve the use of bandwidth. One of the major drawbacks in DMT system is the impairment of Inter Symbol Interference (ISI), caused by channel dispersion or multi-path effect. To avoid the impairment, guard interval is applied. Due to the insertion of guard interval, the efficiency of bandwidth is reduced. Furthermore, the length of guard interval is equal to the one of channel impulse response. One solution to reduce the guard interval is to shorten the impulse response of channel.

Some approaches are based on the idea to achieve the goal, such as TEQ [7-9], TF-TEQ [10]. The cost, however, of these schemes is very high, and the performance is sensitive to the style of channel. One novel approach is proposed to overcome the problem in [1], which equalizing per tone (per sub-channel) individually, and performs lower bit error rate than TEQ and TF-TEQ. But the good performance pays the penalty at hardware complexity.

In this project, we will focus on the study and implementation of xDSL equalizer in frequency domain to achieve low cost, low power, and high performance (high SNR) in system level.

四、 研究方法與成果

In this project, we evaluate and verify the algorithm of per tone equalization (PTEQ) [1]. To compare the performance, we also simulate the traditional TEQ-based algorithm. Then, to reduce the hardware complexity, we evaluate the tone-grouping method [1]. For another reducing approach, we explore the redundancy of the per tone equalization to reduce complexity in another way.

- Evaluation of PTEQ

We evaluate the traditional Time-domain LMS (TLMS) algorithm to update the coefficient of TEQ filter. Consider the adaptive filter problem shown in fig.1, the TEQ and target channel are simply L-tap and (ν + 1)-tap FIR filter, respectively. We utilize the LMS algorithm to update the coefficients of w(n) and b(n) simultaneously. At the beginning of TEQ training, we set the coefficients of w(n) and b(n) to some initial values and perform the updating on each incoming sample.

Per tone equalization structure was proposed in [1]. The method is transform the TEQ operation into FEQ to improve the system performance:

$$Z_i^{(k)} = D_i \cdot row_i(F_N)\cdot(Y\cdot w) = \underbrace{row_i(F_N \cdot Y)}_{TFFTs}\cdot \underbrace{w_i D_i}_{w_i} \qquad (1)$$

In this structure (fig.2) equalization is done with a T-tap per tone equalizer for each tone separately after the FFT-demodulation. This enables true signal-to-noise ratio (SNR) optimization per tone. Therefore, the proposed equalization scheme results in much smoother capacity functions.

The performance evaluation is shown in fig.3 and table. 1. We can conclude that TEQ-based algorithm introduce deep-null resulting in performance degradation. The PTEQ algorithm has a smoother capacity function resulting in better performance.

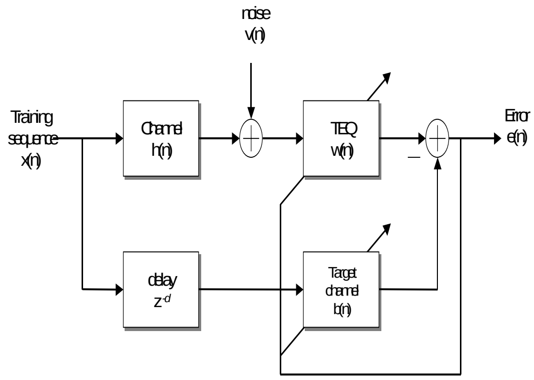

Fig.1 the TEQ-based algorithm

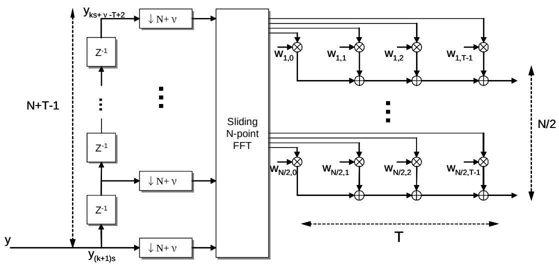

Fig.2 the architecture of per tone equalization

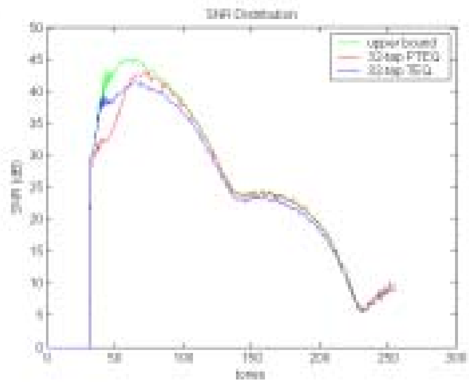

Fig.3 SNR distribution of TEQ-based and PTEQ architecture

	Bit Rate(Mbps)
TEQ	4.13
PTEQ	4.28

Table.1 bit-rate comparison

- Hardware Reduction

A. Tone Grouping

To reduce initialization complexity, we can combine tones into groups. For each group, only the central tone of equalizer coefficients is computed such that weight-update hardware can be reduced. On the other hand, this structure must add additional one-tap

FEQ for each tone, similar to the 1-tap FEQ in the TEQ-based implementation. Note that the complexity during data transmission does not decrease by tone grouping but the initialization complexity is reduced roughly by a factor of the number of tones for a group.

B. Varying Equalizer length

Using the structure of PTEQ, equalization of one tone can be done independent of the other tone. Hence, the equalization effort can be concentrated on the most affected tones by adjusting taps length for each tone. For nonused tones, we can set the length to zero.

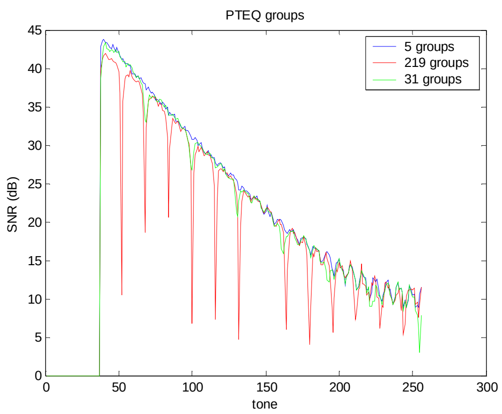

Fig.4 SNR of tone-grouping PTEQ

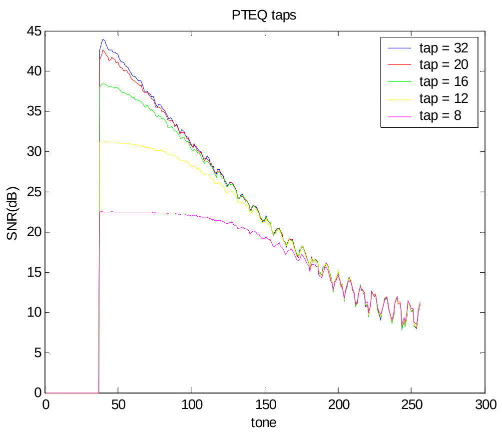

Fig.5 SNR of tap-reduced PTEQ

- Hardware reduction in another way

The original PTEQ suffer from too large hardware complexity. We are aimed at implementing it at tolerable complexity. From tone grouping, we can save a lot of hardware. If we see tone grouping as using the relation between neighboring tones, we may also explore the relation inside a single tone. We can calculate the weight from the neighboring weights such that we can reduce a lot of hardware, i.e. we can remove the redundancy in per tone equalization.

By our exploration, we can "pre-process" the FFT result and using only on-tap (complex) FEQ in replace of the original T-tap (complex) FEQ. The pre-processing is composed of phase-compensating and summation. Then, the complexity is only focused on the one-tap FEQ. Futhermore, we can combine the phase compensating with the phase shift operation in "sliding FFT". The architectue is ahown in the fig.6. By my simulation, this reduced architecture performs equivalent SNR to the per tone equalization.

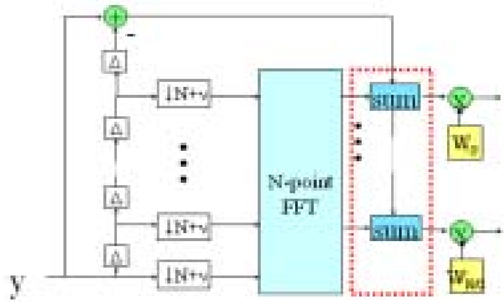

Fig.6 Hardware-reduced PTEQ

	TEQ+FEQ	PTEQ	Fig.6
TEQ	FsT		
FEQ	(Fs/(N+v)) 4Nu	(Fs/(N+v)) (4T+4T-4)Nu	Fs/(N+v) (2T-2+4) Nu
approximation	Fs(T+2)	Fs(4T-2)	Fs(T+1)

Table.2 complexity of the multiplication per unit time

五、 結論與討論

In this project, we evaluate the

performance of the TEQ-based architecture and the PTEQ architecture and we verify that PTEQ indeed has better SNR. Then we evaluate the tone-grouping method. Finally, we discover the relation of the weights in PTEQ and propose a low-cost architecture to implement the PTEQ architecture. After simulation, the proposed architecture has comparable SNR performance but much less complexity than PTEQ. Due to the low complexity and the same SNR performance, the proposed architecture is very attractive to the implementation of DMT-based systems.

六、 參考文獻

[1] Van Acker, K.; Leus, G.; Moonen, M.; van de Wiel, O.; Pollet, T., ” Per tone equalization for DMT-based system, ” IEEE Transactions on Communications, Volume: 49 Issue: 1 , Jan. 2001 Page(s): 109 －119

[2] Arslan, G.; Evans, B.L.; Kiaei, S.,” Equalization for discrete multitone transceivers to maximize bit rate,” Signal Processing, IEEE Transactions ,Volume: 49 , Issue: 12 , Dec. 2001 Pages:3123 – 3135

[3] Vanbleu, K.; Ysebaert, G.; Cuypers, G.; Moonen, M., “Bitrate maximizing time-domain equalizer design for DMT-based systems,” Communications, 2003. ICC '03. IEEE International Conference on ,Volume: 4 , 11-15 May 2003 Pages:2360 - 2364 vol.4

[4] Simon Haykin, “Communication systems”, 4th ed., John Wiley & Sons, Inc. 2001.

[5] J. S. Chow and J. M. Cioffi, ”A cost-effective maximum likelihood receiver for multi-carrier systems,” Proc, IEEE Int. Conf. Commun., vol. 2, pp. 948-952, June 1992.

[6] Melsa, P.J.W.; Younce, R.C.; Rohrs, C.E, “Impulse response shortening for discrete multitone transceivers,” IEEE Transactions on Communications, Volume: 44 , Issue: 12 , Dec. 1996, Pages:1662 - 1672

[7] M. V. Bladel and M. Moeneclaey, “Time-domain equalization for multicarrier communication,” in Global Conf. Telecommun., pp. 167-171, 1995.

[8] N. Al-Dhahir and J. M. Cioffi, “Optimum finite-length equalization for multicarrier transceivers,” IEEE Trans. Commu., vol. 44, no. 1, pp. 56-64, Jan. 1996.

[9] W. Chiu, W. K. Tsai, T. C. Liau, “Time-domain channel equalizer design using the inverse power method,” in Int. Conf. Commun., vol. 2, pp. 973-977, 1999.

[10] Chih-Chi Wang, An-Yeu Wu, and Bor-Ming Wang; “A cost-effective TEQ algorithm for ADSL systems”, IEEE International Conf. on Communications, vol.2, pp. 398 -402, 2001