出國報告（出國類別：出席國際會議）

參加「2013 智慧型訊號處理及通訊系統國際研討會(ISPACS 2013)」

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派赴國家：日本沖繩那霸市
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報告日期：2013 年 11 月 28 日

摘要

智慧型訊號處理及通訊系統國際研討會(International Symposium on Intelligent Signal Processing and Communication Systems, ISPACS 2013)是每年集合泛亞太地區所有頂尖學術研究人員的盛會，這個會議主要聚焦於智慧型訊號處理及通訊系統的理論分析、系統設計與系統實現這幾個領域。與會者都來自各頂尖大學與研究機構，其發表論文品質非常的高，而所有發表論文也會刊登在國際電子與電機協會數位資料庫(IEEE Xplore)之中。本次會議舉辦在日本沖繩那霸市(Naha, Okinawa, Japan)，會議從 2013 年 11 月 12 日至 2013 年 11 月 15 日止，會議舉辦在那霸市的自治會館(Okinawa Jichi-Kaikan)。本系林容杉副教授與劉奕成博士候選人將其與通道估測理論相關之研究論文提至該會議上發表，本報告就參與本次研討會提出心得及建議。

關鍵詞：ISPACS 2013、通道估測理論

目次

壹、 計畫目的

智慧型訊號處理及通訊系統國際研討會(International Symposium on Intelligent Signal Processing and Communication System,簡稱 ISPACS 2013)，目的在於集合泛亞太地區頂尖的學術研究員，將所有在智慧型訊號處理與通訊系統領域任何新的想法與創新的思路，同時間在這一個盛會中溝通分享。這一個國際研討會成立已久，自從 1992 年第一屆在臺灣舉辦開始，之後臺灣總共承辦了三次之多，去年是在新北市的淡水舉辦；也曾經在日本、韓國、新加坡、馬來西亞、澳洲、泰國、美國與中國等地舉辦過，所以與會者多是來自世界各國的菁英齊聚一堂，共同為推動智慧型訊號處理與通訊系統的世界級新技術盡一份心力。

智慧型訊號處理及通訊系統國際研討會今年主辦於日本沖繩那霸市，本次研討會為該會成立以來的第 21 屆，會議從 2013 年 11 月 12 日至 2013 年 11 月 15 日止，會議舉辦在那霸市的自治會館(Okinawa Jichi-Kaikan)。本系林容杉副教授與劉奕成博士候選人，研提論文至本會發表，發表論文題目為「用於時域同步正交分頻多工系統之改良式離散傅立葉通道估測方法」(Modified DFT-Based Channel Estimation for TDS-OFDM Communication Systems)。

簡言之，本次與會的主要目的如下：

一、 發表論文，增進與國外頂尖研究員相關科技技術之分享與交流。

二、 參與研討會，與國外各大學研究員交流，吸取國外相關科技技術進展。

三、 參觀鄰近教育文化設施，尋求與國外學者深遠交流合作關係。

貳、　參與研討會過程

依照研討會議程安排，本次與會人員行程如表 1 所示。

表 1 本系人員參與會議行程表

日期	活動行程
11/11 日 (週一)	去程(臺灣桃園-->日本沖繩)&準備日
11/12 日 (週二)	會議註冊&歡迎餐會
11/13 日 (週三)	會議開場&發表論文
11/14 日 (週四)	參加專題演講&參與各場次論文發表
11/15 日 (週五)	回程(日本沖繩-->臺灣桃園)

基於通訊產業在近幾年來蓬勃的發展，用戶對於資料量的需求急速成長，國內外的學者莫不追求更快速更穩定的通訊技術，來供應這樣的需求，臺灣面臨 4G 通訊產業的即將來臨，更加迫切的需要與國內學者同步技術交流，積極加強臺灣在技術面的進展。到底現今世界上的通訊技術發展的如何呢？是否有更多更新的技術等著我們去發掘呢？每年的智慧型訊號處理及通訊系統國際研討會，都會聚焦在新穎的訊號處理技術以及通訊技術上面，提供了一個交流平台，讓與會的各國菁英研究學者，共聚一堂，讓彼此之間不同領域的技術互相交流，交換訊息。

會議名稱既然是智慧型訊號處理及通訊系統國際研討會，所以兩大議題---智慧型訊號處理以及通訊系統，從這兩大主題作爲根基，衍伸出許多次議題來探討。各次議題之研討內容彙整如表 2 所示。

表 2 研討議題與內容

研討議題	研討內容
智慧型訊號處理 (Intelligent Signal Processing)	影像處理(Image Processing)
	聲音訊號處理(Acoustic Signal Processing)
	適應性訊號處理(Adaptive Signal Processing)
	傳輸影像處理(Video Processing)
	語音處理(Speech and Acoustic Signal Processing)
	非線性訊號處理(Non-linear Signal Processing)
	陣列訊號處理(Array Signal Processing)
	生物訊號處理(Biosignal Processing)
	電路系統(Circuits and Systems)
通訊系統 (Communication Systems)	通訊系統(Communication Systems)
	正交分頻多工系統(OFDM)
	數位濾波器設計(Digital Filter)
	數位電路設計(Analog Circuits)
	感測器網路(Sensor Networks)
	積體電路設計(VLSI)
	寬頻系統(Wideband Systems)
	多輸入多輸出系統(MIMO)
	天線與雷達系統(Antenna and Radar)
	無線通訊系統(Cellular Systems)
	光纖通訊系統(Optical Systems)

參、　參與研討會建議與心得

由於會議室在日本沖繩的首都那霸市舉行，是故本次人員參訪區域多在那霸市區。沖繩因爲地處太平洋島鏈上，與臺灣的距離又很相近，是故氣候風俗習慣也很相近，人處當地其實不會有太多的違和感，並且在當地可以看到許多中國文化的歷史遺跡。唯一不同的是，因爲是美軍駐地，所以外國人種非常的多，頗有夏威夷的感覺。在沖繩大學任教的教授，也有非常大的比例，是旅外學者，這一點非常值得臺灣借鏡。藉由不同文化的衝擊，沖繩的科技學術成長更加的國際化。在參加研討會的過程中，有幸與沖繩大學的教授聊天，他們雖然不是原生的日本人，卻長期的旅居日本教書，或許何種原因會讓旅外的教授長駐在沖繩，這也是值得探討的關鍵。

本次的會議於沖繩縣市町村自治會館(Okinawa Jichi-Kaikan)舉行，此館爲那霸市中心最爲大型的公家聚會場所，幾乎所有的重要會議都會在此舉行，而鄰近就是那霸市政廳，堪稱沖繩的重要地標。

圖 1 自治會館大廳

圖 2 自治會館外部

圖 3 此次與會人員之一(劉奕成)

圖 4 此次與會人員之二(林容杉)

這次會議有三場主要的專題演講，分別是 HiroyokiMorikawa 教授(日本東京大學)主講的 M2M for Driving Social Innovation，這是討論有關大量資料的分析與應用以及機器到機器資訊處理對社會改革創新的影響；其次是 ByeongGi Lee 教授(南韓首爾國立大學)主講的 ICT for Knowledge-Creative Society，這是討論有關資料通訊相關技術對知識能力創造革新社會產業的影響；最後是 Masaki Fujimoto 總裁(日本 GREE 企業)主講的 Managing, and Extending Global Internet Service，這是討論有關經營管理與擴展全球性網際網路服務的議題。這幾場專題演講皆是安排在早上的主要時段於會場的大型演講廳舉行，場面十分隆重且出席人員踴躍，幾乎可說是座無虛席。

不難看出，雖然這次的研討會完全討論的是純技術的通訊系統與訊號處理科技，但是主辦單位更是進一步的點出，如何將科技相關技術運用到社會活動與商業行為，並且能夠為人們進行相關的協助與服務，應用科技在於人們的一般日常生活之上，帶給人類社會無比的便利性，將是我們未來可以思考的方向之一。日本正在做，韓國也是如火如荼在跟進，臺灣的實力並不輸給這幾個國家，如果能夠軟硬體都銜接的上，那台灣在科技產業也當是世界首屈一指，必能進入高科技發展國家之林。

圖 5 會議開幕式

圖 6 專題演講場景

本次與會人員所發表的論文是被安排在第二天(11/13)上午 10:40~12:20 的正交分頻多工系統(OFDM)這場會議，本場次會議主席爲 Satoshi Denno 教授(Okayama University)，本系人員於會議前即與主席及各位在場教授交換訊息，展開友好活動，讓在場人士感受到臺灣積極參與國際場合的企圖心。我們發表的論文被安排於此場次的第二篇文章排程之中進行論文報告，發表的論文題目爲「Modified DFT-Based Channel Estimation for TDS-OFDM Communication Systems」，這是討論有關於在時序同步正交分頻多工系統的通道估測技術研究。

本篇論文首先使用離散傅立葉通道估測技術(Discrete Fourier Transform Based Channel Estimation, DFT-Based CE)所得到的時域通道響應(Time-Domain Channel Impulse Response, TD CIR)，接著提出特徵通道偵測器(Significant Channel Tap Detector, SCTD)進而分別出那些時域通道響應是雜訊抑或是帶有真正通道響應訊息。本論文利用 TDS-OFDM 系統原有的框架標頭(Frame Head, FH)架構的相關性(Correlation)得到一個可以分別雜訊與訊息的門檻值(Threshold)，來實現此 SCTD 方法。這是本篇論文的一大貢獻，因爲傳統的 SCTD 方法都提出於 CP-OPDM，不適用於 TDS-OFDM 架構之下，並且本論文所提出的演算法，在有大的多重路徑延遲環境底下依然適用。本論文也提供許多模擬結果驗證，證明所提出的估測

演算法，相對於使用傳統的方法，在於位元錯誤率效能(Bit Error Rate, BER)上面的提升均有顯著的改善。

本次與會人員在報告時也很有自信地向與會人士展現了研究成果，當時也獲得許多熱烈的回應，是一次很成功的報告。除了發表論文報告之外，也聽取了與會學者不同主題的論文報告，其中包括有盲目形式調變偵測(Constellation Folding for Sub-Optimum Maximum-Likelihood Method in Blind Modulation Detection)、ISDB-T系統的通道估測技術(Low-Complexity Channel Estimation for ISDB-T over Doubly-Selective Fading Channels; Modified Matching Pursuit Based Channel Estimation for ISDB-T)、以及頻率飄移估測(Iterative Frequency Offset Estimation Based on Singular Value Decomposition)等等與正交分頻多工系統相關的研究。與會人員於會議場次結束之後，同時與國內外不同的學者交換意見，並進行學術交流討論，著實獲益匪淺。除此之外，對於有興趣相關於通訊訊號處理的研究議題，也相互討論未來合作的可能性。

最後，建議教育部及國科會等相關單位能多補助學者出國開會發表論文，尤其是論文產量豐富且具有潛力的助理教授或副教授，以及積極認真並深具有研究潛力的碩博士研究生，如此一來，將可以進一步有效提高國內學術研究潛能，並促進國家科技的研究發展。

圖 7 報告者與主席合照

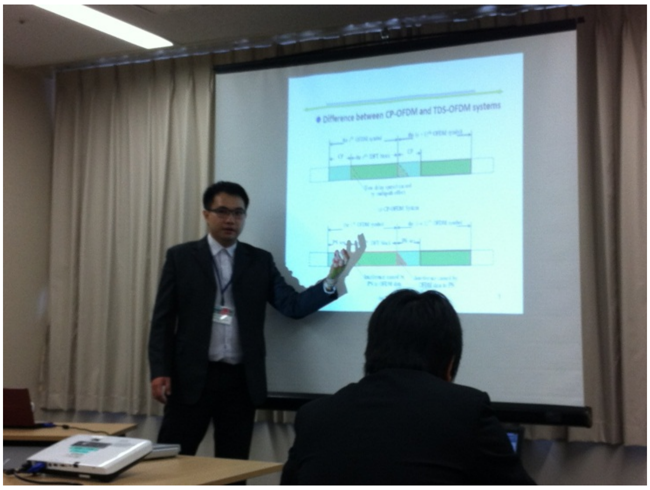

圖 8 論文發表場景

肆、　附錄

附錄一發表論文全文

Modified DFT-Based Channel Estimation for TDS-OFDM Communication Systems

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***Abstract*—This paper proposes the modified discrete Fourier transform (DFT)-based channel estimation technique for time domain synchronous orthogonal frequency division multiplexing (TDS-OFDM) communication systems. The proposed technique based on the concept of significant channel tap detector (SCTD) scheme possesses the potentials to effectively improve the system performance of TDS-OFDM systems. The correlation of two successive preambles is employed to estimate the average noise power as the threshold for obtaining the SCTD threshold estimation error and loss path information resulting in performance degradation in large delay spread channel environments. The proposed estimation scheme can also roughly predict the noise power in order to choose the significant channel taps to estimate the channel impulse response. In addition, some comparative simulations are given to show that the proposed DFT-based technique is capable of improving the bit error rate performance compared to the conventional least squares channel estimation.**

***Keywords*—TDS-OFDM systems; DFT-based channel estimation; SCTD; DTTB.**

I. Introduction

Orthogonal frequency division multiplexing (OFDM) scheme has emerged as a very popular technique to cope with the inter-symbol interference (ISI) over the frequency selective fading channels. The impact of ISI can be effectively removed by inserting the guard interval [1]. Recently, time domain synchronous OFDM system (TDS-OFDM) has been adopted in the national digital television terrestrial broadcasting (DTTB) standard for the People's Republic of China [2], [3]. China started to develop its own DTTB standard in 1994. In August 2006, the standard named "Frame structure, channel coding and modulation for digital television terrestrial broadcasting system" was finally decided [3]. Instead of using cyclic prefix (CP) in traditional CP-OFDM systems, TDS-OFDM systems employ pseudo-random noise (PN) sequence as the guard interval. The PN sequence is also applied for the utilization of channel estimation (CE) [4], [5]. TDS-OFDM systems can greatly improve the spectrum efficiency from 5% to 15% compared to the CP-OFDM systems using frequency domain pilot insertion.

In practice, effective channel estimation techniques for coherent OFDM communications are highly desired for the purpose of demodulating/detecting received signals and improving system performance. This is because they often operate in the environments where signal reception is inevitably accompanied by long multipath delay spreads caused by time-dispersion. Several channel estimation methods classified as frequency domain schemes have been studied, such as least squares (LS) and linear minimum mean-square error (LMMSE) [6]. Some methods have been undertaken dealing with cyclic-prefix OFDM (CP-OFDM) CE problems by using the discrete Fourier transform (DFT) processing [7]–[9]. The main idea of those DFT-based CE methods is to obtain the time-domain channel impulse response (CIR) by using the inverse discrete Fourier transform (IDFT) and only choosing the prior taps with CP-length (i.e., CIR-length is typically assumed to be less than or equal to CP-length). In addition, a method called significant channel tap detector (SCTD) can be employed to derive the optimal threshold to determine significant channel taps [9]. Then, the channel frequency response (CFR) can be obtained by feeding the chosen CIR into DFT. However, the previous studies were only in the context of CP-OFDM where the methods may not be suitable for the TDS-OFDM frame structure.

In this paper, a modified CE technique is investigated in order to extend DFT-based CE methods to TDS-OFDM systems. The proposed technique takes advantage of a DFT-based CE method to obtain the CIR by using IDFT with only preamble-length taps which are less than those of typical DFT-based CE methods (i.e., the typical DFT-based CE methods use data-length taps). While choosing the significant CIR (i.e., the taps contain the multipath information), the proposed technique takes advantage of signal-to-noise (SNR) estimation [10] in order to estimate the average noise power.

The remainder of this paper is organized as follows. In Section II, the TDS-OFDM system description and frame structure are briefly introduced. The conventional CE techniques are mentioned in Section II and the proposed CE technique is developed in Section III. The comparative simulation results obtained by the proposed CE technique and the conventional methods are provided in Section IV. Finally, some concluding remarks are given in Section V.

II. System Model And Channel Estimation

A. TDS-OFDM Systems

A baseband equivalent TDS-OFDM system is shown in Figure 1. At the transmitter side, the TDS-OFDM is a hybrid approach for combined signal in time domain and frequency domain transmission. Data transmission uses OFDM technique in the frequency domain. In the time domain, the PN sequence

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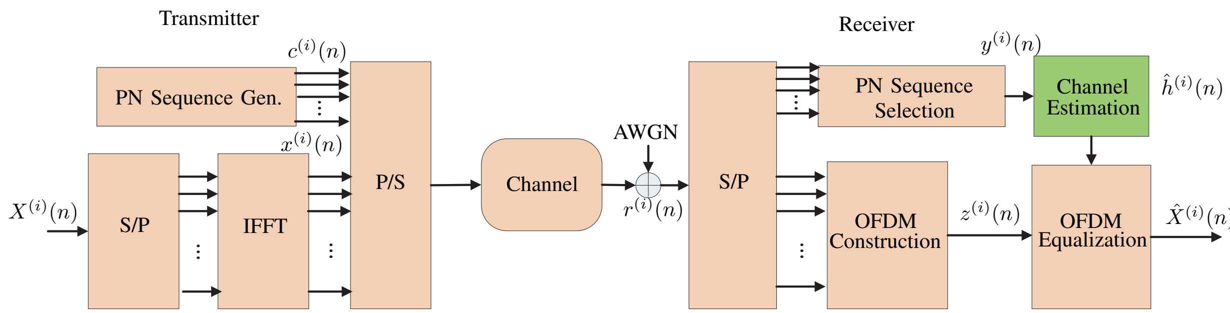
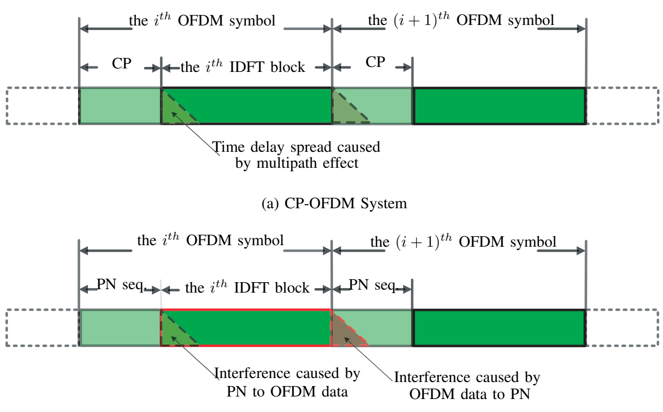


Fig. 1. A TDS-OFDM system.



(a) CP-OFDM System

(b) TDS-OFDM System

Fig. 2. Difference between CP-OFDM and TDS-OFDM systems.

Fig. 3. Signal frame format for DPNP TDS-OFDM systems.

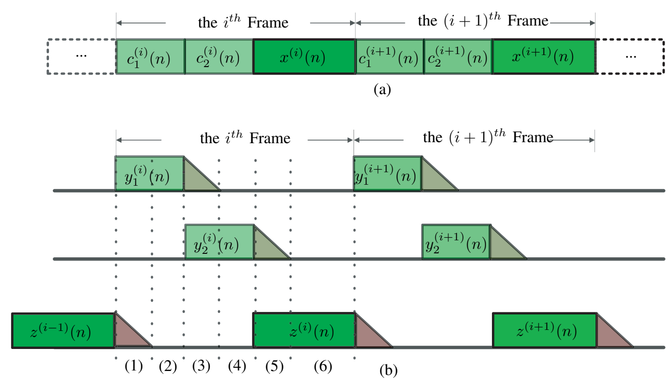


Fig. 4. Transmitted and received TDS-OFDM frame structures: (a) transmitted signal frames; (b) time-domain decomposition for received signal frames.

is inserted as a frame header to replace the CP in CP-OFDM for resisting the inter-symbol interference (ISI, caused by the multipath channel). The correlation characteristic of the PN sequence is similar to $\delta(t)$ (Delta function) which can be used for estimating the CIR. At the receiver side, the priori samples are fed in parallel to the channel estimator in order to perform the CE.

B. Dual PN-Sequence Padding Frame Structure

In Figure 2, the GI of CP-OFDM introduces a “tail” into the data because of the multi-path propagation. Because the cyclic prefix is inserted in GI, the cyclic property of data can be remained. In TDS-OFDM systems, because the GI and the frame body would cause ISI to each other, the cyclic property of the received IDFT block is destroyed. Therefore, a equalization method called iterative interference subtraction method [11] is proposed in order to remove the ISI and reconstruct the cyclic property of the data. However, iterative interference subtraction method needs several iterations that would lead to high complexity. In addition, the ISI can be eliminated accurately only when the accurate CE is obtained. In order to solve the problems, the previous work [12] proposed a simple equalization method based on dual PN sequence padding (DPNP) TDS-OFDM system to reduce the receiver complexity and increase the system performance. By using the signal construction equalizer in the previous work [12], the data can be recovered by the equalization schemes that are used in CP-OFDM.

Figure 3 shows the signal frame structure of DPNP TDS-OFDM systems. The signal frame consists of two parts, including the frame header and the frame body. The DPNP TDS-OFDM is a special case of TDS-OFDM because the cyclical extension of the PN sequence is inserted. The cyclical extension is viewed as the guard interval in order to protect the PN sequence, because it can avoid the multipath effect from the previous OFDM symbol. The PN sequence is used for the channel estimation. Therefore, ISI free data can be obtained without iterative padding subtraction.

Figure 4 illustrates both the transmitted and the corresponding received TDS-OFDM signals. Based on [12], the DPNP sequence can be expressed as

$$c_1^{(i)}(n) = c_2^{(i)}(n), \quad 0 \le n \le M-1 \tag{1}$$

where $M = 256$ is adopted in all TDS-OFDM frames, $c_1^{(i)}(n)$ is cyclic extension and $c_2^{(i)}(n)$ is used to estimate the channel. The multipath ISI impact of the first PN on the second one and the second one on the payload data is the same. Therefore, ISI free data can be obtained without iterative padding subtraction.

Figure 4(b) shows that the i^{th} received frame consists of three overlapping parts (i.e., $y_1^{(i)}(n)$, $y_2^{(i)}(n)$ and $z^{(i)}(n)$).

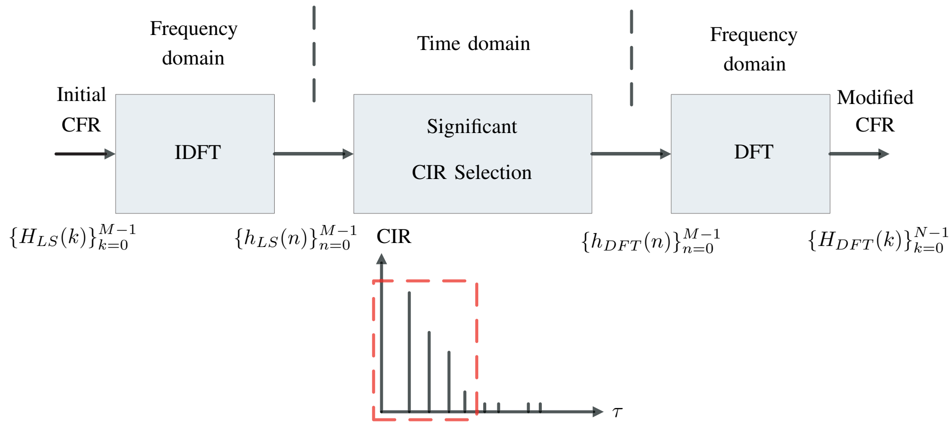


Fig. 5. Fundamental concept of the DFT-based channel estimation.

These three parts can be expressed as

$$\begin{aligned} y_j^{(i)}(n) &= c_j^{(i)}(n) * h^{(i)}(n) \\ &= \sum_{l=0}^{L-1} c_j^{(i)}(n-l)h^{(i)}(l), \\ &\quad 0 \le n < M+L-1, \quad j = 1,2, \end{aligned} \tag{2}$$

$$\begin{aligned} z^{(i)}(n) &= x^{(i)}(n) * h^{(i)}(n) \\ &= \sum_{l=0}^{L-1} x^{(i)}(n-l)h^{(i)}(l), \\ &\quad 0 \le n < N+L-1, \end{aligned} \tag{3}$$

where $N = 3780$ is number of subcarriers and L is the length of actual CIR $h^{(i)}(l)$. From Figure 4, the received signal can be expressed as the cyclic convolution of the transmitted PN sequence and the CIR. The received signal with additive white gaussian noise (AWGN) can be expressed as

$$r^{(i)}(n) = u^{(i)}(n) + w^{(i)}(n), \quad 0 \le n \le 2M+N-1 \tag{4}$$

where $w^{(i)}(n)$ is the zero-mean complex AWGN and $u^{(i)}(n)$ can be expressed

$$u^{(i)}(n) = \begin{cases} z^{(i-1)}(n+N) + y_1^{(i)}(n), \\ \quad 0 \le n < L-1, \\ y_1^{(i)}(n), \\ \quad L-1 \le n < M, \\ y_2^{(i)}(n-M) + y_1^{(i)}(n), \\ \quad M \le n < M+L-1, \\ y_2^{(i)}(n-M), \\ \quad M+L-1 \le n < 2M, \\ z^{(i)}(n-2M) + y_2^{(i)}(n-M), \\ \quad 2M \le n < 2M+L-1, \\ z^{(i)}(n+2M), \\ \quad 2M+L-1 \le n \le 2M+N-1 \end{cases} \tag{5}$$

Therefore, the received signal for CE can be represented as

$$\begin{aligned} r^{(i)}(n+M) &= c_2^{(i)}(n) \otimes h^{(i)}(l) + w^{(i)}(n+M), \\ &= y_2^{(i)}(n) + w^{(i)}(n+M), \\ &\quad 0 \le n \le M-1,\ 0 \le l \le L-1 \end{aligned} \tag{6}$$

C. Least-Squares Channel Estimation

According to the least-squares (LS) algorithm [8], the estimated CIR of the i^{th} signal frame can be derived as

$$\hat{h}_{LS}^{(i)}(n) = IDFT_M\left(\frac{DFT_M\left(r^{(i)}(n+M)\right)}{DFT_M\left(c_2^{(i)}(n)\right)}\right), \quad 0 \le n \le M-1 \tag{7}$$

where DFT_M and $IDFT_M$ are the M-point DFT and IDFT, respectively.

D. DFT-Based Channel Estimation

Figure 5 shows the block diagram of the DFT-based channel estimation algorithm. DFT-based channel estimation exploits a property of CP-OFDM systems having the symbol period much longer than the duration of the CIR. Because the estimated CIR from LS has most of its power concentrated on a few priori samples, the DFT-based estimation reduces the noise power that exists in only outside of the CIR part [8], [9]. The n^{th} estimated sample of CIR can be expressed with the LS estimation. According to (7), the estimated CIR can be expressed as

$$\begin{aligned} \hat{h}_{LS}(n) &= IDFT_M\{\hat{H}_{LS}(k)\}, \quad 0 \le n \le M-1 \\ &= h(n) + \tilde{w}(n) \end{aligned} \tag{8}$$

where

$$\tilde{w}(n) = IDFT_M\left(\frac{DFT_M(w(n))}{DFT_M(c_2(n))}\right).$$

Because the actual CIR length L is unknown to the receiver, the assumption $L \le M$ is considered. Therefore, the CIR can be written as

$$h(n) = \begin{cases} IDFT_M\{H(k)\}, & 0 \le n \le L-1 \\ 0 & L \le n \le M-1 \end{cases} \tag{9}$$

According to (9), the estimated CIR in (8) can be divided into two parts: CIR with noise part and only noise existing part. CIR is contained in the priori L samples and other samples are only noise. These processes can be expressed as follows

$$\hat{h}_{DFT}(n) = \begin{cases} \hat{h}_{LS}(n), & 0 \le n \le L-1 \\ 0, & L \le n \le M-1 \end{cases} \tag{10}$$

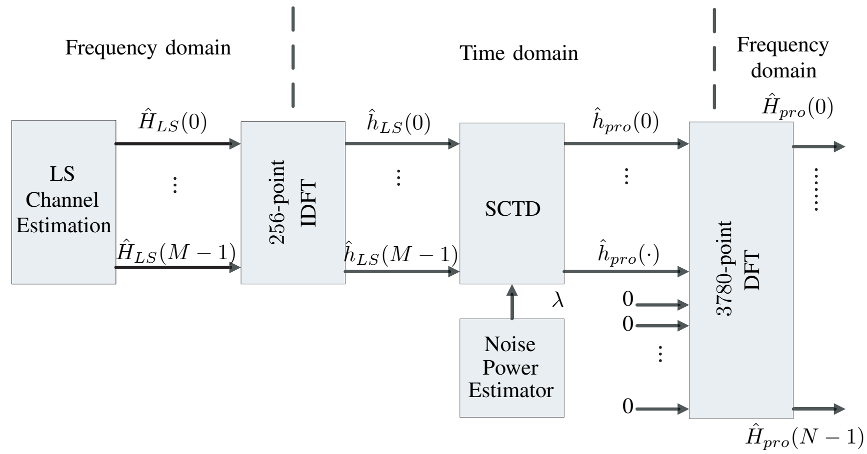


Fig. 6. Block diagram of the proposed channel estimation technique for TDS-OFDM systems.

From (10), the DFT-based channel estimation is denoted as

$$\hat{H}_{DFT}(k) = DFT_N\{\hat{h}_{DFT}(n)\}, \quad 0 \le k \le N-1 \tag{11}$$

III. Proposed Channel Estimation

According to the previous work [10], the average SNR is given as

$$\rho_{avg} = \frac{E\{|y_2^{(i)}(n)|^2\}}{E\{|w^{(i)}(n)|^2\}} = \frac{S^{(i)}}{W^{(i)}} \tag{12}$$

where $W^{(i)}$ is the noise power and $S^{(i)}$ is the signal power which can be expressed as

$$S^{(i)} = R_I^{(i)} + R_Q^{(i)} \tag{13}$$

where R_I and R_Q are correlations of in-phase and quadrature-phase components. They can be written as

$$\begin{aligned} R_I^{(i)} &= E\{r_I^{(i)}(n+M)r_I^{(i+1)}(n+M)\} \\ R_Q^{(i)} &= E\{r_Q^{(i)}(n+M)r_Q^{(i+1)}(n+M)\} \end{aligned}$$

where $r_I^{(i)}(n)$ and $r_Q^{(i)}(n)$ are the in-phase and quadrature-phase components of the received signal $r^{(i)}(n)$.

In this paper, the CIR is considered to be time-invariant. The proposed SNR estimator $\hat{S}^{(i)}$ based on correlation method to estimate the signal power $S^{(i)}$ can be written as

$$\begin{aligned} \hat{S}^{(i)} = \frac{1}{M}\sum_{n=0}^{M-1}[r_I^{(i)}(n+M)r_I^{(i+1)}(n+M) \\ +r_Q^{(i)}(n+M)r_Q^{(i+1)}(n+M)] \end{aligned} \tag{14}$$

The received signals for SNR estimation are $y_2^{(i)}(n)$ in the present frame and $y_2^{(i+1)}(n)$ in the next frame. Because the noise is zero-mean and independent, (14) can be re-written as

$$\begin{aligned} \hat{S}^{(i)} = \frac{1}{M}\sum_{n=0}^{M-1}[y_{2,I}^{(i)}(n+M)y_{2,I}^{(i+1)}(n+M) \\ +y_{2,Q}^{(i)}(n+M)y_{2,Q}^{(i+1)}(n+M)] \end{aligned} \tag{15}$$

TABLE I. System parameters of DPNP TDS-OFDM

Parameter	Specification
Baseband sampling frequency	7.56MHz
Number of total carriers N	3780
Symbols in frame header ($2M$)	510
PN sequence length (M)	255
Frame body period	$500us$
Subcarrier spacing	2kHz

Therefore, the noise power can be estimated by subtracting the estimated signal power from the total received power as follows:

$$\hat{W}^{(i)} = \frac{1}{M}\sum_{n=0}^{M-1}|r^{(i)}(n+M)|^2 - \hat{S}^{(i)} \tag{16}$$

As a result, the CIR can be chosen from the following decision rule

$$\hat{h}_{pro}(n) = \begin{cases} \hat{h}_{LS}(n), & \text{otherwise} \\ 0, & \text{if} \quad P_{LS}(n) < \lambda \end{cases} \tag{17}$$

where $P_{LS}(n) = |\hat{h}_{LS}(n)|^2$ represents the power of n^{th} channel tap and λ is the threshold. The optimal threshold is obtained by multiplying the estimated noise power and a constant weight. The threshold can be expressed as

$$\lambda = \alpha\hat{W}^{(i)}, \tag{18}$$

where α is a positive constant to be chosen according to the later experiment results. Therefore, the proposed channel estimation can be chosen as follows:

$$\hat{H}_{pro}(k) = DFT_N\{\hat{h}_{pro}(n)\}, \quad 0 \le k \le N-1 \tag{19}$$

As a result, the block diagram of our proposed channel estimation algorithm for TDS-OFDM systems is illustrated in Figure 6.

IV. Simulation Results

The fundamental requirements of the DPNP TDS-OFDM system investigated here are shown in Table I. The commonly-used tapped-delay-line channel model was employed in the following simulation experiments. The China test 8 (CT8) channel [13] and the COST 207 typical urban (TU) environment with the power intensity profile listed in Table II

TABLE II. CHANNEL PARAMETERS OF CT8 AND TU 12-PATH

	CT8		TU	
Tap	Amp. (dB)	Delay (μs)	Amp. (dB)	Delay (μs)
1	0	0.0	-4	0.0
2	-18	-1.8	-3	0.2
3	-20	0.15	0	0.4
4	-20	1.8	-2	0.6
5	-10	5.7	-3	0.8
6	0	30.0	-5	1.2
7			-7	1.4
8			-5	1.8
9			-6	2.4
10			-9	3.0
11			-11	3.2
12			-10	5.0

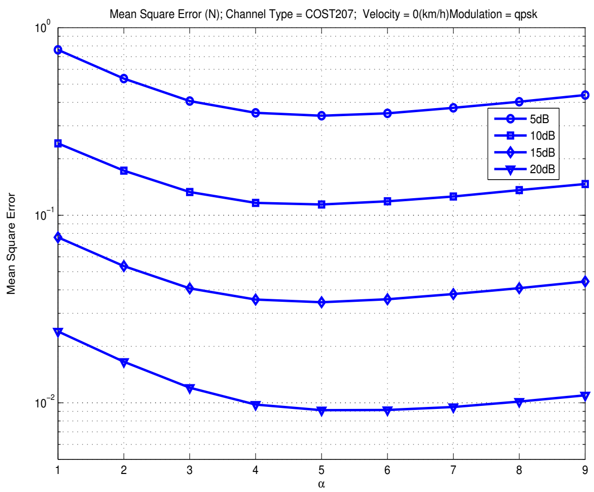


Fig. 7. MSE comparison with various values of threshold α for different SNR.

were also employed in the simulations. The CT8 channel has large spread and two significant paths. The main reason we used CT8 channel is that some conventional methods like DFT-based channel estimation and SCTD method which are originally performed in CP-OFDM but no longer suitable for TDS-OFDM, because the TDS-OFDM system structure uses preamble to perform channel estimation instead of conventional pilots. The TU channel has exponential decay without significant path. The main reason we used TU channel is that it is difficult to define which taps contain channel information or noise. The threshold should be carefully chosen in order to keep most channel information and remove the noise. Therefore, we used TU channel to find the optimal threshold and demonstrate our method can have better performance over various multipath channel environments.

Figure 7 shows that the mean square error (MSE) for the various values of design constant α with different SNR. The MSE means the difference between actual channel and estimated channel in frequency domain. The lower MSE implies the estimated channel frequency response is more similar to the actual channel frequency response. $\alpha = 1$ means the proposed channel estimation method use the original estimated noise power as threshold. Although $\alpha = 1$ can surely keep most of the channel information, it will also introduce lots of noise interference. So, $\alpha = 1$ can not be chosen as candidate. $\alpha = 9$ means the proposed channel estimation method obtained the

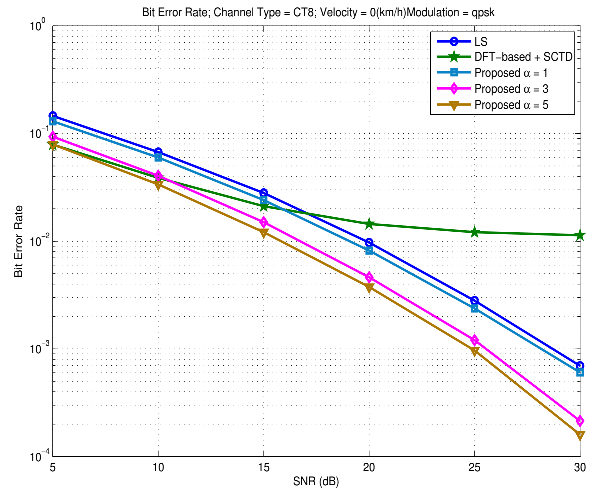


Fig. 8. BER performance comparison with various CE algorithms under CT8.

threshold by multiplying the estimated noise power and a constant weight 9. Although $\alpha = 9$ can surely remove most of the noise power, it will also remove most of the useful CIRs. So, $\alpha = 9$ can not be chosen as candidate either.It is obvious that the threshold is optimal when $\alpha = 5$. Our main purpose is to reduce the noise interference in order to improve the system performance and also keep most of the useful channel information in order to reform the channel frequency response. The result shows that the larger threshold may cause path information leakage and the smaller threshold may introduce noise effect.

In Figure 8, the proposed channel estimation method has better performance than the DPNP TDS-OFDM CE with conventional LS technique. The conventional LS channel estimation method simply takes all the estimated frequency response. The conventional LS channel estimation method will introduced large noise interference, because the noise did not be removed. Based on the main idea of DFT-based channel estimation method, we know that the channel information is only included in the prior CIRs. Therefore, DFT-based channel estimation method can remove part of the noise interference (i.e., By removing the CIRs large than L taps), but it can not remove the noise inside the prior CIRs. Therefore, we takes the advantage of the SCTD method, because SCTD method can effectively remove the noise effect inside the prior CIRs. But, the SCTD can not be directly used for TDS-OFDM system because the TDS-OFDM CE performs only in M taps (i.e., the conventional SCTD performs in N taps). That means the conventional SCTD must choose the estimation part which only contains noise. The CP-OFDM system use pilot to estimate the channel response, so it can be sure that the CIRs large than CP length only contains noise. If the conventional SCTD chose the estimation part which contains channel information, the SCTD will cause estimation error. The TDS-OFDM uses preamble to perform the estimation. It is possible that the whole estimation CIRs can contains channel information. The simulation applies the last 32 taps for the SCTD method in order to calculate the noise power in the TDS-OFDM system. That means if the channel has

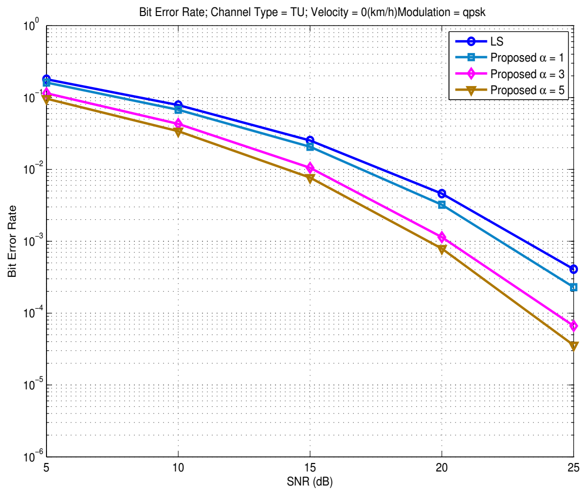


Fig. 9. BER performance comparison with various CE algorithms under COST 207 TU.

large spread like CT8, even the last CIRs can contains channel information which can cause the SCTD estimation error. Based on the idea of SCTD method, we change the way to estimate the noise by using the convolution of two preambles in order to extract the noise power. The simulation result shows the proposed channel estimation can effectively remove the effect of noise and achieve better performance.

Figure 9 shows the BER performance in TU channel. That means the proposed algorithm also has better performance in the relatively small delay spread and more path environment. We can note that the CT8 channel has few paths and two significant CIRs compared with TU channel. Figure 8 shows that $\alpha = 3$ and $\alpha = 5$ have similar performance at high SNR. That is to say, if we get enough channel information power (i.e., we use the proposed estimation method to remove the noise and get the 2 significant CIRs), the MSE and BER performance would be similar. However, TU channel is exponentially decayed. It is hard to define which channel tap is the significant CIR. Therefor, the threshold should be carefully chosen. Figure 9 shows that $\alpha = 5$ has better performance than $\alpha = 3$, because the chosen threshold can not only remove the noise interference but also save most of the channel information. The simulation results demonstrate that the proposed algorithm can improve the BER performance over various multipath channel environments.

V. Conclusions

A modified DFT-based channel estimation technique has been proposed for DPNP TDS-OFDM systems over various multipath environments. The main contribution is the proposed estimation scheme combined and modified the conventional estimation scheme which originally used in CP-OFDM can be suitable performed in TDS-OFDM system. The proposed estimation scheme adopted a DFT-based channel estimation and a significant channel tap detector with the use of a noise power predictor to improve the channel estimation performance. The proposed technique has taken advantage of a DFT-based CE method to obtain the CIR by using IDFT with only preamble-length taps which are less than those of the conventional DFT-base CE methods. While choosing the significant CIR, the proposed technique has taken advantage of SNR estimation in order to estimate the noise power and does not require any information about the channel statistics. It could roughly predict the noise power for choosing the significant CIR.

Some comparative simulations have been given to show that using the proposed technique can improve the bit error rate performance compared with the conventional least-squares channel estimation, because the proposed technique not only can effectively remove the noise interference but also can keep most channel information. It would not leak the main path information to cause performance degradation in high SNR. The proposed estimation scheme is suitable for TDS-OFDM system over a variety of multipath environments.

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