行政院國家科學委員會專題研究計畫　期中進度報告

後三代行動通訊處理器設計(1/3)

計畫類別：個別型計畫
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執行單位：國立臺灣大學電信工程學研究所

計畫主持人：陳光禎

報告類型：精簡報告

處理方式：本計畫可公開查詢

中　華　民　國 92 年 5 月 26 日

行政院國家科學委員會補助專題研究計畫期中進度報告

後三代行動通訊處理器設計 (1/3)

計畫類別：個別型計畫
計畫編號：NSC－91－2811－E－002－044
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計畫主持人：陳光禎教授
共同主持人：張朝明
計畫參與人員：

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執行單位：國立臺灣大學電機資訊學院電信工程學研究所

中　華　民　國 9 2 年　5 月　 3 1　日

後 三 代 行 動 通 訊 處 理 器設計 (1/3)

Beyond 3G Receivers Design

計劃編號: NSC 91-2811-E-002-044

執行期限: 91/08/01 ~ 92/07/31

主持人: 陳光禎　　臺灣大學電機系　　教授

一、中文摘要

在後三代的行動通訊系統中，主要的任務是藉由更有效率的使用有限的頻寬，以提供比第三代行動通訊系統(IMT-2000)更大量、更高品質的多媒體資訊傳輸。另外，透過可程式化的通訊系統設計，使得後三代的通訊系統不但能與其它世代的行動電話相通訊，更能與其它無線網路系統(例如：無線區域網路 IEEE 802.11a, IEEE 802.11g）或是無線個人通訊系統（例如：藍芽通訊系統等）相連接，以實現個人全域通訊系統。

在第一年的計畫中，藉由保持頻域上不同使用者的訊號正交來避免使用者之間訊號的干擾(MAI，multiple access interference）[2]；以及學習正交頻域多工（OFDM）避免相鄰訊號干擾（ISI，inter-symbol interference）的方法，我們首先提出一個既無多人訊號干擾，也無相鄰訊號干擾的一個多人通訊系統（FDOMC-IT，frequency-domain orthogonal multiuser communications with inverse transformation）。這個多人的通訊系統適用於非同步傳輸（asynchronous transmission）的情況，並且適用於真實的選頻衰退通道(frequency-selective slowly fading channels）中。更值得一提的是，這個通訊系統最佳解調的複雜度，無視於多人通訊與選頻衰退通道的情況，跟單人點對點（point-to-point）的傳輸系統在最簡單的通道中的最佳解調的複雜度一樣低。此外，我們進一步的提出一個能充份使用選頻通道(frequency-selective channels）的相異增益（diversity gain）的通訊系統（FDOMC-DS，frequency-domain orthogonal multiuser communications with direct spreading）來改進因為處於衰退通道（fading channels）的系統效能。這兩個提出的通訊系統不但複雜度低、製造的成本低，更能提供可變資訊傳輸量的服務，使得它們成為後三代通訊系統中的最佳後選者。

我們還更進一步的根據最大事後機率的規則（*maximal a posteriori* probability),設計出最佳效能的時序估測法（timing estimation)。這個時序估測法考慮到了在選頻衰退通道中所可能產生的相鄰訊號間的干擾，並且有效的利用選頻通道的相異增益來正確地估計訊號的時序。更值得一提的是，這個估測法不需要知道選頻衰退通道的資訊即可操作。我們不但用數學分析的方法，找出此估測法有效的充份條件，更以實驗數據來驗證此估測法的良好表現。最後，我們還推導出不需要訊號資訊即可估計的設計。這個時序估測法考慮到了真實通道上的各種複雜問題，因此可適用於許多真實的通訊系統的設計中。

藉由我們提出的通訊系統以及其所需的時序估測法，我們完成了絕大部份的系統設計。而這些設計的良好特性

（例如其高效能與低複雜度）使得後三代的行動通訊系統的設計得以完成。

關鑑詞：後三代行動通訊系統，頻域正交多工通訊系統，最佳時序估測，選頻衰退通道。

英文摘要

In the communications systems beyond the third generation (B3G) mobile communications, the primary concept leads to develop the efficiently utilization of spectrum to provide the higher data rate services than IMT-2000 and to develop the programmable systems adaptive to multiple communications systems, such as the wide-band CDMA in IMT-2000, OFDM in IEEE 802.11a [1] and IEEE 802.11g, the Bluetooth technologies.

In the first year of the project, by inheriting the properties of the frequency-domain approach [2] to avoid MAI in the asynchronous multiuser communications and sharing the rationale behind OFDM systems to mitigate ISI, we propose an asynchronous multiuser communications system (i.e. the frequency-domain orthogonal multiuser communications with inverse transformation (FDOMC-IT)) over frequency-selective slowly fading channels such that the optimal demodulation with similar complexity to point-to-point communications is possible. In addition, by spreading the symbol energies to the whole transmission frequency band, we further introduce another asynchronous multiuser communications system (i.e. the frequency-domain orthogonal multiuser communications with direct spreading (FDOMC-DS)) to utilize the frequency diversity gain. These proposed systems not only mitigate MAI and ISI efficiently with simple complexity but also are flexible for variable rates transmission to suggest their applications to practical multimedia services.

Applying the composite hypothesis testing procedure, we further introduce the *maximum a posteriori probability* (MAP) symbol synchronization in the wireless communications systems with statistical channel information over frequency-selective slowly fading channels. This proposed estimation takes the presence of interference due to frequency-selective channels into account and efficiently utilizes the inherited frequency-diversity to combat the channel fading impairment. By mathematical analysis, we prove the fundamental condition to have a consistent symbol synchronizer over frequency-selective slowly fading channels when the channel impulse response is unknown. We further conduct simulations to justify its performance considering the practical implementation with a finite number of timing candidates and extend its applications to the case without training symbols. This proposed timing estimation considers more generalized scenarios with feasible complexity and therefore could be extensively applied in many practical communications systems.

With the introduction of the frequency-domain orthogonal multiuser communications systems (FDOMC) and the optimal timing estimation over frequency-selective slowly fading channels, it is promised to design the high-rate B3G systems for multi-media services with simple complexity.

Keywords: B3G, FDOMC, Optimal Timing Estimation, and Frequency-selective slowly fading channels.

二、前言

Since the first introduction of analog cellular (the first generation) AMPS in 1983, cellular communication has become as one of the fastest growing industry. While migrating from the analog cellular systems into the second generation digital systems such as GSM in Europe and IS-54 in North America using TDMA technology, and IS-95 applying CDMA technology, all of them are regional standard and technologies. In light the need of world wide common standard for mobile users, ITU-R (International Telecommunication Union – Radio) started the effort of the third generation wireless communication systems, initially known as FPLMTS (Future Public Land Mobile Telecommunication System). Later on, it has been changed to a new name, International Mobile Telecommunications – 2000 (IMT-2000). The meaning of 2000 is two-fold, with frequency range around 2000 MHz and being realized around year 2000. The ultimate goal of this ITU-R effort is to create a world-wide common system on a world-wide common frequency band to fully realize the no-boundary mobile communications.

Due to the success of narrow-band CDMA cellular to demonstrate advantages in high system capacity and other networking management considerations, adopting CDMA technology for IMT-2000 is the main stream concept in the industry. However, some inherent difficulties for IS-95 narrow-band CDMA exist:

- ❑ Based on IS-95 1.2288 Mcps and 8 Kbps basic transmission rate, many high-bandwidth applications required by IMT-2000 are not practically feasible even by using multi-code CDMA.
- ❑ IMT-2000 operates for wide range applications in higher frequency band and in much more complicated environments such as indoor and other severe fading channels. 1.2288 Mcps might not suffice to support high-quality wireless transport simply due to channel bandwidth and more receiving techniques are needed to meet basic link performance.

Next generation wireless communication systems beyond 3G wireless shall be implemented in the form of a communication processor to integrate multiple system functions into one platform with a common RF front end, which is a more precise and realistic way for software radio. Its counterpart in networking area is network processor to integrate multiple networking purposes as the key building block for re-configurable networks. This proposed project shall concentrate on the design of pioneer general communication processor to take care of flexible physical layer transmission and medium access control as portion of network processor.

三、研究目的

In mobile communications systems, multiple access to the common channel resources is vital. In a system based on the conventional direct sequence code division multiple access (DS-CDMA) technique, code division provides simultaneous access for multiple users.

Ideally, by selecting mutually orthogonal spreading codes in time-domain for all users, interference-free single-user performance can be achieved. It is, however, impossible to maintain orthogonal spreading codes at the receiver in a mobile environment, and thus multiple-access interference (MAI) is inevitable in the DS-CDMA systems. The multiple access interference severely degrades the performance of conventional DS-CDMA detection techniques and is the major limiting factor to system capacity.

Over the years researchers have sought ways to improve system performance and to extend user capacity by seeking for more advanced detection strategies. In [3], Verdu developed the optimal (0,1)-constrained maximum likelihood (ML) detector for multi-user DS-CDMA systems. Since then, multi-user detection (MUD) has become the most attractive technique to improve the system performance. Nevertheless, the majority of multi-user detectors have very high complexity and consequently sub-optimal structures have been presented in practical implementations.

In [2], a frequency-domain code division multiple access scheme over additive white Gaussian noise (AWGN) channel was proposed as an alternative to mitigate the multiple access interference due to asynchronous transmissions in the DS-CDMA systems. This scheme considers a novel but equivalent spreading approach and employs mutually orthogonal sequences in the frequency-domain as spreading codes. Due to the fact that shift of a signal in time-domain simply corresponds to multiplication by a scalar factor in frequency domain, orthogonality over frequency-domain can be retained among all users, which eliminates the requirement of perfectly synchronous receptions at the receiver [4,5]. Therefore, the optimal demodulator can be realized with significantly reduced complexity.

By extending this frequency-domain approach to frequency-selective slowly fading channels, this frequency-domain approach is interfered by inter-symbol interference (ISI) introduced by frequency-selective channels, although the signature sequences remain orthogonal to have zero MAI.

In the first year of this project, we first introduce the frequency-domain orthogonal multiuser communications systems that are not interfered by ISI over frequency-selective slowly fading channels. In addition, we propose the optimal timing estimation over frequency-selective slowly fading channels to provide the received timing required to the receiver.

四、研究方法

We consider the asynchronous multiuser communications systems with K users over frequency-selective slowly fading channels such that the channel impulse response of all users are time-invariant within a couple of frames. In order to avoid the ISI introduced from frequency-selective slowly fading channels, sharing the similar rationale behind OFDM systems, we insert the guard intervals of proper length which is the cyclic prefix of the signal as shown in Figure 1. In addition, we employ the frequency-domain orthogonal spreading and the frequency-domain orthogonal signature sequence as shown in Figure 2(a) to mitigate the MAI. As can be seen in Figure 2(b), the receiver only need two discrete Fourier transformation blocks to optimally demodulate the received signals. The transceiver block for FDOMC-DS is plotted in Figure 3.

In the second part, applying the composite hypothesis testing rule, we introduce the optimal timing estimation based on the *maximal a posteriori* probability with unknown channel impulse response over frequency-selective slowly fading channels. The block diagram of the proposed estimation is in Figure 4.

五、結果與討論

Two frequency-domain orthogonal multiuser communications (FDOMC) schemes, namely FDOMC-IT and FDOMC-DS, have been proposed to mitigate the multiple access interference for the asynchronous communications system over frequency-selective slowly fading channels. In addition, the FDOMC-IT system is further not interfered by ISI introduced by frequency-selective channels and can be optimally demodulated with low complexity. This is the consequence of concentrating the energies of independent information symbols into different sub-bands such that each sub-band experiences frequency-nonselective fading. This approach does not earn the frequency diversity gain inherited from frequency-selective channels without efficiently establishing the correlation between information symbols.

By spreading the energies of independent information symbols into the whole frequency band, the FDOMC-DS system utilizes the frequency diversity to combat channel fading impairment so that it outperforms the FDOMC-IT scheme with similar complexity. Moreover, it was verified by the numerical analysis that the LMMSE estimation is much more efficient than the ML estimation to utilize the frequency diversity by taking the noise enhancement effects into consideration.

We further proposed the optimal symbol synchronization based on MAP criterion over frequency-selective slowly fading channel. In particular, the proposed estimator, designed according to the composite hypothesis testing rule, does not require the information of channel impulse response of the frequency-selective channels. By releasing the assumption in [6], our proposed estimator can be applicable to many wireless communications systems, in addition to the DSSS communications systems with large spreading gain.

This proposed optimal estimator, as justified by the conducted simulations, not only utilizes the frequency-diversity to combat fading channels but also properly mitigates the mutual interference due to multi-path components. In addition, we proposed the sufficient condition for the proposed optimal estimation to be consistent. This introduced sufficient condition can be explained as the consequence of the lack of channel impulse response and therefore is stricter to the case with known channel impulse response. Fortunately, a lot of training symbols can easily satisfy this sufficient condition to have a consistent symbol synchronizer.

六、參考文憲

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七、圖表

Figure 1: Frame structure of frequency-domain orthogonal multiuser communications (FDOMC) systems.

(a) Transmitter of user k.

(b) Optimal receiver of user k

Figure 2: Transceiver of frequency-domain orthogonal multiuser communications systems with inverse transformation for user k.

(a) Transmitter of user k

(b) Receiver of user k.

Figure 3: Transceiver of frequency-domain orthogonal multiuser communications system with direct spreading for user k.

Figure 4: Optimal timing estimation with unknown channel information over frequency-selective slowly fading channels.

附件一

可供推廣之研發成果資料表

□ 可申請專利　　□ 可技術移轉　　日期：92 年 5 月 31 日

國科會補助計畫	計畫名稱：後三代行動通訊處理器設計(1/3) 計畫主持人：　陳光禎教授 計畫編號：　NSC91-2811-E-002-044　　學門領域：電信學門
技術/創作名稱	Frequency-domain orthogonal multiuser communications
發明人/創作人	張朝明、陳光禎 Chao-Ming Chang and Kwang-Cheng Chen

<table>
<tr><td rowspan="2">技術說明</td><td>中文：
藉由保持頻域上不同使用者的訊號正交來避免使用者之間訊號的干擾；以及學習正交頻域多工避免相鄰訊號干擾的方法，我們首先提出一個既無多人訊號干擾，也無相鄰訊號干擾的一個多人通訊系統（FDOMC-IT，frequency-domain orthogonal multiuser communications with inverse transformation）。這個多人的通訊系統適用於非同步傳輸（asynchronous transmission）的情況，並且適用於真實的選頻衰退通道（frequency-selective slowly fading channels）中。更值得一提的是，這個通訊系統最佳解調的複雜度，無視於多人通訊與選頻衰退通道的情況，跟單人點對點（point-to-point）的傳輸系統在最簡單的通道中的最佳解調的複雜度一樣低。此外，我們進一步的提出一個能充份使用選頻通道（frequency-selective channels）的相異增益（diversity gain） 的通訊系統（FDOMC-DS，frequency-domain orthogonal multiuser communications with direct spreading）來改進因為處於衰退通道（fading channels）的系統效能。這兩個提出的通訊系統不但複雜度低、製造的成本低，更能提供可變資訊傳輸量的服務，使得它們成為後三代通訊系統中的最佳後選者。</td></tr>
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可利用之產業 及 可開發之產品	Applicable to the next generation (B3G) cellular systems. Advanced multiuser communications systems.
技術特點	1. Optimal demodulation with simple complexity; 2. Zero MAI and ISI; 3. For asynchronous channels; 4. Multiuser communications with variable rate transmission; 5. For practical frequency-selective slowly fading channels.
推廣及運用的價值	These proposed systems not only mitigate MAI and ISI efficiently with simple complexity but also are flexible for variable rates transmission to suggest their applications to practical multimedia services.

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