2008 年中央研究院「年輕學者研究著作獎」得獎人簡介

姓名：陸曉峯 	學歷：（自大學起；註明起迄年份） 大同工學院電機系學士(79 年 09 月 至 83 年 06 月) University of Southern California 電機研究所碩士(87 年 09 月 至 88 年 12 月) University of Southern California 電機研究所博士(89 年 01 月 至 92 年 08 月) 現職及經歷：（由近至遠） 1. 中正大學通訊工程學系副教授(2007-) 2. 中正大學通訊工程學系助理教授 (2004-2007) 3. University of Waterloo 博士後研究 (2003-2004)

得獎著作名稱：（請以申請時之格式填入）

1. H. F. Lu, “On Constructions of Algebraic Space-Time Codes with AM-PSK Constellations Satisfying Rate-Diversity Tradeoff,” *IEEE Trans. Inform. Theory*, vol. 52, no. 7, pp. 3198-3209, Jul. 2006.
2. P. Elia, S. A. Pawar, K. Raj Kumar, P. V. Kumar, and H. F. Lu, “Explicit Construction of Space-Time Block Codes Achieving The Diversity-Multiplexing Gain Tradeoff,” *IEEE Trans. Inform. Theory*, vol. 52, no. 9, pp. 3869-3884, Sep. 2006.
3. H. F. Lu and M. C. Chiu, “Constructions of Asymptotically Optimal Space-Frequency Codes for MIMO-OFDM Systems,” *IEEE Transactions on Information Theory*, vol. 53, no. 5, pp. 1676-1788, May. 2007.

得獎著作簡介: （2000 字左右）

直覺上，無線通訊是由一個傳送及一個接收天線所組成，且訊號是由傳送天線送往接收端。事實上，這個概念可以直接適用於你周遭所有的無線通訊器材。就拿你的手機或者無線寬頻分享器來說，你會發現你的手機上只有一個天線。就算有時你的無線寬頻分享器會有兩個天線，但別被它混淆了，這兩個天線具有不一樣的功能，它們分別處理傳送和接收的訊號。然而，這個概念將在未來幾年改變。

近十年來，通訊研究學者逐漸瞭解，在傳送與接收端同時使用更多的天線不僅能得到較高的傳輸速率，也同時能提升訊號的品質。這個優點在現今資料通訊需求大增時更加顯的重要。試想，多少次你抱怨著當你想要用手機或筆電傳送訊息時你的無線網路卻是出奇的慢。為了解決當前的窘境，多天線的通訊方法幾乎

是唯一而且已被證明為正確的解決之道。事實上，多天線通訊在最近的無線通訊標準中已被廣泛採用，例如無線區網的 IEEE 802.11n 及下一代行動通訊標準的 WiMAX。

我的研究著重在多天線環境中的錯誤更正碼設計，特別是針對下一代的無線通訊系統。由於這樣的編碼可在多天線環境下的空間與時間域中同時使用，故常被稱為空時碼(space-time code)。在消息理論的觀點裡，我所提出的空時碼設計是目前全世界少數已知的最佳編碼設計。這裡所指的最佳是，當給定想要的傳送速率後這些編解碼系統能達到最小的傳輸錯誤率或是達到所謂的最大的分集增益(diversity gain)。因此，配備有這些最佳編碼系統的多天線通訊設備在傳送速率及可靠度上都將會有最好的效能表現。接下來我將簡短的描述我論文中主要的貢獻。

在第一篇文章我們提出數個具有 AM-PSK 星座圖架構的空時碼設計。第一種設計稱為 P 半徑的 AM-PSK 時空碼，意指當星座圖的大小為一質數 P 的次方時，此設計可藉由延伸 Hammons' 二元半徑架構而得。我們所提出的方法除可設計出達到傳送速率與分集增益最佳權衡 (rate-diversity tradeoff)的空時碼外，並同時具有 AM-PSK 星座圖的調變方式。另外，此文亦將針對近來所發表的各種空時碼提出其所有非明顯的最佳子集-子碼，其數量及種類亦在文中明確的計算出。

在第二篇文章我們針對 Zheng and Tse 所使用之另一種權衡方式，稱為 diversity-multiplexing gain (D-MG) tradeoff 提出最佳空時碼的設計方法。此方法是先將 cyclic division 代數中某些元素以左正規化(left-regular) 的方式表示矩陣而成，這些矩陣的行列式均具有 non- vanishing 的特性，並且無論傳送與接收天線的數量為何，我們所提出的設計皆可達到 D-MG tradeoff，此外我們更證明我們所提出的空時碼設計其效能可大幅改良原始的 D-MG tradeoff 並達到最小延遲，此外，這也是全球首創的 D-MG 最佳的空時碼設計。

在第三篇文章我們提出兩個多輸入輸出正交分頻多工(MIMO-OFDM)系統的空間頻率碼(space-frequency code)設計。之前的研究指出，當空間頻率碼中的矩陣若具有大的秩距(rank distance)及行距(column distance) ，則此空頻碼就會有較優的效能表現。這裡所謂矩陣的行距是指倘若有 A 與 B 兩個矩陣，則 A、B 矩陣的行距定義為(A-B) 矩陣中非零行向量的數目。依據這個原理，我們所提出的第一個空間頻率碼設計是將 maximum rank distance(MRD)空時碼中的矩陣，以右乘的方式乘上某些的非奇異矩陣而得，而所得的碼則可擁有接近 Gilbert-Varshamov bound 的最大行距，我們稱此種空間頻率碼為 linearly-transformed MRD 碼。就以(2x256) QPSK 調變的空間頻率碼來說，之前所有文獻的空頻碼設計僅能達到 3、5 或 6 的行距，然而我們提出的 linearly-transformed MRD 碼卻可提供大於等於 50 行距。我們提出的第二個空頻碼設計稱為 cyclotomic 設計，此設計法與傳統熟知的 Reed-Solomon 碼有些許相似但更為複雜。文中我們並計算出 cyclotomic 編碼設計可提供的秩距與行距，並且證明在 rate-diversity tradeoff 中此設計為 asymptotic 最佳 。

評審簡評：

陸曉峰博士近年來的研究，主要以通訊/消息理論領域中之「時空編碼」為主軸，針對第四代行動通訊中，多傳輸及多接收天線的通訊傳輸系統，設計出達到理論極限的最佳錯誤更正編碼。陸博士的研究內容遍及時空碼相關的重要課題，深入利用代數以及代數數論中嚴謹的理論，解決了一連串深具困難度、挑戰性、以及應用價值的時空編碼課題。研究論文無論在質與量上，均極為豐碩與傑出。三篇代表作發表於IEEE Transactions on Information Theory此無線通訊領域最頂尖的國際期刊。陸博士在時空編碼方面的研究，除了在理論方面獲得突破性的貢獻外，對於下一代無線通訊技術，更提供了極重要的應用價值。陸博士的研究成果，即使以國際上最嚴格的審查標準而言，均屬最尖端。此次得獎，可謂是實至名歸。

2008 Academia Sinica Research Award for Junior Research Investigators

Name：Hsiao-feng (Francis) Lu 	Education: B.S., Electrical Engineering, Tatung Institute of Technology (1990-1994) M.S., Electrical Engineering, University of Southern California (1998-1999) Ph.D., Electrical Engineering, University of Southern California (2000-2003) Employer(s)/Job Title(s): Associate Professor, Department of Communications Engineering, National Chung-Cheng University (2007-) Assistant Professor, Department of Communications Engineering, National Chung-Cheng University (2004-2007) Postdoctoral Research Fellow, University of Waterloo (2003-2004)

Award publications：

1. H. F. Lu, “On Constructions of Algebraic Space-Time Codes with AM-PSK Constellations Satisfying Rate-Diversity Tradeoff,” *IEEE Trans. Inform. Theory*, vol. 52, no. 7, pp. 3198-3209, Jul. 2006.
2. P. Elia, S. A. Pawar, K. Raj Kumar, P. V. Kumar, and H. F. Lu, “Explicit Construction of Space-Time Block Codes Achieving The Diversity-Multiplexing Gain Tradeoff,” *IEEE Trans. Inform. Theory*, vol. 52, no. 9, pp. 3869-3884, Sep. 2006.
3. H. F. Lu and M. C. Chiu, “Constructions of Asymptotically Optimal Space-Frequency Codes for MIMO-OFDM Systems,” *IEEE Transactions on Information Theory*, vol. 53, no. 5, pp. 1676-1788, May. 2007.

Summary of the Award publications（around 2000 words）：

It is often intuitive to think of wireless communication to be comprised of one transmit and one receive antenna, and the signals be sent from the transmit antenna to the receive. In fact, such concept can be safely applied to most of existing wireless communication equipments beside you. Take a look at your cellular phone or the access point of your wireless LAN equipment. You will find there is only one antenna appearing in your cellular phone. Yes, it is true that sometimes there are two antennas available at your wireless access point. But don’t be fooled by that. These two antennas have different functions; one is for transmitting signal and the other is for receiving. However, things are about to change in the next few years.

During the last decade, communication researchers have come to realize that by placing more antennas at both transmitter and receiver ends, one can communicate not only at a much higher rate, but also in a much better signal quality. Such advantage is more and more pronounced when the demand of data communication has quickly risen in our daily life. Imagine that, how many times you have complained about the slow speed of your wireless network when you want to access information from either your cellular phone or your laptop. To resolve such dilemma, the usage of multiple antennas is a must and has proven to be the right cure. In fact it has been adopted for use in most of the latest wireless communication standards, for example, the IEEE 802.11n for wireless LAN, and the WiMAX for next generation mobile communication.

My research has focused on of the design of error correcting codes for multiple-antenna environments, and in particular, for the next generation wireless communication systems. Such codes are often coined the name “space-time codes” due to the information coding is applied across both space (multiple antennas) and time. The space-time codes I have proposed are optimal in the information theoretic sense, and are so far among the very few known optimal designs in the world. By optimal I mean that given the desired transmission rate, these codes can achieve the minimal possible error performance, or equivalently, can achieve the largest possible diversity gain advantage. Hence, it follows that the multi-antenna communication systems equipped with these optimal codes would be able to yield the best possible performance, not only in transmission rate, but also in reliability. Below I will briefly describe the major contributions made in some of my papers.

In the first article, several constructions of space-time codes with AM-PSK constellations are presented. The first construction, termed P-radii construction, is obtained by extending Hammons' dyadic dual-radii construction to the cases when the size of the constellation is a power of a prime P. The resulting code meets the rate-diversity tradeoff and has an AM-PSK constellation. Also contained in this paper is the identification of rich classes of nontrivial optimal subset-subcodes of the newly constructed space-time codes. The exact number of distinct subset-subcodes is given and is related to the Dobinski-type sum in combinatorics.

The second article contains an explicit construction of space-time codes that is optimal with respect to the diversity-multiplexing gain (D-MG) tradeoff proposed by Zheng and Tse. The construction is based on the left-regular representation of elements in some cyclic division algebra. The resulting codes possess the

non-vanishing determinant property and are shown to achieve the D-MG tradeoff for any number of transmit and receive antennas. Our result also improves greatly the D-MG tradeoff by showing that the tradeoff is exact up to the minimal delay case. This is the first known universal D-M optimal construction in the world.

Finally, in the third article we present two constructions of space-frequency codes (SFCs) for MIMO-OFDM systems. It is known that SFCs having larger rank and minimum column distances achieve better performance. Following this principle, the first construction is obtained by right-multiplying the code matrices in a maximal rank distance (MRD) code by some fixed nonsingular matrix. The resulting codes are called linearly transformed MRD (LT-MRD) codes whose minimum column distance is shown to meet the Gilbert-Varshamov bound. For the case of constructing fully-diverse (2x256) QPSK-modulated SFCs, the LT-MRD codes can provide a minimum column distance at the value of >= 50, compared to the values of 3, 5, or 6 obtained by other codes in the literature. The second construction, termed cyclotomic construction, is reminiscent of the construction of the Reed-Solomon codes. Exact minimum rank distances of these codes are presented and are shown to be asymptotically optimal in terms of rate-diversity tradeoff. Bounds on the minimum column distances of these codes are also given.