出國報告（出國類別：國際會議）

參加第 13 屆 IEEE 車輛技術協會亞太區無線通訊研討會(APWCS2016)會議報告

服務機關：國防大學理工學院電機電子系

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派赴國家：日本 (Japan)

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摘　　要

第 13 屆 IEEE 車輛技術協會亞太區無線通訊研討會(13th IEEE VTS Asia Pacific Wireless Communications Symposium, APWCS 2016)，於 105 年 8 月 25 日至 26 日在日本東京的東京都市大學(Tokyo City University, Tokyo, Japan)世田谷校區(Setagaya-Campus)舉行，本人投稿該研討會論文乙篇，論文題目為「結合多重天線及通道分配機制以改善超密集毫微微細胞之吞吐率」，因榮獲刊登，且大會議程邀請於 8 月 25 日下午場次以口頭發表研究成果，故於 8 月 24 日搭機前往與會。

第 13 屆 IEEE 車輛技術協會亞太區無線通訊研討會是由電子電機工程協會(IEEE)的車輛技術協會(Vehicular Technology Society: VTS)所主辦的會議，該會議每年由東京分會、首爾分會、台北分會和新加坡分會共同主辦。該研討會主要的目的在提供亞太區一個研究交流平台，讓研究學者可以在這裡分享最新的無線技術研究成果，並透過討論之方式，獲得其他學者寶貴的意見，甚至是合作的機會。今年的主題著重在第五代行動通訊的關鍵技術，藉由參加此次會議，不但可以增加與相關領域人士的互動，彼此交換研究上的心得，亦使得業界熟知學術界的研發成果，促進業界與學術界更緊密的合作，也激發了未來研究的新想法及方向。最後感謝科技部補助方得出席今年的 APWCS2016 學術研討會。

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參加第 13 屆 IEEE 車輛技術協會亞太區無線通訊研討會(APWCS2016)會議報告內容

一、目的：

亞太區無線通訊研討會每年由 IEEE 車輛技術協會東京分會、首爾分會、台北分會和新加坡分會共同主辦。該研討會主要的目的在提供亞太區一個研究交流平台，讓研究學者可以在這裡分享最新的無線技術研究成果，並透過討論之方式，獲得其他學者寶貴的意見，甚至是合作的機會。今年 2016 年的研討會於 8 月 25 日至 26 日在日本東京的東京都市大學(Tokyo City University, Tokyo, Japan)世田谷校區(Setagaya-Campus)舉行。圖一為該會議的官方網頁。

本人於此研討會計有投稿會議論文乙篇，論文題目為「結合多重天線及通道分配機制以改善超密集毫微微細胞之吞吐率」，因榮獲刊登，依大會議程，將於 8 月 25 日下午場次以口頭報告發表研究成果，故於 8 月 24 日搭機前往與會。本人有幸能參加此研討會，除了藉由聽講與發表，可以讓自己的研究領域與世界接軌，同時又可以透過與各國學者的討論，了解自己研究上的優點與不足，相信這趟旅程一定能增加自己在學術方面的見聞以及拓展自己的國際視野。

圖一：APWCS2016 官方網站，網址：http://apwcs2016.cn.tcu.ac.jp/index.html

二、過程：

第 13 屆 IEEE 車輛技術協會亞太區無線通訊研討會於 8 月 25 日至 26 日舉行，研討會的會場就辦在日本東京的東京都市大學(Tokyo City University, Tokyo, Japan)世田谷校區(Setagaya-Campus)舉行，如圖二。

圖二：APWCS2016 研討會在東京都市大學(Tokyo City University)的世田谷校區(Setagaya-Campus)內舉辦。

本人在報到後就前往主演講廳 21C 會議室參加開幕式，由日本東京都市大學 Mamoru Sawahash 教授主持(如圖三)，隨後即開始了兩日的研討會。研討會的議程如圖四。

圖三：日本東京都市大學 Mamoru Sawahash 教授主持研討會開幕式。

Program at a Glance

Wednesday 24 August					
17:00 - 18:00	Registration (Lounge Oak, 4F Building 1)				
18:00 - 20:00	Welcome Reception (Lounge Oak, 4F Building 1)				
Thursday 25 August					
8:10 - 9:00	Registration (Lobby, 1F Building 2)				
9:00 - 9:10	Welcome Addresses (21C)				
9:10 - 9:50	Invited Speech 1 (21C) : Dr. Fumio Watanabe, Chairman of the Board of Directors, KDDI R&D Laboratories Inc., CTO, UQ Communications Inc., Japan				
9:50 - 10:30	Invited Speech 2 (21C) : Prof. Inkyu Lee, School of Elec. Eng., Korea University, Korea				
10:30 - 10:50	Coffee Break				
10:50 - 12:30	Special Session 1 : 5G Vision, Standardization, and Air Interface (21C), Organizer: Dr. Satoshi Suyama, NTT DOCOMO INC., Japan Special Session 2 : R&D Activities for 5G Mobile Communications (22C), Organizer: Prof. Hidekazu Murata, Kyoto University, Japan				
12:30 - 14:00	Lunch				
14:00 - 15:40	A1: Signal Processing for Communications I (21A)	A2: Relaying I (21B)	A3: Modulation and Coding I (21C)	A4: mmWave Communications (22A)	A5: Heterogeneous Networks I (22B)
15:40 - 16:00	Coffee Break				
16:00 - 17:40	B1: Non-orthogonal Multiple Access (21A)	B2: Sensor Networks (21B)	B3: Massive MIMO (21C)	B4: Heterogeneous Networks II (22A)	B5: Cognitive Radio and Wireless Ad hoc Networks (22B)
18:00 - 20:00	Dinner Banquet (Memorial Hall, 4F Building 3)				
Friday 26 August					
8:20 - 8:50	Registration (Lobby, 1F Building 2)				
8:50 - 9:30	Keynote Speech : Mr. Takehiro Nakamura, Vice President, Management Director, 5G Laboratory, NTT DOCOMO INC., Japan				
9:30 - 10:10	Invited Speech 3 (21C) : Dr. Li Fung Chang, Chief Architect, 5G Program Office, DoIT/MoEA, Taiwan				
10:10 - 10:50	Invited Speech 4 (21C) : Dr. Feng Bao, Director of Security and Privacy Lab, Huawei Technologies, Singapore				
10:50 - 11:10	Coffee Break				
11:10 - 12:50	Special Session 3 : Massive MIMO Technology for 5G (21C), Organizer: Prof. Takeo Ohgane, Hokkaido University, Japan Special Session 4 : Heterogeneous Network for 5G Multi-RAT (22C), Organizer: Prof. Kei Sakaguchi, Tokyo Institute of Technology, Japan				
12:50 - 14:10	Lunch				
14:10 - 15:50	C1: IoT for Machine Type Communications (21A)	C2: Optical/Visible Light Communications (21B)	C3: Resource Management (21C)	C4: Signal Processing for Communications II (22A)	C5: Modulation and Coding II (22B)
15:50 - 16:10	Coffee Break				
16:10 - 17:50	D1: Antenna and Propagation, and Microwave Devices (21A)	D2: Channel Estimation (21B)	D3: Heterogeneous Networks III (21C)	D4: Wireless Networks (22A)	D5: Relaying II (22B)

圖四：APWCS2016 研討會議程。

兩天會議的上午主要是安排專題演講，邀請來自日本、韓國、台灣和新加坡在學界及業界著名的教授與專業人士針對目前學界及產業界的最新無線技術發表演說。下午則是分組論壇，由投稿的學者依據各自的主題在不同的討論室以口頭報告方式發表研究成果。

第 1 天早上的第 1 場專題演講(Invited Speech)，講者為 Fumio Watanabe 博士，題目為 Innovative strategies to tackle real challenges of future mobile systems and services，現場照片如圖五。

圖五：Fumio Watanabe 博士演講。

Watanabe 博士認為第 5 代行動網路除了要強化行動寬頻服務以外，還要考慮大量機器型態通訊(massive-machine type communication)的需求，以及超可靠與超低延遲的通訊服務。而如何保持第 5 代行動網路的彈性是目前最重要的課題，尤其是要如何與現有的第 3 代、第 4 代行動網路及 WI-Fi 共存，並維持網路同時運作，以避免巨額的資本支出。Watanabe 博士認為軟體定義網路(Software defined networking, SND)軟體定義網路具彈性及延伸性，可以立即地提供服務並幫助營運商降低成本，會是第 5 代行動網路成功的關鍵之一。

Watanabe 博士認為下世代行動網路的挑戰如下：

1. 具有高效能的無線接取技術是未來的目標。
2. 利用多波束(multi-beam)、三維波束成型(3D beam forming)、多點協作(CoMP)及波束追蹤(beam tracking)等技術，可以充分使用高頻帶在範圍較小的熱點服務區。
3. 對於營運商而言，第 4 代行動網路和第 5 代行動網路的共存性是必要的。
4. 為了在服務範圍較小的熱點區能夠提供高速無線接取服務，發展新的網路架構，例如資料中心網路(information centric networking, ICN)架構，是必須的。
5. 超彈性是下世代行動網路最重要的考慮因素。
6. 透過具有邏輯性的片狀網路(sliced network)，加入端對端協調控制器(E2E orchestrator)，妥善管理虛擬無線接取網路(radio access network, RAN)、核心網路及服務系統等功能，將會是下世代行動網路成功的關鍵。
7. 第 5 代行動網路未來將會透過資通產業整合來實現。

第 1 天早上的第 2 場專題演講(Invited Speech)，講者為 Inkyu Lee 教授，題目為 Wireless Powered Communication Networks in a two-user interference channel，現場照片如圖六。

圖六：Inkyu Lee 教授演講。

Inkyu Lee 教授提出了一種無線功率式通訊網路(Wireless Powered Communication Networks, WPCN)來解決用戶間的通訊干擾問題，同時建議利用無線資源管理來增加系統傳輸率，其中無線資源管理包含了傳輸功率分配以及傳輸時間分配。Inkyu Lee 教授透過模擬結果分析，可以利用這個無線功率式通訊網路來得到全域的最佳解決方案。

第 2 天早上有一場主題演講(Keynote Speech)，講者為日本 NTT DOCOMO 5G 實驗室管理處的副總裁 Takehiro Nakamura 先生，題目為 5G Deployment in 2020 and Beyond，現場照片如圖七。

圖七：日本 NTT DOCOMO 5G 實驗室管理處的副總裁 Takehiro Nakamura 先生演講。

Takehiro Nakamura 先生從業界的觀點來探討第 5 代行動通訊的標準需求，也特別提到因為日本於 2020 年即將在東京舉辦奧林匹克運動會，所以應該會將第 5 代行動通訊的標準實現，並展現給全世界。Takehiro Nakamura 先生提到未來 2020 年以後的行動通訊，所有設備會透過無線網路連結，例如個人電子裝置(personal device)、交通工具(transportation)、消費性電子設備(consumer electronics)、手錶、外套、衣服等等。Takehiro Nakamura 先生也特別提到在密集都會區必須利用巨量多天線(massive MIMO)技術來延伸系統涵蓋率(coverage)以及提高用戶傳輸率(throughput)。

第 2 天早上的第 1 場專題演講(Invited Speech)，講者為台灣經濟部技術處張麗鳳(Li Fung Chang)博士，題目為 5G & The Industrial IoT，現場照片如圖八。

圖八：台灣經濟部技術處 Li Fung Chang 博士演講。

張麗鳳博士以台灣的觀點來看第 5 代行動通訊的技術發展，認為第 5 代行動通訊是一種異質性、安全性以及可靠性的蜂巢式系統，該系統讓所有地區的不同需求服務的應用連結起來。

張麗鳳博士認為第 5 代行動通訊的挑戰與機會如下：

- 巨量機器型態通訊(Massive Machine Type Communications, mMTC)
  - ■ 設備設計最佳化(Devices design optimization)
  - ■ 低複雜度，低功耗，低成本(Low complexity, low power, low cost)
  - ■ 可免費使用及基於設計上的競爭(Grant-free, contention based design)
- 強化式行動寬頻(enhanced Mobile BroadBand, eMBB)
  - ■ 功率消耗(Power consumption and power dissipation)
  - ■ 射頻組件的複雜度及其效率(Complexity/efficiency of RF components)
  - ■ 巨量天線陣列，波束成形與追踪(Massive antenna array, beam forming and tracking)
  - ■ 毫米波涵蓋範圍(mmWave coverage)
- 超可靠低延遲通信(Ultra-Reliable Low Latency Communications, uRLLC)
  - ■ 低延遲及低震動(Low latency & jittering)
  - ■ 安全和隱私(Security & privacy)
- 超密集網路(Ultra dense network)
  - ■ 分佈式/集中式天線系統(Distributed/centralized antenna system)
  - ■ 無線接取網路劃分(RAN functional split)
  - ■ 自我組織網路(Self-Organizing Network, SON)
  - ■ 智慧行動邊緣計算(Intelligent mobile edge computing, IMEC)
- 整體系統最佳化(Overall system optimization)

■ 巨量連接(分散式/集中式功能劃分)(Massive connectivity (distributed/centralized functional partitions)

■ 可支持不同垂直應用的彈性、相容性及重置系統(Flexible, scalable, reconfigurable system to support various vertical applications)

■ 針對不同的垂直應用，可使用網路功能虛擬化(Network Function Virtualization，NFV)或軟體定義網路(Software-defined networking, SDN)的系統配置以確保數據傳輸率與延遲時間(System configuration of NFV/SDN to ensure throughput, latency met for different vertical applications)

- 新的介面效能及其相關價值鏈(New air interface performance and its associated value chain)
- 第 5 代行動通訊和工業物聯網的結合應用(5G & industrial IoT)

第 2 天早上的第 2 場專題演講(Invited Speech)，講者為 Feng Bao 博士，題目為 5G Security Forward Thinking，現場照片如圖九。

圖九：Feng Bao 博士演講。

Feng Bao 博士的演講主要在探討第 5 代行動通訊在安全上的挑戰及相關議題。Feng Bao 博士認為在設計通訊系統之前，要先考慮安全及隱私的保護功能，才能讓使用者安心使用。

Feng Bao 博士認為第 5 代行動通訊在安全的關鍵議題如下：

- 安全性架構(Security Architecture)
- 認證機制(Authentication)
- 安全機制和密鑰管理(Security context and key management)

- 無線接取網路安全(RAN security)
- 網路群組用戶安全性(Security within NG-UE)
- 授權機制(Authorization)
- 用戶隱私(Subscriber privacy)
- 切片網絡安全性(Network slicing security)
- 中繼台安全性(Relay security)
- 互聯網路安全性(Interconnect network security)
- 安全性視覺化及與配置(Security visibility and configurability)
- 憑證提供方式(Credential provisioning)
- 小數據傳輸的安全性(Security for aspects of small data)
- 廣播及多播的安全性(Broadcast/Multicast Security)

而會議的第一天及第二天下午主要是以分組論壇(sessions)的方式進行學術發表及交流，主要是由這次投稿的作者們，區分成各種主題，以分組的方式進行口頭報告，相關的議程如圖四。

在第一天下午的論壇，本人聆聽了下列兩場，分別是“A5: Heterogeneous Networks I”以及“B4: Heterogeneous Networks II”。

關於“A5: Heterogeneous Networks I”的討論，包含了下列文章：

1. Initial Cell Search Time Performance in Heterogeneous Networks with Same Frequency Spectrum
2. Effect of Transmit Diversity on Cell Search Using Two-step Frequency Offset Estimation in Heterogeneous Networks
3. Throughput Performance of Adaptive Control CRE in HetNet Incorporating eICIC
4. A Study on Improvement in Convergence Rate of Adaptive User Association Method for System Throughput Maximization
5. Pioneering Dual-Connectivity Handover Scheme in C/U Split Networks

關於“B4: Heterogeneous Networks II”的討論，包含了下列文章：

1. Joint Power and Frequency-Domain Inter-Cell Interference Coordination in Heterogeneous Networks
2. Distributed Coverage and Capacity Joint Optimization for Ultra-Dense Small Cell Deployment in 5G Systems
3. Throughput Improvement with Multiple Antennas and Channel Allocation for Ultra-Dense Femtocells
4. Distributed STBC Transmit Diversity In The Presence of CCI From Adjacent Macro-Cells
5. Impact of CSI Error on OFDM-MU-MIMO Downlink of Distributed Antenna Small-cell Network

上述兩場論壇的主題都是異質性網路(Heterogeneous Networks)，是探討在異質性的網路架構下，利用不同的技術來強化網路效能。特別是第一場論壇的第一篇文章，題目為"Initial Cell Search Time Performance in Heterogeneous Networks with Same Frequency Spectrum"，讓本人覺得很有創意。該篇文章主要是針對 LTE 異質性無線網路的架構下，假設巨細胞(macro cell)基地台與小細胞(small cell)基地台使用相同的頻帶，因此巨細胞與小細胞之間會有很強烈的干擾，致使手機用戶無法快速搜尋到適合的基地台來取得服務，因此該篇文章建議使用主同步信號(primary synchronization signal, PSS)偵測與次同步信號(secondary synchronization signal, SSS)偵測的相互應用，來改善細胞搜尋時間。

本人投稿的文章因榮獲刊登，並以口頭方式發表，依大會議程，發表時間排在星期四下午的第二場論壇，也就是"B4: Heterogeneous Networks II"的場次。本人所發表的論文英文題目為"Throughput Improvement with Multiple Antennas and Channel Allocation for Ultra-Dense Femtocells"，論文中文題目為「結合多重天線及通道分配機制以改善超密集毫微微細胞之吞吐率」，主要是針對超密集之多重天線正交分頻多工接取巨細胞與毫微微細胞共存之異質網路，探討多重天線與通道資源分配機制對用戶鏈結可靠度及吞吐率之影響，同時以數學模式建構了一個最佳化的問題。針對這個最佳化問題，我們提出了一種分散式結合傳輸天線選擇與通道分配機制來改善用戶的鏈結可靠度及毫微微細胞系統之吞吐率並達到吞吐率與用戶鏈結可靠度之間的平衡。該機制以兩階段式地比較資源區塊及天線的通道增益，來決定適當的資源區塊及天線並用以傳輸資料。模擬結果發現，在滿足用戶的鏈結可靠度最低需求下，使用該機制可以使毫微微細胞基地台搭載 10 根天線傳輸，而使用隨機分配機制的毫微微細胞基地台只能搭載 4 根天線傳輸，因此，相較於隨機分配機制，本研究提出的結合傳輸天線選擇與通道分配機制可以改善 130% 的毫微微細胞系統之吞吐率。

在第二天下午的論壇，本人聆聽了下列兩場，分別是"C3: Resource Management"以及"D3: Heterogeneous Networks III"。

關於"C3: Resource Management"的討論，包含了下列文章：

1. A 4-guideline Downlink Scheduling Strategy to Support Fairness and QoS for LTE Networks
2. LTE-A Downlink Resource Management for Green Communication
3. Capacity and Fairness Analysis of User Scheduling in Full-Duplex Cellular Networks
4. An Extended CCA Control Mechanism for LTE and Wi-Fi Coexistence

關於"D3: Heterogeneous Networks III"的討論，包含了下列文章：

1. A Study of Energy- and Spectral-Efficiency for Dense HetNet Scenario with Non-Unifom BS and UE Distribution
2. Improved Methods for Online Probabilistic Activation Control of Base Stations Based on Observed System Throughput in Heterogeneous Networks
3. On the Range in Inter-Base Station Information Exchange in Online Probabilistic Activation Control of Base Stations Based on Observed System Throughput

4. A Cross-Layer Sleep Scheme in LTE-A Networks
5. A Study on Online Transmission Power Control of Base Stations Based on Observed System Throughput in Heterogeneous Networks

上述第一場論壇的主題主要是探討如何利用無線資源管理技術來改善未來無線網路的效能。尤其是功率與頻率的分配控制，影響了整個系統的效能。特別是在"C3: Resource Management"這場論壇中的第 2 篇發表文章，題目為"LTE-A Downlink Resource Management for Green Communication"，作者提出一個降低能耗的資源管理機制，用來分配用戶可用的頻寬，以改善用戶與基地台的能量效率，達到綠色通訊之目的。這給了本人一個很好的借鏡。

而在第二場論壇中，本人所選擇聆聽主題是"D3: Heterogeneous Networks III"， 本人也特別注意到第五篇發表文章，題目為"A Study on Online Transmission Power Control of Base Stations Based on Observed System Throughput in Heterogeneous Networks"，該篇文章在異質性網路架構下提出一個下行鏈路傳輸功率控制機制，透過基地台之間的合作，使系統的數據傳輸率得以最大化。該篇文章的想法相當有趣。

三、心得及建議：

第 13 屆 IEEE 車輛技術協會亞太區無線通訊研討會(13th IEEE VTS Asia Pacific Wireless Communications Symposium, APWCS 2016)是由電子電機工程協會(IEEE)的車輛技術協會(Vehicular Technology Society: VTS)所主辦的會議，該會議每年由東京分會、首爾分會、台北分會和新加坡分會共同主辦。該研討會主要的目的在提供亞太區一個研究交流平台，讓研究學者可以在這裡分享最新的無線技術研究成果，並透過討論之方式，獲得其他學者寶貴的意見，甚至是合作的機會。

此次會議討論的議題著重在第 5 世代行動通訊的關鍵發展技術。藉由參加此次會議，不但可以增加與相關領域人士的互動，彼此交換研究上的心得，亦使得業界熟知學術界的研發成果，促進業界與學術界更緊密的合作，也激發了未來研究的新想法及方向。

這次出國參加國際研討會，不論在學術上或文化上，讓本人有更寬廣的視野，實在獲益良多。本人認為，國際研討會是國際學術交流一個很好的平台，應該多多鼓勵台灣的學者與學生參加，以提升台灣學者及學生個人的專業素養以及國際視野。

四、攜回資料名稱及內容：

- 大會議程手冊
- 大會論文資料隨身碟

五、感謝：

承蒙「科技部」的國外差旅費補助得以順利參加本次第 13 屆 IEEE 車輛技術協會亞太區無線通訊研討會(APWCS2016)，讓我有機會參與國際性的研討會，增進國際視野及專業領域的成長，內心深表感謝之意。

附　　錄

附錄一、發表論文中英文摘要

Throughput Improvement with Multiple Antennas and Channel Allocation for Ultra-Dense Femtocells

結合多重天線及通道分配機制以改善超密集毫微微細胞之吞吐率

Ang-Hsun Tsai, *Member, IEEE*, Chung-Hsien Tsai, *Member, IEEE*, and Li-Chun Wang, *Fellow, IEEE*

蔡昂勳；蔡宗憲；王蒞君

Abstract

In this paper, we investigate the impacts of channel allocation with multiple antennas on link reliability and throughput, and formulate an optimization problem in the ultra-dense multi-antenna orthogonal frequency-division multiple access (OFDMA)-based macrocell and femtocell heterogeneous network. We develop a distributed joint transmission antenna selection and channel allocation scheme to achieve the tradeoff between the throughput and link reliability in this optimization problem, and to improve the users' link reliability and the femtocell throughput. This scheme can jointly allocate suitable antennas and resource blocks (RBs) for transmission with two steps of comparisons on channel gains of RBs and antennas. Simulation results show that the proposed scheme with ten antennas can achieve 130% higher throughput for femtocells than the random channel allocation scheme with four antennas under the link reliability requirement.

Index Terms—Small cell; femtocell; heterogeneous network; resource block allocation; multiple antennas; link reliability; throughput.

中文摘要

在本文中，我們針對超密集之多重天線正交分頻多工接取巨細胞與毫微微細胞共存之異質網路，探討多重天線與通道資源分配機制對用戶鏈結可靠度及吞吐率之影響，同時以數學模式建構了一個最佳化的問題。針對這個最佳化問題，我們提出了一種分散式結合傳輸天線選擇與通道分配機制來改善用戶的鏈結可靠度及毫微微細胞系統之吞吐率並達到吞吐率與用戶鏈結可靠度之間的平衡。該機制以兩階段式地比較資源區塊及天線的通道增益，來決定適當的資源區塊及天線並用以傳輸資料。模擬結果發現，在滿足用戶的鏈結可靠度最低需求下，使用該機制可以使毫微微細胞基地台搭載 10 根天線傳輸，而使用隨機分配機制的毫微微細胞基地台只能搭載 4 根天線傳輸，因此，相較於隨機分配機制，本研究提出的結合傳輸天線選擇與通道分配機制可以改善 130%的毫微微細胞系統之吞吐率。

關鍵詞：小細胞；毫微微細胞；異質性網路；資源區塊分配；多重天線；鏈結可靠度；吞吐率。

附錄二、發表論文全文

13th IEEE VTS Asia Pacific Wireless Communications Symposium (APWCS 2016)

Throughput Improvement with Multiple Antennas and Channel Allocation for Ultra-Dense Femtocells

Ang-Hsun Tsai, *Member, IEEE*, Chung-Hsien Tsai, *Member, IEEE*, and Li-Chun Wang, *Fellow, IEEE*

***Abstract*—In this paper, we investigate the impacts of channel allocation with multiple antennas on link reliability and throughput, and formulate an optimization problem in the ultra-dense multi-antenna orthogonal frequency-division multiple access (OFDMA)-based macrocell and femtocell heterogeneous network. We develop a distributed joint transmission antenna selection and channel allocation scheme to achieve the tradeoff between the throughput and link reliability in this optimization problem, and to improve the users' link reliability and the femtocell throughput. This scheme can jointly allocate suitable antennas and resource blocks (RBs) for transmission with two steps of comparisons on channel gains of RBs and antennas. Simulation results show that the proposed scheme with ten antennas can achieve 130% higher throughput for femtocells than the random channel allocation scheme with four antennas under the link reliability requirement.**

***Index Terms*—Small cell; femtocell; heterogeneous network; resource block allocation; multiple antennas; link reliability; throughput.**

I. Introduction

Small cells are low-power, low-cost and operator-managed wireless access points that can improve coverage and system throughput. In general, small cells are divided into three types: microcells, picocells, and femtocells. Microcells are often deployed in the outdoor environment, such as rural and urban areas. Picocells and femtocells are deployed in the indoor environment, including enterprise buildings and apartment houses. With the popularity of small cell networks, the amount of mobile devices connecting to the networks grows massively, and the traffic demand increases rapidly. For three types of small cells, the amount of femtocells is the most, hence the interference problem is the most serious. With an ultra-dense macrocell and femtocell heterogeneous network, a femtocell user (FUE) suffers the femto-to-femto and macro-to-femto interference, and a macrocell user (MUE) undergoes the femto-to-macro and macro-to-macro interference [2], [3], [6], [10]. Therefore, managing the two-tier interference becomes a key to the success of improving the service quality and system throughput.

For an orthogonal frequency-division multiple access (OFDMA)-based femtocell system, adaptively allocating radio resource can help manage the two-tier interference due to the increase of channel diversity and user diversity. Moreover, increasing the number of antennas equipped on the femtocell base station (FBS) can provide the spatial degrees of freedom to increase more available channels to be selected for reliable transmission. Consequently, the design of resource allocation schemes needs to simultaneously consider the link gains on all channels with multiple antennas for a user to control the two-tier interference and improve the throughput.

In the literature, most papers [1], [4], [5], [7], [8] investigated resource allocation schemes in the femtocell network system without considering the effect of multiple antennas. The authors in [4] proposed a distributed resource allocation algorithm in the OFDMA femtocell networks to maximize the total minimum spectrum efficiency of femtocells with two conditions: fairness among the femtocell users and quality of service (QoS) protection for macrocell users. The work in [1] proposed a semi-distributed interference management scheme to cluster the femtocell base stations, and performed a channel and power allocation scheme for each group in the two-tier cellular OFDMA femtocell network. An iterative algorithm to jointly allocate subchannels and control the transmission power in [7] for the OFDMA mixed macrocell and femtocell network. The works in [8] and [5] formed a multi-objective optimization problem to maximize the throughput of users and to solve the admission control problem with resource allocation, respectively. However, these papers [1], [4], [5], [7], [8] did not investigate the impact of multiple antennas for femtocells.

In this paper, we develop a distributed joint transmission antenna selection and resource block allocation scheme to help femtocells select the antenna with highest link gain from the standpoint of channel for transmission for the ultra-dense OFDMA macrocell and femtocell heterogeneous network. The developed scheme can jointly allocate suitable antennas and resource blocks (RBs) for transmission with two steps of comparisons. Firstly, the scheme compares all the link gain of

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antennas on all RBs, and selects the antenna with the highest average channel gain on each RB as the candidate antenna for transmission. Secondly, the scheme compares all the average channel gains on the candidate antennas, and allocates the suitable antennas and RBs from these candidate antennas. With the limit of available femtocell RBs, the scheme can achieve higher femtocell throughput and link reliability than the random channel allocation scheme for femtocells.

The remainder of this paper is organized as follows. Section II introduces the problem formulation, and the proposed resource allocation scheme is detailed in Section III. We show the simulation results in Section IV. Finally, our concluding remarks are given in Section V.

II. Problem Formulation

In the ultra-dense multi-antenna OFDMA femtocell network, system throughput and link reliability are both essential factors in resource allocation schemes. From the throughput perspective, the system can increase the number of RBs allocated to the femtocell to increase the data rate. However, the FUEs may suffer the strong interference from all adjacent femtocells, and the link reliability decreases. Alternatively, the FBS can equip more antennas to increase the available channels with high link gains for improving the throughput. Nevertheless, this may result in lower link reliability due to the decreasing transmission power of each antenna. From the link reliability viewpoint, allocating fewer RBs to femtocell system can decrease the interference effect for users, but this brings about system throughput degradations. Therefore, the resource allocation scheme needs to simultaneously consider the number of allocated RBs, channel gains and transmission antennas in the ultra-dense multi-antenna OFDMA femtocell network to achieve the optimal system throughput and link reliability of users.

To achieve the tradeoff between throughput and link reliability, we formulate an optimization problem to determine the optimal number of antennas equipped on each femtocell N_t^F for transmission and the optimal femtocell RB usage ratio ρ_F, and the optimal RB allocation with antenna selection, where ρ_F is defined as the ratio of the number of used RBs to the total number of RBs. The objective of formulation aims to maximize the i-th femtocell throughput C_i^F subject to the link reliability requirement $P_{rel,th}$ for all outdoor MUEs and indoor FUEs. The optimization problem can be expressed as

$$\max_{N_t^F, \rho_F, \varepsilon^F_{RB,n,\phi,i}} C_i^F = \sum_{n=1}^{N_{RB}} \sum_{\phi=1}^{N_t^F} \varepsilon^F_{RB,n,\phi,i} \cdot B_{RB} \cdot \eta^F_{n,\phi,i} \quad (1)$$

subject to

$$\varepsilon^F_{RB,n,\phi,i} = \{0,1\}, \quad \forall n, \forall \phi, \forall i, \quad (2)$$

$$\sum_{\phi=1}^{N_t^F} \varepsilon^F_{RB,n,\phi,i} = \{0,1\}, \quad \forall n, \forall i, \quad (3)$$

$$\sum_{n=1}^{N_{RB}} \sum_{\phi=1}^{N_t^F} \varepsilon^F_{RB,n,\phi,i} = \rho_F \cdot N_{RB}, \quad \forall i, \quad (4)$$

$$P_{rel,FUE} \geq P_{rel,th}, \quad (5)$$

$$P_{rel,MUE} \geq P_{rel,th}, \quad (6)$$

where N_{RB} is the total number of RBs, and B_{RB} is the effective bandwidth of a single RB. $\eta^F_{n,\phi,i}$ is the theoretical spectrum efficiency of the RB n for the i-th femtocell using the ϕ-th antenna to transmit. $\varepsilon^F_{RB,n,\phi,i}$ is the allocation outcome for the RBs and antennas in the i-th femtocell. In the following, we explain the above constrains. The constraint (2) represents that $\varepsilon^F_{RB,n,\phi,i}$ is an indicator function and can indicate if the RB n is allocated to the FUE in the i-th femtocell with the antenna ϕ. If the RB n is allocated to the FUE in the i-th femtocell with the antenna ϕ, $\varepsilon^F_{RB,n,\phi,i} = 1$; otherwise, $\varepsilon^F_{RB,n,\phi,i} = 0$. The constraint in (3) states the limitation that each RB can be allocated to the FUE through at most one antenna in a femtocell. With the constraint (4), the total number of RBs allocated to the FUE in the i-th femtocell is limited to $(\rho_F \cdot N_{RB})$. The link reliability of indoor FUE and outdoor MUE must be higher than the minimum link reliability requirement with the constraints (5) and (6), respectively.

III. Joint Transmission Antenna Selection and Resource Block Allocation Scheme

In this section, we combine the resource block allocation with multiple antenna selection for the optimization problem in (1) in the ultra-dense multi-antenna OFDMA femtocell system. A channel-oriented channel allocation scheme (COCAS) is proposed to help femtocells select the antenna with highest link gain from the standpoint of channel for transmission by two steps of comparisons on channel gains of RBs and antennas. In the first comparison, the scheme compares the average channel gain of each antenna on each RB, and selects the antenna with the highest average channel gain as the candidate antenna for each RB. In the second comparison, the scheme compares the average channel gain of each candidate antenna on each RB, and selects the top $(\rho_F \cdot N_{RB})$ RBs to transmit. Therefore, the COCAS can determine the optimal $\varepsilon^F_{RB,n,\phi,i}$ with a given ρ_F and a given N_t^F to transmit for the ultra-dense multi-antenna OFDMA femtocell system. The allocation procedure of the COCAS is described as **Algorithm 1**.

We explain these steps by the following example in Fig 1. In Fig 1(a), there are $N_t^F = 3$ antennas equipped on each FBS and $N_{RB} = 4$ RBs, and the corresponding channel gains

Algorithm 1 COCAS

Input:

$h_{F,\ell,\phi,i}$, $\forall \ell, \forall \phi, \forall i$. \\ All the channel gains of each subcarrier from users in the i-th femtocell.

Output:

$\varepsilon^F_{RB,\hat{n},\hat{\phi}_{\hat{n}},i}$. \\ Femtocell RB allocation.

Pseudo-code:

$h_{avg,n,\phi,i} = \frac{1}{N_{sc}} \sum_{\ell=(n-1)N_{sc}+1}^{nN_{sc}} |h_{F,\ell,\phi,i}|^2, \ \forall n, \forall \phi$.
    \\ Calculate the average channel gain of each RB for each antenna.
$\varepsilon^F_{RB,n,\phi,i} = 0, \quad \forall n, \forall \phi, \forall i.$
$\Omega = \{1, 2, \ldots, N_{RB}\}$.
for $n = 1$ to N_{RB} **do**
    $\hat{\phi}_n = \arg\max_{1 \le \phi \le N_t^F} h_{avg,n,\phi,i}$,
    for $\mu = 1$ to $(\rho_F \cdot N_{RB})$ **do**
        $\hat{n} = \arg\max_{1 \le n \le N_{RB}} h_{avg,n,\hat{\phi}_n,i}, \quad \forall n \in \Omega$,
        $\varepsilon^F_{RB,\hat{n},\hat{\phi}_{\hat{n}},i} = 1$,
        $\Omega = \Omega - \{\hat{n}\}$.
    end for
end for

are presented as the histogram. Assume that the femtocell RB usage ratio is $\rho_F = 0.75$, i.e., there are $\rho_F \times N_{RB} = 3$ RBs allocated with the proper antennas for the user. The procedures are described as follows:

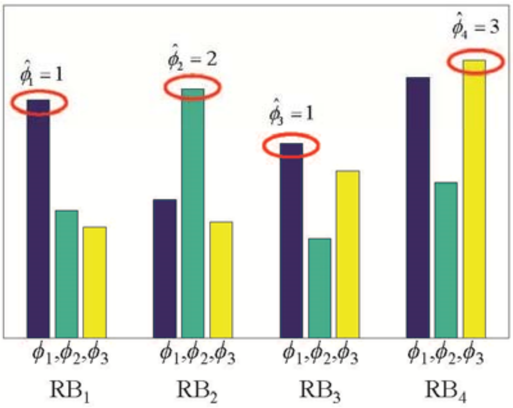
(a) First comparison:
- $h_{avg,RB_1,\phi_1,i} > h_{avg,RB_1,\phi_2,i} > h_{avg,RB_1,\phi_3,i}$ $\Rightarrow \hat{\phi}_1 = 1 \Rightarrow h_{avg,RB_1,\hat{\phi}_1,i}$
- $h_{avg,RB_2,\phi_2,i} > h_{avg,RB_2,\phi_1,i} > h_{avg,RB_2,\phi_3,i}$ $\Rightarrow \hat{\phi}_2 = 2 \Rightarrow h_{avg,RB_2,\hat{\phi}_2,i}$
- $h_{avg,RB_3,\phi_1,i} > h_{avg,RB_3,\phi_3,i} > h_{avg,RB_3,\phi_2,i}$ $\Rightarrow \hat{\phi}_3 = 1 \Rightarrow h_{avg,RB_3,\hat{\phi}_3,i}$
- $h_{avg,RB_4,\phi_3,i} > h_{avg,RB_4,\phi_1,i} > h_{avg,RB_4,\phi_2,i}$ $\Rightarrow \hat{\phi}_4 = 3 \Rightarrow h_{avg,RB_4,\hat{\phi}_4,i}$

(b) Second comparison:
- $\underbrace{h_{avg,RB_4,\hat{\phi}_4,i} > h_{avg,RB_2,\hat{\phi}_2,i} > h_{avg,RB_1,\hat{\phi}_1,i}}_{\text{the top 3 candidates}}$
  $> h_{avg,RB_3,\hat{\phi}_3,i}$
  $\Rightarrow \hat{n} = 4, 2, 1.$
  $\Rightarrow \varepsilon^F_{RB,4,3,i} = 1.$
  $\Rightarrow \varepsilon^F_{RB,2,2,i} = 1.$
  $\Rightarrow \varepsilon^F_{RB,1,1,i} = 1.$

(c) The allocation outcome is shown in Fig 1(b).

IV. Simulation Results

In this section, we show performance improvements of the channel-oriented channel allocation scheme (COCAS) for the ultra-dense multi-antenna OFDMA heterogeneous macrocell and femtocell network with the complicated two-tier interference, compared to the random channel allocation scheme. The downlink of the multi-antenna OFDMA femtocell system with two-tier interference in the apartment houses is considered. The simulation environment is shown in Fig. 2(a), where a group of 25 femtocells are separated by $d_{sf} = 20$ m, and covered by a macrocell with a radius of $R_m = 500$ m. Each FBS is equipped with N_t^F antennas. Figure 2(b) shows that each house covers an area of 100 (meter^2) and has four 5×5 (meter^2) rooms. The FBS is deployed at the center of the house with a shift of (0.1m, 0.1m). It is assumed that there is only one FUE in each house, and only one MUE is appeared in the street area of 25 femtocells. The indoor FUEs' locations are uniformly distributed within the house, and the outdoor MUE is located in the shadowed region with width of $(d_{sf} - 10)/2$ (meters) surrounding the house, as shown in Fig. 2(b). Additionally, both FUE and MUE are equipped with only one antenna.



(a) Channel gain of each antenna for each RB

$\varepsilon^F_{RB,n,\phi,i}$	RB_1	RB_2	RB_3	RB_4
ϕ_1	1	0	0	0
ϕ_2	0	1	0	0
ϕ_3	0	0	0	1

(b) Allocation outcome

Fig. 1. An example of COCAS. Assume that the number of antennas equipped on each FBS is $N_t^F = 3$, the number of RBs is $N_{RB} = 4$, and the femtocell RB usage ratio is $\rho_F = 0.75$. The average channel gain of each antenna on each RB are presented as the histogram.

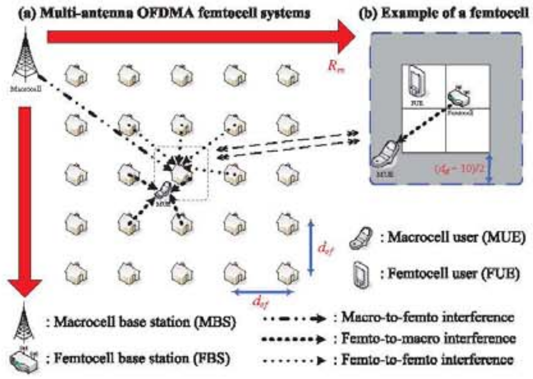


Fig. 2. An illustrative example of the two-tier interference scenario in multi-antenna OFDMA femtocells: (a) a cluster of 25 femtocells, each indoor femtocell user faces femto-to-femto and macro-to-femto interference, and the outdoor macrocell user undergoes the femto-to-macro interference from all neighboring femtocells. (b) each femtocell is surrounded by the streets with $(d_{sf}-10)/2$ (m) and one macrocell user is appeared in the street area of 25 femtocells.

TABLE I
THE DOWNLINK MULTI-ANTENNA OFDMA FEMTOCELL SYSTEM PARAMETERS

Parameters	Values
Carrier frequency (f_c)	2.0 GHz
Macrocell radius (R_m)	500 m
Transmission power (MBS/FBS)	46 dBm / 20 dBm
MBS antenna gain (G)	15 dB
Noise figure (MBS/FBS/UE)	5 dB / 5 dB / 7 dB
System bandwidth (B)	10 MHz
FFT size (N_{FFT})	1024
Number of RBs (N_{RB})	50
RB bandwidth (B_{RB})	180 KHz
Number of data subcarriers (N_d)	600
Number of subcarriers for each RB (N_{sc})	12
Predefined effective CINR threshold (γ_{th}) for link reliability requirement	-2.5 dB
Minimum link reliability requirement ($P_{rel,th}$)	90%

The channel model and the definitions of link reliability and femtocell throughput are referred to our previous work in [9]. Table I lists the related system parameters for the downlink multi-antenna OFDMA femtocell system. With the simulation results, we can design the optimal N_t^F, ρ_F and $\varepsilon^F_{RB,n,\phi,i}$ for higher throughput and link reliability by using the COCAS in the multi-antenna OFDMA femtocell system.

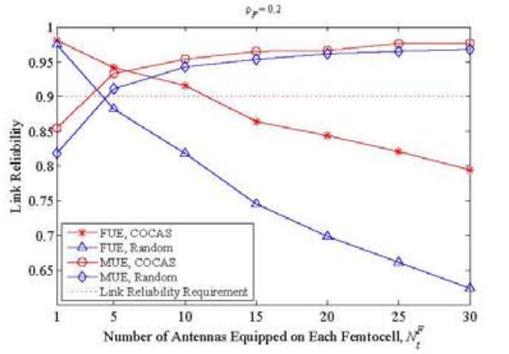


Fig. 3. Link reliability of outdoor macrocell user and indoor femtocell user versus number of antennas equipped on each femtocell, for the COCAS and random channel allocation scheme in multi-antenna OFDMA femtocell systems with femtocell resource block usage ratio $\rho_F = 0.2$.

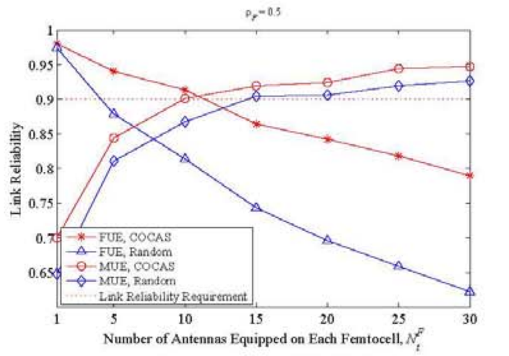


Fig. 4. Link reliability of outdoor macrocell user and indoor femtocell user versus number of antennas equipped on each femtocell, for the COCAS and random channel allocation scheme in multi-antenna OFDMA femtocell systems with femtocell resource block usage ratio $\rho_F = 0.5$.

A. Impacts on Link Reliability

Figures 3 and 4 show that the link reliability performance of indoor FUE and outdoor MUE against the number of antenna equipped on each femtocell N_t^F in the shared-spectrum-allocation femtocell system with femtocell resource block usage ratio $\rho_F = 0.2$ and $\rho_F = 0.5$. From the figures, we have the following observations:

1) As the femtocell RB usage ratio ρ_F decreases, the link reliability of the indoor FUE increases slightly, while the link reliability of the outdoor MUE increases obviously because of the decreasing femto-to-femto and femto-to-macro interference.

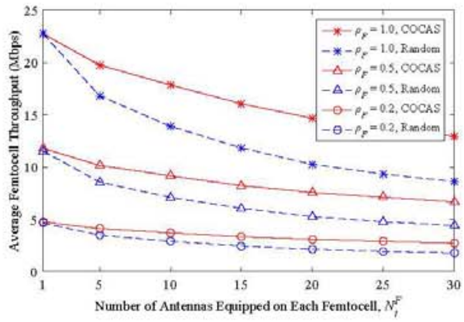


Fig. 5. Average femtocell throughput versus number of antennas equipped on each femtocell, for the COCAS and random channel allocation scheme in multi-antenna OFDMA femtocell systems.

2) With the link reliability requirement $P_{rel} \geq 90\%$ for indoor FUE and outdoor MUE under the femtocell RB usage ratio $\rho_F = 0.2$, the optimal number of antenna equipped on each femtocell $N_t^F \approx 12$ and $N_t^F \approx 4$ for COCAS and random channel allocation scheme, respectively. For the femtocell RB usage ratio $\rho_F = 0.5$, the optimal number of antenna equipped on each femtocell $N_t^F = 10$ for COCAS with the link reliability requirement $P_{rel} \geq 90\%$ for indoor FUE and outdoor MUE. Nevertheless, the optimal number of antenna equipped on each femtocell N_t^F does not exist if the femtocell RB usage ratio $\rho_F = 0.5$.

B. Impacts on Femtocell Throughput

Figure 5 shows the average femtocell throughput against the number of antennas equipped on each femtocell N_t^F in the shared-spectrum-allocation femtocell system. From the figure, we have the following observations:

1) The average femtocell throughput decreases as the number of antennas equipped on each FBS increases because the FBS evenly distribute the power into multiple antennas, which decreases the signal power to the FUE. Moreover, the COCAS can achieve higher average femtocell throughput than the random channel allocation scheme with the same number of antenna equipped on the FBS.
2) As the femtocell RB usage ratio ρ_F decreases, the average femtocell throughput decreases because the FBS uses fewer RBs for transmission. Nevertheless, the link reliability of MUE can be increased due to the decreasing femto-to-macro interference.
3) From Figs. 3 and 4, the optimal number of antenna equipped on each femtocell with the link reliability requirement $P_{rel} \geq 90\%$ are $N_t^F \approx 10$ with $\rho_F = 0.5$ and $N_t^F \approx 4$ with $\rho_F = 0.2$ for COCAS and random channel allocation scheme, respectively. Therefore, the achieved average femtocell throughput from Fig. 5 can be 10 Mbps and 4 Mbps for COCAS and random channel allocation scheme, respectively. It represents that the COCAS can achieve 130% higher average femtocell throughput than the random channel allocation scheme under the link reliability requirement $P_{rel} \geq 90\%$ for all users.

V. Conclusion

In this paper, an optimization problem was formulated to investigate the effects of multiple antennas and resource allocation on femtocell throughput and link reliability in the ultra-dense multi-antenna OFDMA macrocell and femtocell heterogeneous network. To achieve the tradeoff between the throughput and link reliability in this optimization problem, we proposed a low-complexity distributed channel-oriented channel allocation scheme for the multi-antenna OFDMA femtocell network. Because the COCAS can jointly select the antennas and allocate RBs with the higher link gain for transmission under the limit of femtocell RB usage ratio, the femtocell throughput can be improved and user's link reliability can be guaranteed. It is shown that our proposed COCAS with ten antennas can improve 130% higher throughput for femtocells than the random channel allocation scheme with four antennas under the link reliability requirement.

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