出國報告（出國類別：國際會議）

參加第 14 屆 IEEE 車輛技術協會亞太區無線通訊研討會(APWCS2017)會議報告

服務機關：國防大學理工學院資訊工程學系

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派赴國家：韓國

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摘要

第 14 屆 IEEE 車輛技術協會亞太區無線通訊研討會(14th IEEE VTS Asia Pacific Wireless Communications Symposium, APWCS 2017)，於 106 年 8 月 23 日至 25 日在韓國仁川的國立仁川大學(Incheon National University, Incheon, Korea)舉行，本人投稿該研討會論文乙篇，論文題目為「多對裝置間通訊在異質性網路下之網路協助裝置決定式循環排程之研究」，因榮獲接受，故大會議程邀請於 8 月 24 日下午場次以口頭發表研究成果，故於 8 月 22 日搭機前往與會。

第 14 屆 IEEE 車輛技術協會亞太區無線通訊研討會是由國際電機電子工程師學會(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、台北分會與新加坡分會輪流主辦。該研討會主要目的是在提供亞太地區相關無線通訊與行動運算研究交流平台，讓與會的研究人員透過交流平台相互分享最新無線通訊與行動運算研究成果與討論，並透過主題與專題講座，獲得最新產業界、官方與學術界最新資訊，以及獲得其他學者的寶貴研究意見或是合作機會。今年大會主題為第五代行動通訊關鍵技術，隨著國軍事務革新的同時，越來越多戰演訓平台需要最新資通訊系統的輔助與協助，返國報告除說明研討會內容之外，亦指出國軍需要新一代行動通訊技術，後續將於資通訊領域研究方向持續努力，並感謝科技部補助得以參與今年 APWCS 2017 學術研討會。

目　　次

本　文

一、 目的

本次參與「第 14 屆 IEEE 車輛技術協會亞太區無線通訊研討會」，是由東京分會、首爾分會、台北分會與新加坡分會輪流主辦。該研討會主要目的是在提供亞太地區相關無線通訊與行動運算研究交流平台，讓與會的研究人員透過交流平台相互分享最新無線通訊與行動運算研究成果與討論，並透過主題與專題講座，獲得最新產業界、官方與學術界最新資訊，以及獲得其他學者的寶貴研究意見或是合作機會。今年 106 年 8 月 23 日至 25 日在韓國仁川的國立仁川大學(Incheon National University, Incheon, Korea)舉行，圖一為本次會議官方網頁。

本人參與本次研討會主要目的為發表論文，論文題目為「Network-Assisted Device-Decided (NADD) Round Robin Scheduling for Multi-Pair Device-to-Device (D2D) Communications in Heterogeneous Networks」，因榮獲接受，故大會議程邀請於 8 月 24 日下午場次以口頭發表研究成果，故於 8 月 22 日搭機前往與會。參與會議過程中除了與各國學者進行論文意見交換與經驗交流，以期進一步將研究成果，更完整投稿至國際知名期刊論文之外，更透過參與論壇方式與國際知名相關產業界與研究學者接軌，一方面累積研究能量，一方面更拓展國際視野。

圖一、APWCS 2017 官方網站，網址為 http://apwcs2017.incheon.ac.kr/。

二、 過程

第 14 屆 IEEE 車輛技術協會亞太區無線通訊研討會於 8 月 23 日至 25 日舉行，研討會的會場就辦在韓國仁川的仁川大學(Incheon National University, Incheon, Korea)舉行，如圖二。

圖二、APWCS2017 研討會在韓國仁川的仁川大學(Incheon National University, Incheon, Korea)舉辦。

本人在報到後，如圖三，就前往主演講廳會議室參加開幕式，隨後即開始了兩日的研討會。研討會的議程如下表一。

圖三、本人於 APWCS2017 研討會報到處留影。

August 23, 2017 (Wednesday)

Time	Program
12:00~17:00	Registration : Lobby, Convention Center (Building #12)
17:00~19:00	Welcome reception : Lobby, Convention Center (Building #12)

August 24, 2017 (Thursday)

Time	Program			
	Room #103	*Room #105*	*Room #107*	*Room #108*
08:30~09:20	Registration : Lobby, Convention Center (Building #12)			
09:20~10:10	Invited Speech : The 4th Industrial Revolution and Our Strategy for a Better World (Prof. Heung-No Lee, Gwangju Institute of Science and Technology, Korea)			
10:10~11:00	Invited Speech : Industrial Internet of Things (Dr. Sun Sumei, Institute for Infocomm Research (I2R), Singapore)			
11:00~11:30	Coffee Break			
11:30~12:30	A1 : 3 papers	A2 : 3 papers	A3 : 3 papers	A4 : 3 papers
12:30~14:00	Lunch			
14:00~15:40	B1 : 5 papers	B2 : 5 papers	B3 : 5 papers	B4 : 5 papers
15:40~16:10	Coffee Break			
16:10~17:50	C1 : 5 papers	C2 : 5 papers	C3 : 5 papers	C4 : 5 papers
18:00~20:00	Banquet : Room #106, Faculty Office Building (Building #2)			

August 25, 2017 (Friday)

Time	Program			
	Room #103	*Room #105*	*Room #107*	*Room #108*
09:20~10:10	Invited Speech : Data Driven Cognitive Networks, (Prof. Li-Chun Wang, National Chiao Tung University, Taiwan)			
10:10~10:30	Coffee Break			
10:30~11:30	D1 : 3 papers	D2 : 3 papers	D3 : 3 papers	D4 : 3 papers
11:30~12:30	E1 : 3 papers	E2 : 3 papers	E3 : 3 papers	E4 : 3 papers
12:30~14:00	Lunch			
14:00~14:50	Keynote Speech : 5G technology in Samsung Electronics (Dr. Kyungwhoon Cheun, Executive Vice President Next Generation Communications Business Team IT and Mobile Communications Division, Samsung Electronics Co., Ltd, Korea)			
14:50~15:40	Invited Speech : Perspectives towards 5G (Mr. Akira Matsunaga, Senior Director, Mobile Network Technical Development Division Technology Sector KDDI Corporation, Japan)			
15:40~16:10	Coffee Break			
16:10~17:50	F1 : 5 papers	F2 : 5 papers	F3 : 5 papers	F4 : 5 papers
17:50~18:00	Closing			

表一、IEEE VTS APWCS 2017 會議議程。

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與行動運算發表演說。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研討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 Talk)，講者為韓國知名光州科技學院(Gwangju Institute of Science and Technology, GIST)，Heung-No Lee 博士，題目為「The 4th Industrial Revolution and Our Strategy for a Better World」，現場照片如圖四。

圖四、Heung-No Lee 博士演講。

Heung-No Lee 博士首先點出第四波工業革命(4^{th} Industrial Revolution)已經到來，並引用世界經濟論壇(WEF)主席，Klaus Schwab 博士指出這將是破壞式科技(Disruptive Technology)的創新，將為人們的生活帶來前所未有的巨變。接者，這波工業革命至少在 2016 年春季時韓國職業九段棋士李世乭與 Google DeepMind 開發的電腦圍棋軟體 AlphaGo 對弈的五局三勝制圍棋比賽中，已經獲得很大的啟發，並證實工業自動化技術將獲得突破性的進展。最後結論，誰可以掌握這波趨勢將可掌握龐大的機會，並可以帶領人們到更高層級的生活品質。從先進國家，例如德國與美國所進行的先導研發成果看來，德國所推動的智慧工廠(Smart Factory)來看，已獲得初步豐碩的效益。這將影響未來數十年國際經濟領土的重新分配與人們生活。

第一天早上的第二場專題演講(Invited Talk)，講者為新加坡 Institute for Infocomm Research (I2R)機構 Sun Sumei 博士，題目為「Industrial Internet of Things」，現場照片如圖五。

圖五、Sun Sumei 博士演講。

Sun Sumei 博士以工業物聯網(Industrial Internet of Things, IIoT)為出發點，探討工業物聯網可以提供串起在生產機具、操作機器人與感測器的連結，並提供智慧化、高效率、持續性與自動化的生產能力。演講內容並進一步點出設計工業物聯網時所需通訊技術鴻溝，例如異質性無線通訊、多重無線網路的干擾、訊號資源管理與低資料遺失率與低延遲等都是急待解決的問題。最後，Sun Sumei 博士以感知通訊(Cognitive Communication)為主軸，說明感知通訊可以透過周遭感知資源、干擾與行動管理、錯誤偵測與預防，以及強健連結性等優勢來解決上述問題，演講中並論及工業物聯網的新興議題，例如資料分析、網路安全等重要議題。

第二天早上第一場專題演講(Invited Talk)，講者為台灣交通大學電機工程學系王蒞君教授，題目為「Data Driven Cognitive Networks」，現場照片如圖六。

圖六、王蒞君教授演講。

王蒞君教授以資料科學為主軸，探討無線網路重要的研究趨勢。近來越來越多無線信號源，提供越來越多資料，包含頻道(Channel)、位置(Location)、信號連結選項(Radio Access

Option)、社群網路(Social Networks)、網路狀態管理(Network State Management)，傳統以知識為基礎驅動(Knowledge Driven)研究方式將可以藉由新一代機器學習(Machine Learning)、資料探勘(Data Mining)、人工智慧(Artificial Intelligence)與統計推理(Statistical Reasoning)技術，轉化為以資料為基礎的感知網路(Data Driven Cognitive Network, D2CN)研究方式，將可進一步針對信號處理、網路規劃、使用者資源客製化等領域更明顯提升效能。演講內容包含資料科學相關背景知識介紹，並以超密集小細胞(Ultra-dense Small Cells, UDSC)架構為例，說明如何運用資料為基礎的研究方法，強化自組織網路(Self-organization Network, SON)，有效提升 UDSC 的傳輸量(Throughput)及能量效率(Energy Efficiency)，並可提供應用導向網路品質管控。最後，並介紹相關資料科學在無線網路未來研究方向。

第二天下午主題演講(Keynote Speech)，講者為韓國三星電子(Samsung Electronics)集團副總裁 Kyungwhoon Cheun 先生，題目為 5G technology in Samsung Electronics，現場照片如圖七。

圖七、Kyungwhoon Cheun 先生演講。

Kyungwhoon Cheun 先生以三星電子集團的 5G 願景與新商機為主題，首先針對光纖最後一哩路關鍵技術，固定無線接入（Fixed Wireless Access，FWA），FWA 兼具無線寬頻用戶的多樣化需求，白天，FWA 可以為鄰近的行動用戶提供高速無線寬頻；夜裡，當人們下班回家，FWA 可以通過改變波束方向，指向家庭中的 FWA 終端，為家庭提供高速上網。這使得 FWA 技術具備擴展性和持續性。接者，另針對 5G 中毫米波(mmWave)最新研究挑戰進行說明，其中包含樹葉遮蔽(Foliage Blocking)與戶外至室內穿透損失(Outdoor-to-indoor Penetration Loss)等，並以全世界第一套毫米波雛型系統說明最新 5G 的無線射頻規劃技術。最後，簡報內容點出最新 5G 的實現願景，其中包含智慧城市(Smart City)、高速火車與車聯網(V2X)等新興應用。

第二天下午專題演講(Invited Talk)，講者為日本第二大電信營運商 KDDI 集團資深經理

Akira Matsunaga 先生，題目為 Perspectives towards 5G，現場照片如圖八。Akira Matsunaga 先生以 5G 的願景、技術挑戰以及 5G 實現進度為主軸進行說明 KDDI 集團最新發展近況。簡報內容觸及由現有 4G 轉換 5G 技術過程兩種選項於網路架構與頻段轉換的重要考量，一種為「非獨立」(NSA)架構；一種為「獨立」(SA)架構，非獨立架構為過渡選項，透過現有 4G 基地台與新設 5G 基地台共存實現 5G 無線寬頻技術；而獨立架構則是完全採用新式 5G 基地台提供 5G 無線寬頻服務，KDDI 集團配合日本將於 2020 年東京奧運跟世人展現先進 5G 無線寬頻技術，並以車載虛擬實境系統展示最新研發進度。

圖八、Akira Matsunaga 先生演講。

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，相關的議程如表一。

在第一天上午與下午的論壇，本人聆聽下列三場，分別是「A3: Resource Management and Scheduling I」、「B3: Resource Management and Scheduling II」以及「C1:Sensor Network and IoT」。

- 關於「A3: Resource Management and Scheduling I」的討論，包含了下列文章：
  1. QoS-Based Admission Control and Traffic Balancing Strategy for Unlicensed Band in Heterogeneous Networks
  2. Energy-Efficient Resource Allocation for LTE-A MBSFN Networks
  3. A practical tessellation-based load-balancing scheme in Heterogeneous Cellular Networks using MIMO
- 關於「B3: Resource Management and Scheduling II」的討論，包含了下列文章：
  1. Network-Assisted Device-Decided (NADD) Round Robin Scheduling for Multi-Pair Device-to-Device (D2D) Communications in Heterogeneous Networks
  2. Impact of Multi-User Scheduling on Distributed Antenna Small-Cell Network using STBC Transmit Diversity

3. Conflict-Free Data Scheduling on Multiple Wireless Broadcast Channels
4. A Novel Beamwidth Adaptation Protocol for Tracking in Mobile Communication System
5. Traffic Prediction-Based Green Scheduling under DRX Operation for Power Saving of Base Station in LTE-A System

- 關於「C1:Sensor Network and IoT」的討論，包含了下列文章：
  1. Error Bound Analysis for 3-D Distributed RSS-AoA Based Localization in Wireless Sensor Networks
  2. A study on Phase Characteristics for Backscatter Sensor Networks
  3. Effects of Time and Space Diversity for Physical Cell ID Detection for NB-IoT
  4. A GPU Implementation of Access Point to Support Massive Connectivity in MTC
  5. The Challenges of Applying SDN/NFV for 5G & IoT

上述三場論壇的主題都是著重於異質性網路(Heterogeneous Networks)的網路資源管理與排程問題，以及物聯網技術的新興研究議題。異質性網路問題研究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「QoS-Based Admission Control and Traffic Balancing Strategy for Unlicensed Band in Heterogeneous Networks」，對於災害通訊提供可參考研究選項。該篇文章主要是針對 LTE 異質性無線網路的架構下，針對 LTE Unlicensed 以及 Licensed-Assisted Access 通訊網路等兩種不同網路架構，提出一套利用 Wi-Fi 無線寬頻網路進行 LTE 網路卸載機制，可有效最佳化通訊範圍內載具的能源效益，並可確保次級使用端(Secondary User Equipment, SUE)頻寬最低需求。

本人投稿的文章因榮獲接受，並以口頭方式發表，依大會議程，發表時間排在第一天下午的第二場論壇，也就是「B3: Resource Management and Scheduling II」的場次。本人所發表的論文英文題目為「Network-Assisted Device-Decided (NADD) Round Robin Scheduling for Multi-Pair Device-to-Device (D2D) Communications in Heterogeneous Networks」，論文中文題目為「多對裝置間通訊在異質性網路下之網路協助裝置決定式循環排程之研究」，主要是在巨細胞、毫微微細胞以及多個裝置對共存的異質性網路中，提出一個網路協助裝置決定式之循環排程資源管理，在不降低用戶的服務品質來改善系統的傳輸率，同時達成多個裝置對的公平性。透過巨細胞以及毫微微細胞所廣播的最大干擾容忍量訊息，我們所提出的方案可以替各個傳輸的裝置決定各個資源塊適當的傳輸功率。我們假設透過巨細胞的廣播，每個裝置對都能知道所有裝置對的數量以及相對應的排序號碼。因此，我們的方案能夠替所有的裝置對來公平地分配資源塊以及相對應的傳輸功率。模擬結果顯示，我們所提出的網路協助裝置決定式之循環方案，除了能改善整體的系統傳輸率，還可以維持巨細胞及毫微微細胞用戶的服務品質，同時又能確保所有裝置對的公平性。

在第二天上午與下午的論壇，本人聆聽了下列三場，分別是「D2: Location」、「E2: Network Performance I」以及「F2: Network Performance II」。

- 關於「D2: Location」的討論，包含了下列文章：
  1. An Indoor Localization Scheme Based on Integrated Artificial Neural Fuzzy Logic
  2. LTE Indoor Positioning based on 3D Channel Model
  3. Improved Localization Accuracy using IMU Sensor Data with RSSI based Path Loss Model Maps
- 關於「E2: Network Performance I」的討論，包含了下列文章：
  1. Handoff Performance Evaluation of Prefetching Approaches in SDN-enabled Mobile Networks
  2. Crowdsourcing-based Handover Scheme for Wireless LAN in Vehicular Environments
  3. Using Two-Hop Neighborhood Information to Enhance Geographic Routing in Sparse MANETs
- 關於「F2: Network Performance II」的討論，包含了下列文章：
  1. Seamlessly Deliver Low Latency Content in Ultra Dense Networks
  2. Evaluation of Wi-Fi Interference from a Large Number of APs in IEEE 802.15.4 Perspective
  3. Optimal Distance Threshold of Fractional Frequency Reuse Cellular Systems
  4. Machine Learning based Self-Fault Diagnosis in an LTE-A Network
  5. Full Duplex MAC Protocol Based on Neighbor Node Information

上述 D2 論壇的主題主要是探討運用無線網路訊號進行室內定位技術，其中以第二篇台灣台北科技大學研究團隊所報告的「LTE Indoor Positioning based on 3D Channel Model」最令人印象深刻，研究方法是利用無線訊號到達定位點時間差機制，運用三維通道模型以接收端與傳送端在特定時間點所反映的通道響應來進行定位，解決傳統二維通道無法適切反映室內環境多重路徑問題。這項技術啟發室內定位現有新的研究方向，值得後續再深入研究。

而在 E2 與 F2 論壇中，本人所選擇聆聽主題是「Network Performance I」與「Network Performance II」，台灣交通大學研究團隊分別報告的「Handoff Performance Evaluation of Prefetching Approaches in SDN-enabled Mobile Networks」與「Machine Learning based Self-Fault Diagnosis in an LTE-A Network」等兩篇報告特別引人注意與熱烈討論，更深入淺出的點出軟體定義網路(Software-Defined Network, SDN)在無線通訊網路的重要性，透過體定義網路的網路監控的能力，藉由流量辨識以及動態的網路繞送，提升網路換手效能的服務品質。另外運用機器學習技術，針對 LTE-A 無線寬頻網路進行自我偵錯技術也是創新的方法，值得以機器學習的角度重新思考無線通訊與行動運算等新興研究議題。

三、心得與建議

「第 14 屆 IEEE 車輛技術協會亞太區無線通訊研討會」為本人第一次參與有關無線通訊與行動運算的國際研討會且也是本人第一次到韓國，此次參與研討會成員雖然來自全世界各地，不過大多還是韓國與亞洲有關研究學者，整個參與過程，除了對於韓語陌生與交通動線較不夠熟悉之外，其餘對於大會所用心安排的行政與住宿等感到非常滿意，尤其對於韓國的熱情文化與謹慎小心的工作態度更是感到非常佩服，提供以後辦理相關國際研討會非常許多參考，例如，研討會所在會議中心應該在主要捷運站附近，且能提供多樣化住宿選擇；另外議程與動線安排上亦可以結合地方政府周邊宣傳與贊助，擴大研討會學者與研究專家參與效益，提升國家整體軟實力。

此次會議討論的議題著重在第五代行動通訊的關鍵發展技術。藉由參與本次研討會觀摩與研討，得以瞭解第五代無線通訊技術的最新研究方向，並透過論文發表逐漸與國際著名學者接軌，對在學術研究與國際視野有相當大的提升，希望未來能持續朝這個方向努力為國軍教育訓練與國防科技奉獻己力。

國防大學理工學院扮演國防科技整合的重要角色，適時提供國軍各級單位顧問諮詢與技術支援等任務，近年來隨著國軍作戰形態已逐步轉型為聯合作戰，資通電軍的成立更凸顯資訊、通訊與電子戰技術日受重視，建議未來國軍各級單位可朝向行動運算(Mobile Computing)平台與環境進行研究與分析，如此一來即可一方面將可提升國軍人員專業能力，另一方面更可提升作戰訓練效益。

最後，非常感謝本次在國防大學理工學院各級長官指導與科技部計畫協助下，得以參與此次的國際研討會。對於個人研究與視野皆有明顯的助益，未來將更努力於教學、服務與研究，以提升本校於國際學術界知名度與專業素養。

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：

非常感謝國防大學理工學院各級長官指導與科技部的國外差旅費補助得以順利參加本次第 14 屆 IEEE 車輛技術協會亞太區無線通訊研討會(APWCS2017)，讓本人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

Network-Assisted Device-Decided (NADD) Round Robin Scheduling for Multi-Pair Device-to-Device (D2D) Communications in Heterogeneous Networks

多對裝置間通訊在異質性網路下之
網路協助裝置決定式循環排程之研究

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 propose a network-assisted device-controlled (NADD) round-robin (RR) resource management to improve the system throughput without degrading the link reliability of users, and achieve the fairness for multiple device-to-device (D2D) pairs in the macrocell, femtocell and D2D communications coexisting heterogeneous network. The proposed NADD RR scheme can determine the suitable transmission power of each resource block (RB) based on the information of the maximum interference tolerance (MIT) broadcast by macrocells and femtocells. We assume that each D2D pair can realize the amount of D2D pairs and the arranged sequence number by macrocell's broadcast. Therefore, the scheme can fairly allocate the resource blocks (RBs) with corresponding transmission power for D2D communications. Simulation results show that our proposed NADD RR scheme can improve the system throughput and maintain the original link reliability of macrocell and femtocell users while guarantee the fairness factor among the D2D pairs.

Index Terms—Device-to-device (D2D) Communications; small cell; femtocell; heterogeneous network; resource management.

中文摘要

在本文中，我們在巨細胞、毫微微細胞以及多個裝置對共存的異質性網路中，提出一個網路協助裝置決定式之循環排程資源管理，在不降低用戶的服務品質來改善系統的傳輸率，同時達成多個裝置對的公平性。透過巨細胞以及毫微微細胞所廣播的最大干擾容忍量訊息，我們所提出的方案可以替各個傳輸的裝置決定各個資源塊適當的傳輸功率。我們假設透過巨細胞的廣播，每個裝置對都能知道所有裝置對的數量以及相對應的排序號碼。因此，我們的方案能夠替所有的裝置對來公平地分配資源塊以及相對應的傳輸功率。模擬結果顯示，我們所提出的網路協助裝置決定式之循環方案，除了能改善整體的系統傳輸率，還可以維持巨細胞及毫微微細胞用戶的服務品質，同時又能確保所有裝置對的公平性。

關鍵詞：裝置間通訊；小細胞；毫微微細胞；異質性網路；資源管理。

Network-Assisted Device-Decided (NADD) Round Robin Scheduling for Multi-Pair Device-to-Device (D2D) Communications in Heterogeneous Networks

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

***Abstract*—In this paper, we propose a network-assisted device-decided (NADD) round-robin (RR) resource management to improve the system throughput without degrading the link reliability of users, and achieve the fairness for multiple device-to-device (D2D) pairs in the macrocell, femtocell and D2D communications coexisting heterogeneous network. The proposed NADD RR scheme can determine the suitable transmission power of each resource block (RB) based on the information of the maximum interference tolerance (MIT) broadcast by macrocells and femtocells. We assume that each D2D pair can realize the amount of D2D pairs and the arranged sequence number by macrocell's broadcast. Therefore, the scheme can fairly allocate the resource blocks (RBs) with corresponding transmission power for D2D communications. Simulation results show that our proposed NADD RR scheme can improve the system throughput and maintain the original link reliability of macrocell and femtocell users while guaranteeing the fairness factor among the D2D pairs.**

***Index Terms*—Device-to-device (D2D) Communications; small cell; femtocell; heterogeneous network; resource management.**

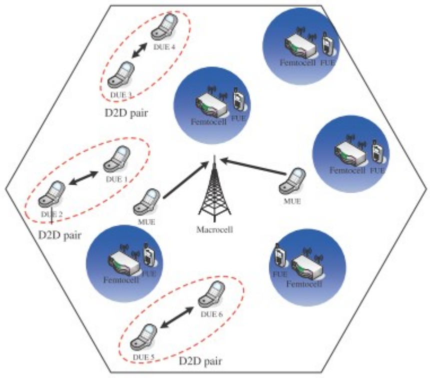

Fig. 1. Multi-pair device-to-device (D2D) communications with three-tier interference in ultra-dense heterogeneous networks.

I. Introduction

Device-to-device (D2D) communications, which allows direct communication with low power between proximate devices [2], [3], can offload the traffic and improve the system capacity. As shown in Fig. 1, D2D pairs (e.g., device 1 and device 2) can directly communicate with each other in the ultra-dense heterogeneous network (HeNet). Because the data transmission of D2D pairs does not pass through the macrocell base station (MBS) and femtocell base station (FBS), D2D communications can offload the traffic from the macrocell system and femtocell system. The D2D users (DUEs) have reliable communication with very low transmission power due to the short distance between proximate DUEs. In addition, with the frequency reuse, the D2D communications can improve the spectrum efficiency. Therefore, the D2D communications is an important technology in the fifth-generation (5G) mobile communications.

However, the complicated three-tier interference is the challenge to D2D communications in the Macro/Femto/D2D HeNet. The received DUE may suffer the macro-to-device, femto-to-device, and device-to-device interference, while the transmitted DUE may interferes with the MBS, FBSs and the other D2D pairs. The serious three-tier interference may decrease the throughput and service quality of DUEs.

In the literature, some studies [4], [8] on D2D communications investigated the impacts of resource management on the system throughput and link reliability for the cellular macrocell networks with proximity communications systems. In [8], the authors proposed a time-frequency hopping scheme to analyze the rate performance for a D2D-enabled cellular

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network with assuming that D2D links can use the same resources or different resources with the macrocell system. With the analysis, the paper [8] shown that the D2D-enabled cellular network can achieve a higher average total rate when DUEs use the orthogonal resources with the cellular network. The paper [4] investigated the impacts of the D2D spectrum sharing schemes and D2D mode selection on the system capacity and coverage, and concluded that the network should decrease the available spectrum for D2D communications to limit the interference if the number of D2D pairs increases. Some researches [5], [6] studied the D2D communications with considering the fairness issue. The paper [6] proposed a group fairness scheduling with considering both the spatial frequency reuse and multi-user diversity to improve the spectrum efficiency, while guaranteeing the fairness among users in a D2D-enabled cellular system. The authors in [5] combined the scheduling algorithms (i.e., the round robin scheduling and the proportional fair scheduling) and spatial reuse to improve the users' throughput for D2D communications. However, these works [4]–[6], [8] considered the resource management schemes only for the macrocell and D2D coexistent network system, and the issue of three-tier interference in the Macro/Femto/D2D HeNet was not discussed. In our previous work [7], we proposed a network-assisted device-decided (NADD) resource management to enhance the system throughput and guarantee the service quality of users for the Macro/Femto/D2D HetNet. Nevertheless, the resource allocation scheme considered the single pair D2D communications only. The issue of multiple D2D pairs did not discussed in the paper [7].

In this paper, we propose an NADD round-robin (RR) resource management to enhance the system throughput and service quality of users, while achieving an acceptable capacity fairness for D2D pairs. For the NADD scheme [7] only, DUEs can determine the available transmission power on the corresponding resource block (RB) based on the information of the maximum interference tolerance (MIT) broadcast by MBS and FBSs. However, with the proposed NADD RR scheme, we assume that the MBS realizes total number of D2D pairs, and sequentially gives each D2D pair a single order number, i.e., number 1 for the first D2D pair, number 2 for the second D2D pair, etc. The MBS also broadcasts these specific order numbers to DUEs. Accordingly, D2D pairs can sequentially and autonomously select the RBs and adjust the suitable transmission power to mitigate the complicated three-tier interference, which improves the system throughput. In addition to system throughput, the link reliability of users and the fairness among D2D pairs are taken into account in this paper. The simulation results show that our proposed NADD RR scheme can improve the system throughput without sacrificing the service quality of macrocell users (MUEs) and femtocell users (FUEs), and can achieve an acceptable fairness.

The remainder of this paper is organized as follows. Section II introduces the problem formulation, and the proposed NADD RR 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

D2D communications can increase the system throughput for the Macro/Femto/D2D heterogeneous network (HetNet) if the three-tier interference can be controlled well. In conventional macrocell network with D2D communications, the macrocell can schedule the most suitable RBs and transmission power for D2D pairs to control the macro-to-device and device-to-macro interference and to enhance the system throughput. However, in the Macro/Femto/D2D HetNet, the macrocell cannot correctly estimate the interference between D2D pairs and femtocells because a FBS can be deployed by users in any location and femtocells can autonomously allocate the radio resource for FUEs. Consequently, the macrocell cannot allocate the suitable radio resource for D2D pairs, and DUEs should have the ability to participate in managing their radio resource. With multiple D2D pairs in the HetNet, the network should assist D2D pairs to fairly allocate the radio resource to avoid the unfair allocations among D2D pairs (i.e., some D2D pairs can use a lot of radio resource and the others may have no radio resource for transmission). In this paper, we propose the NADD RR scheme to help D2D pairs fairly allocate RBs with the proper transmission power to improve the system throughput. Furthermore, the NADD RR scheme can ensure that the link reliability of MUEs and FUEs does not be sacrificed for the improvement of the system throughput.

III. Network-Assisted Device-Decided (NADD) Round Robin (RR) Scheme

In this section, we detail the NADD RR scheduling. We assume that the MBS and FBSs can provide the maximum interference tolerance (MIT) information of each RB for all D2D pairs. With the MIT information from MBS and FBSs, D2D pairs can estimate the maximum allowable transmission power on each RB for D2D communications to ensure the link reliability of MUEs and FUEs. For reliable communication, D2D pairs can estimate the minimum transmission power on each RB. We assume that the MBS knows the amount of D2D pairs and assign numbers to these D2D pairs (e.g., number 1 for the first D2D pair, number 2 for the second D2D pair, etc.) to help D2D pairs fairly allocate the RBs. Therefore, each D2D pair can understand the D2D identification (ID) number, and can select the RBs with corresponding transmission power by turns.

Denote N_{D2D} as the number of D2D pairs, $P^{MIT}_{D2D,n,i}$ as the maximum allowable transmission power on the n-th RB for the i-th D2D pair, and $P^{Criterion}_{D2D,n,i}$ as the minimum transmission power on the n-th RB for the i-th D2D pair.

TABLE I
OFDMA MACRO/FEMTO/D2D NETWORK SYSTEM PARAMETERS

Parameters	Values
Macrocell radius (R_m)	500 m
Carrier frequency	2.0 GHz
System bandwidth (B)	10 MHz
FFT size (N_{FFT})	1024
Number of RBs (N_{RB})	50
Number of data subcarriers (N_{SC})	600
RB bandwidth (B_{RB})	180 KHz
Number of MUEs (N_{MUE})	50
Number of D2D pairs (N_{D2D})	5~20
Number of FBSs (N_{FBS})	100
Separation distance between a D2D pair (d_{D2D})	10 m
Maximum transmit power of MUE/FUE/DUE	23 dBm
Noise figure (MBS/FBS/UE)	5 dB / 5 dB / 7 dB
Predefined effective CINR threshold for link reliability requirement (γ_{th})	-2.5 dB

The procedures of the NADD RR scheduling are described in the following:

The MBS forwards the assistant information to all the D2D pairs, such as the number of D2D pairs N_{D2D} and the D2D ID numbers, etc.
Each D2D pair collects all the MIT information from the MBS and FBSs, and determines the maximum allowable transmission power $P_{D2D,n,i}^{MIT}$ for each RB based on the MIT information.
Each D2D pair determines the minimum transmission power criterion $P_{D2D,n,i}^{Criterion}$ on each RB.
for $i = 1$ to N_{D2D} **do**
    $n = i$.
    while $n \leq N_{RB}$ **do**
        if $P_{D2D,n,i}^{MIT} \geq P_{D2D,n,i}^{Criterion}$ **do**
            The D2D pair i selects the RB n for transmission, and adjusts the transmission power on the RB n to $P_{D2D,n,i}^{MIT}$.
        end if
    end while
end for

IV. SIMULATION RESULTS

In this section, we show performance improvements of the NADD RR scheme in the OFDMA-based Macro/Femto/D2D HetNet system subject to the complicated three-tier interference. Figure 1 shows the simulation environment, where there are N_{FBS} femtocells uniformly distributed in a macrocell with a radius of R_m (m). One FBS is deployed at the center of one house, which covers an area of 100 square meters. Each femtocell serves one indoor user, and the femtocell user's locations are uniformly distributed within the house. In addition, N_{D2D} D2D pairs are uniformly distributed in the macrocell, and the distance between two devices of a D2D pair is assumed to be d_{D2D} (m). Table I lists the related system parameters for the considered OFDMA-based Macro/Femto/D2D systems.

We assume that the macrocell system is fully-loaded, i.e., all the RBs are occupied by the MUEs. We also assume that femtocells can appropriately adjust the number of used RBs to lower the interference. We define the resource block usage ratio as $\rho_F = N_{data}/N_{RB}$ for femtocells, where N_{data} is the number of used RBs by femrocells and N_{RB} is the number of total RBs. In this paper, we assume $\rho_F = 0.1$ for mitigating the femto-to-macro, femto-to-femto and femto-to-device interference. The channel model, definitions of link reliability and throughput can refer to our previous work in [7], but we make some modifications for multiple D2D pairs in the ultra-dense HetNet. The capacity fairness among D2D pairs is also considered in this paper. Denote C_i as the throughput of the i-th D2D pair. For these N_{D2D} D2D pairs, the fairness factor is defined as [1]

$$F = \frac{\left(\sum_{i=1}^{N_{D2D}} C_i\right)^2}{N_{D2D} \sum_{i=1}^{N_{D2D}} C_i^2}, \quad (1)$$

with the range between 0 and 1. With $F = 1$, it represents that all the D2D pairs achieve the perfect fairness situation, and have the same throughput.

Three cases are compared with the conventional Macro/Femto systems without D2D. Case I represents the proposed NADD RR scheduling scheme. Case II represents the NADD scheme only. That means D2D users can select all the RBs that $P_{D2D,n,i}^{MIT} \geq P_{D2D,n,i}^{Criterion}, \forall n, \forall i$, and adjust the corresponding power for transmission without in turn selections. Case III represents the situation that the D2D pair uses all the RBs and maximum power for transmission without power control in the Macro/Femto/D2D systems.

A. Impacts on Link Reliability

Figures 2 and 3 show the link reliability performance of FUEs, DUEs, and MUEs against the number of D2D pairs. From the figures, we have the following observations:

1) Because of the increasing device-to-femto, device-to-macro and device-to-device interference, the link reliability decreases as the amount of D2D pairs increases. The FUEs have the best link reliability performance because of the wall protection. With the shorter distance between DUEs of each one D2D pair, the DUEs can achieve better link reliability than the MUEs. The MUEs have the worst link reliability performance due to the strong femto-to-macro and device-to-macro interference.
2) The proposed scheme (case I) can achieve higher link reliability than case II and case III for DUEs. This is because the proposed NADD RR scheme can help

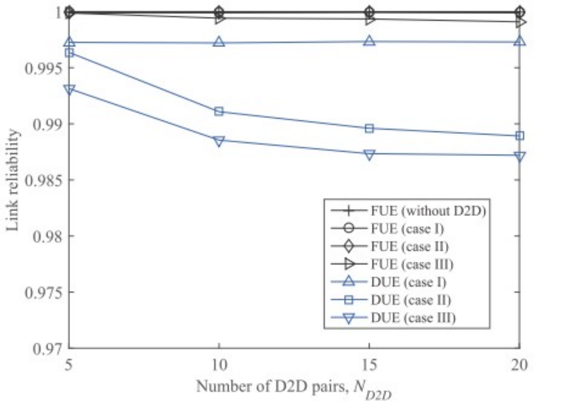

Fig. 2. Link reliability of femtocell user and D2D users versus number of D2D pairs.

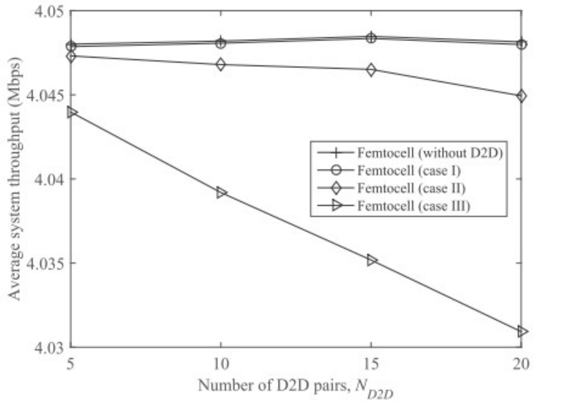

Fig. 4. Average throughput of femtocell system versus number of D2D pairs.

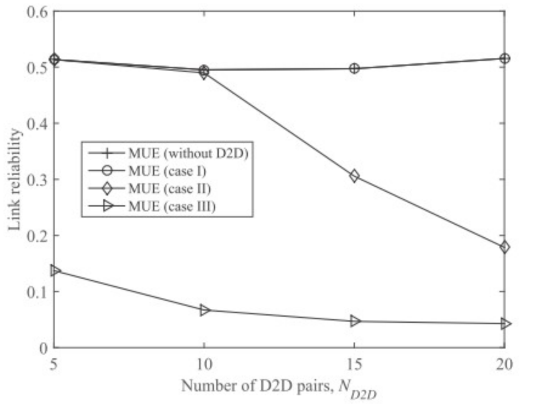

Fig. 3. Link reliability of macrocell users versus number of D2D pairs.

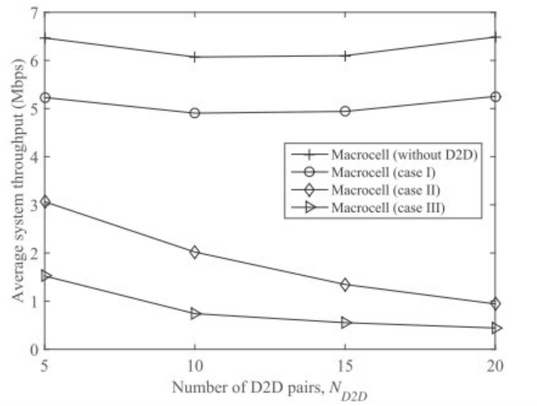

Fig. 5. Average throughput of macrocell system versus number of D2D pairs.

D2D pairs select the RB in turn, and the device-to-device interference is not existing among D2D pairs. In addition, the NADD RR scheme dose not degrade the link reliability of FUEs and MUEs as the number of D2D pairs increases.

3) For DUEs, the proposed NADD RR scheme can have some improvement compared with case II and case III. Moreover, the proposed NADD RR scheme can improve link reliability 188% and 1100% for MUEs with $N_{D2D} = 20$ D2D pairs, compared to case II and case III.

B. Impacts on Average System Throughput

Figures 4, 5 and 6 shows the average system throughput of femtocell, macrocell, and D2D system against the number of D2D pairs. From the figures, we have the following observations:

1) The system throughput decreases as the number of D2D pairs increases due to the increasing device-to-femto, device-to-macro and device-to-device interference. The proposed NADD RR scheme can achieve approximate average system throughput for femtocell and macrocell, compared to the scheme without D2D pairs. This is because the NADD RR scheme can in turn allocate the RBs and control the transmission power with guaranteeing the link reliability of MUEs and FUEs.
2) Case III has the best throughput while case I has the worst for DUEs. This is because each D2D pair can use all the RBs for transmission in case III while all the D2D pairs can allocate the RBs by turns in case I. However, case II and case III have worse system throughput than case I for femtocells and macrocells. That means the

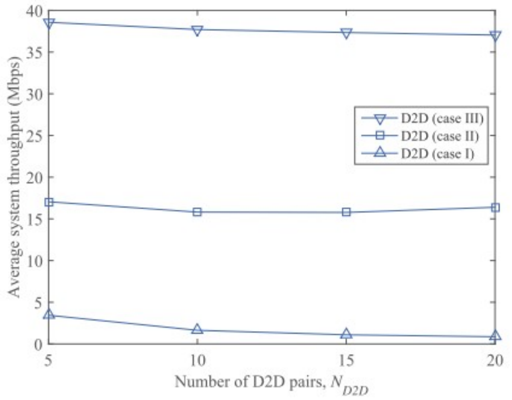

Fig. 6. Average throughput of D2D system versus number of D2D pairs.

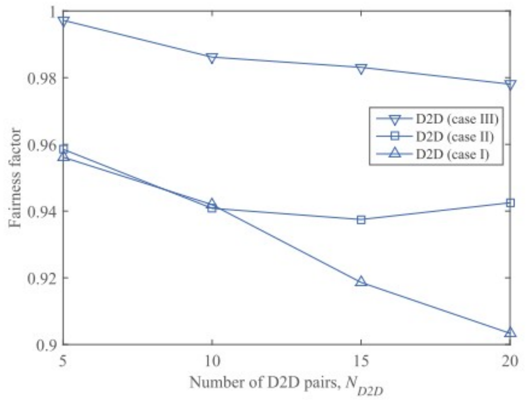

Fig. 7. Fairness factor of D2D versus number of D2D pairs.

scheme of case III has the strongest interference to macrocell and femtocell systems.

C. Impacts on Fairness

Figure 7 shows the fairness factor of D2D pairs against the number of D2D pairs. From the figure, we have the following observations:

1) The fairness factor decreases as the amount of D2D pairs increases due to the increasing difficulty in fairly allocating the RBs and power. Case III can has the best fairness factor, because any D2D pair uses all the RBs and maximum power for transmission without power control. However, the scheme has the most serious interference situation.
2) Case II and case I have the similar fairness factor when the number of D2D pairs $N_{D2D} \leq 20$, while case II has the better fairness factor than case I when the number of D2D pairs $N_{D2D} \geq 20$. We explain as following. In case II, D2D pairs can select all the RBs with corresponding transmission power if the maximum allowable transmission power is higher than the minimum transmission power criterion (i.e., $P_{D2D,n,i}^{MIT} \geq P_{D2D,n,i}^{Criterion}, \forall n, \forall i$) for these RBs. The scheduling of case II is independent of the number of D2D pairs N_{D2D}. However, the proposed NADD RRscheme (case I) the D2D pairs in turn select the RBs with corresponding transmission power. The scheduling of case I is dependent on the number of D2D pairs N_{D2D}. As the number of D2D pairs N_{D2D} approaches the amount of RBs N_{RB}, the scheduling of case I can not allocate the RB fairly. Nevertheless, the fairness factors are above 90% for the three cases.

V. Conclusion

In this paper, for the Macro/Femto/D2D HetNet with the complicated three-tier interference, we investigated the effects of scheduling schemes and multiple D2D pairs on link reliability, system throughput and fairness. We proposed the NADD RR scheme to help D2D pairs in turn select appropriate RBs with the corresponding transmission power to improve the system throughput and link reliability of all users. Three cases are compared with the conventional Macro/Femto systems without D2D in the simulation. With the simulation results, we showed that our proposed NADD RR scheme can improve the system throughput, and achieve the good link reliability as well as the fairness.

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