論文 / 著書情報
Article / Book Information

題目(和文)	将来セルラシステムに向けたヘテロジニアスネットワークと基地局協調伝送の組み合わせに関する研究
Title(English)	Study of Heterogeneous Networks and Cooperative Transmissions toward Future Cellular Systems
著者(和文)	下平英和
Author(English)	Hidekazu Shimodaira
出典(和文)	学位:博士（学術）, 学位授与機関:東京工業大学, 報告番号:甲第10354号, 授与年月日:2016年9月20日, 学位の種別:課程博士, 審査員:阪口 啓,安藤 真,廣川 二郎,府川 和彦,髙田 潤一,渡邉 文夫,樋口 健一
Citation(English)	Degree:, Conferring organization: Tokyo Institute of Technology, Report number:甲第10354号, Conferred date:2016/9/20, Degree Type:Course doctor, Examiner:,,,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

Doctoral Dissertation

Study of Heterogeneous Networks and Cooperative Transmissions toward Future Cellular Systems

Supervisors
Associate Professor Kei Sakaguchi
Professor Makoto Ando

Department of Electrical and Electronic Engineering
Graduate School of Engineering
Tokyo Institute of Technology

Hidekazu Shimodaira

Contents

Abstract **vii**

Acknowledgments **ix**

Chapter 1 Introduction **1**

1.1 Evolution of cellular networks 1

1.2 5G researches and developments 6

1.3 Thesis structure 7

Chapter 2 Conclusion **13**

2.1 Summary of the thesis 13

2.2 Suggestion for future works 14

Appendix I List of Publications **17**

I.1 Journal papers 17

I.2 International conferences 17

I.3 Domestic conferences 18

I.4 Awards 19

Reference **21**

List of Figures

1.1 Capabilities of IMT-2000 and system beyond IMT-2000 [5]. 4
1.2 Cellular network evolution. 6
1.3 Enhancement of key capabilities from IMT-Advanced to IMT-2020 [14]. 8
1.4 Structure of the thesis. 11

List of Tables

Abstract

The cellular networks have been developed for about 40 years and a new style of wireless communications has been provided together with its evolution. This evolution made the wireless communication more attractive, i.e. people have been able to not only talk but also exchange any types of digital data ubiquitously. However, in order to realize these targets, it is inevitable to achieve higher throughput. Indeed, the history of cellular network evolution is also the struggle to attain high throughput. First of all, the modulation scheme was changed from analog to digital to achieve higher spectral efficiency. Then the cell size was shrunk and the multiple access scheme was also changed to more effectively provide wireless resources to users. Multiple-Input Multiple-Output (MIMO) technique was also introduced to gain higher throughput. These evolutions are mainly related to improving access links' communication qualities. In recent year, to achieve further higher throughput, it becomes essential to improve network topology. Two technologies are employed, coordinated multi point transmission (CoMP) and heterogeneous networks. CoMP can alleviate inter cell interference by coordinating with neighboring cells. Ultimately, CoMP can completely eliminate inter cell interference and can turn it into useful signal, i.e. multi point MIMO transmission can be operated. On the other hand, heterogeneous network is constructed with conventional large coverage cells and small coverage add-on cells (small cells). These small cells are basically deployed near the congestion area (hotspot). The next generation, 5th generation (5G) cellular networks consider to utilize new frequency band above 6GHz for small cells. Since the radio wave in higher frequency band is easier to attenuate than that of conventional band, cell size becomes smaller and cell density becomes denser. Therefore, CoMP technique would play a key role for the interference mitigation. Although there are many candidate bands above 6GHz for 5G, there were not so many investigations on that which frequency band is best for 5G and what is the best combination of each frequency band and CoMP scheme. This thesis analyses CoMP and heterogeneous networks with respect to

some KPIs (Key Performance Indicators) and proposes the best combination of CoMP and heterogeneous network for future cellular networks.

Acknowledgments

I owe my deepest gratitude to my research advisor, Associate Professor Kei Sakaguchi for his constructive suggestions and insightful comments. Without his help, this dissertation would not have materialized. I should also thank Emeritus Professor Kiyomichi Araki for his tremendous support in all stages of the student life and research, especially the period when Prof. Sakaguchi is out of Tokyo Tech. Also, I would like to thank the rest of my thesis examination committee whose comments and advices helped me a lot in improving the quality of this thesis: Professor Makoto Ando, Professor Jiro Hirokawa, Professor Junichi Takada, Professor Fumio Watanabe, Professor Kazuhiko Fukawa, and Professor Kenichi Higuchi. I am also deeply grateful to Assistant Professor Gia Khanh Tran, who always gives me many useful advice, checks my manuscripts, and teaches me a lot of knowledge. Again, thanks to my research advisor, Associate Professor Kei Sakaguchi, I had the chance to meet and work with many experts and experienced people from different companies and incorporations. I should specially thank to Dr. Satoshi Konishi from KDDI Inc., Dr. Shinobu Nanba and Mr. Takahiro Hayashi from KDDI R&D labs. Regular contact and meetings with these experts was a guideline to keep the research in a correct direction. From July 2015 to December 2015, I had a chance to join the internship at Intel Corporation in U.S. I would like to show my greatest appreciation to Dr. Ali S. Sadri, the manager of mmWave Standard Advanced Technology (mSAT) group, and Dr. Joongheon Kim who continuously support my life and work in U.S. I could have priceless experience during the internship thanks to their kindness and hospitality. During the study in Sakaguchi lab. I was blessed with a nice and friendly environment and colleagues. I am grateful to all of them. Especially, I should explicitly thank Dr. Roya Ebrahim Rezagah for her helpful advice and in-depth discussion in all stages of this research. Finally my deep gratitude to my family who are the true light of my life. I am thankful to their constant support and encouragement in every moment of my life. Finally, it should be mentioned that a part of this research is done as a project named Milimeter-Wave

Evolution for Backhaul and Access (MiWEBA) under international cooperation program of ICT-2013 EU-Japan supported by FP7 in EU and MIC in Japan.

Chapter 1

Introduction

1.1 Evolution of cellular networks

In 1864, J.C. Maxwell established theoretical formulae explaining the behavior of electromagnetic (EM) field as a wave. After this magnificent work, in 1888, H.R. Hertz made an experiment system to 'emit' and 'detect' the EM wave and successfully demonstrated its existence. 7 years later from this demonstration, G. Marconi succeeded to 'transmit' and 'receive' the Morse signal. The distance between the transceivers was 2.4km. This is the first demonstration of wireless communication in the world. Wireless gave us a new degree of freedom, i.e. mobility.

In order to realize the mobile communication, tons of technologies have been proposed. In 1953, K. Bullington in Bell Labs proposed splitting geographic area into many segments and deploying base stations in each area with enough distance to avoid the interference [1]. In 1969 and 1970, J.S. Engel and R.H. Frenkiel analyzed this small zone split system and called it "Cell" [2][3]. In 1979, V.H. MacDonald introduced "handoff" technique which is a fundamental function to operate cellular network [4]. After establishing these bases, the development of cellular network was rapidly progressed.

The 1st generation (1G) cellular network started to be used commercially in 1980s. 1G system employs FDD (Frequency Division Duplex) for the duplex scheme, FDMA (Frequency Division Multiple Access) for the multiple access scheme, and analog frequency modulation (FM) for the modulation scheme. Since there was no standardization organization in this era, each country employed their own system.

AMPS

AMPS (Advanced Mobile Phone System) was developed by Bell Labs and used in United States. The carrier frequency is 800MHz.

TACS

TACS (Total Access Communication System) was developed by Motorola based on AMPS. It was used in United Kingdom.

HiCAP

HiCAP was developed by NTT and used in Japan. The carrier frequency is 800MHz.

NMT

NMT (Nordic Mobile Telecommunication System) was developed by Ericsson and used in several countries (mainly Northern Europe). The carrier frequencies are 450 MHz and 900MHz.

In 1990s, the 2nd generation (2G) cellular network was developed. 2G employed digital communication system to improve the spectral efficiency. Additionally, the first standardization body was established in Europe. In 1982, CEPT (Conference of European Postal and Telecommunication Administration) established the standardization group, GSM (Group Special Mobile, later the name changed to Global System for Mobile communications) to develop a unified cellular network in Europe. Then in 1988, ETSI (European Telecommunications Standards Institute) was established as an individual standardization body and GSM was moved from CEPT to ETSI. GSM introduced SIM (Subscriber Identity Module) card so as to use a same mobile terminal internationally. GSM is widely used all over the world as they expected. However, Japan and partial U.S. employed other systems. In Japan, PDC (Personal Digital Cellular) started to be used in 1993. Initially only the circuit switching was employed, then packet switching was introduced to transfer digital data efficiently. On the other hand, D-AMPS (Digital AMPS) was employed in U.S. in 1993. Although all of them employ FDD and TDMA (Time Division Multiple Access), modulation scheme is different. GSM (and extended technology of GPRS (Global Packet Radio Service)) employs GMSK (Gaussian Minimum Shift Keying), PDC and D-AMPS employs $\pi/4$-DQPSK. Through several stages of development, finally the peak data rate of 2G achieves 1.3Mbps in downlink.

Through 2G development, the importance of a world standard was recognized. Based on this experience, ITU (International Telecommunication Union) started the standardization activity, named FPLMTS (Future Public Land Mobile Telecommunication Systems) as the 3rd generation (3G) cellular networks from middle of 1980s. Later on, the name was changed to IMT-2000 (International Mobile Telecommunications 2000). “2000” means several milestones which should be included in 3G system, e.g. launched until 2000, use 2000MHz frequency bands, and achieve 2000kbps peak throughput. According to the requirement of IMT-2000, world wide standardization projects were started. 3GPP (3rd Generation Partnership Project) is one of the largest projects established in 1998. 3GPP calls each technical specification “Release”. The first Release, Release 99, mainly defined the basic specifications of 3G. The next three Releases, Release 5, 6, and 7, extended several functionalities to achieve more higher throughput. W-CDMA and CDMA 2000, which are widely used all over the world, employed FDD and CDMA (Code Division Multiple Access). Thanks to the evolution of technology, hardware, and network, over 20Mbps is achieved in downlink throughput.

After 3G launched, the discussion about 4th generation (4G) mobile communication system was started in ITU-R (ITU Radiocommunication Sector). In 2003, they defined the framework and overall objectives of the future development of IMT-2000 and system beyond IMT-2000 in the recommendation [5]. Figure 1.1 shows the capabilities of IMT-2000 and system beyond IMT-2000. In 2007, the name of systems beyond IMT-2000 was defined as IMT-Advanced. In order to answer the large requirement gap between IMT-Advanced and IMT-2000, it was necessary to introduce the bridge system firstly. This system is named LTE (Long Term Evolution) as the 3.9th generation. The technical specification of LTE was frozen in 3GPP Release 8 in 2009 and launched in 2010. LTE can employ both FDD and TDD. Multiple access schemes are OFDMA (Orthogonal Frequency Division Multiple Access) for downlink and SC-FDMA (Single Carrier FDMA) for uplink. By introducing OFDMA, bandwidth can be chosen flexibly from 1.4MHz to 20MHz. The peak data rate of downlink of basic LTE achieves 300Mbps by applying MIMO (Multiple Input Multiple Output) technique. In the 3GPP release 9, the LTE network functions are mainly enhanced.

In 2010, 3GPP release 10 was frozen. This means that 4th generation (4G), LTE-Advanced, is started. LTE-Advanced just enhanced the functionalities of LTE to keep the backward compatibility. The main enhancements in release 10 are listed below.

- Carrier Aggregation (CA) up to 100MHz
- MIMO layer enhancement (DL: 8, UL: 4, multiuser capability)
- Heterogeneous Network (HetNet) related techniques

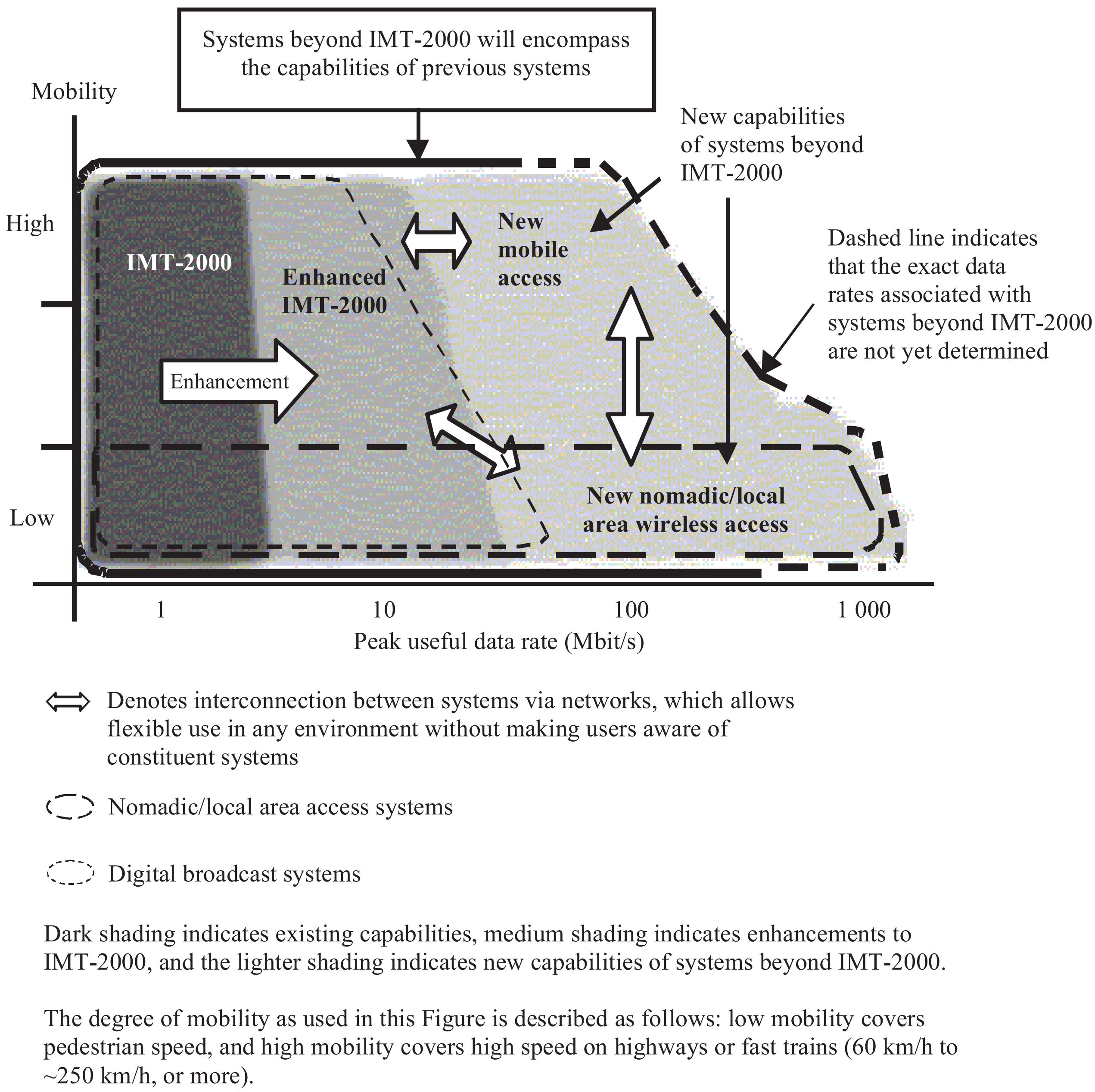

Figure 1.1 Capabilities of IMT-2000 and system beyond IMT-2000 [5].

HetNet is completely a new aspect in the history of the cellular network evolution. HetNet is constructed by the conventional large coverage base station (Macro BS) and small coverage add-on BSs (Smallcell BSs). The additional smallcell BS can work as the hotspot offloading and macro cell edge boosting. Additionally, since the coverage of smallcell BS is small, the users accommodated into smallcell BS can obtain better quality signal and more wireless resources than that of macro BS in many cases. From this aspect, HetNet is considered as the necessary technology to maintain the future mobile network.

3GPP release 11 enhanced the performance of LTE-Advanced. Especially, CoMP (Coordinated Multi Point operation) is a new key feature. CoMP can mitigate inter cell interference by coordinating with neighboring cells. Three interference mitigation techniques are defined in CoMP specification.

Dynamic Point Selection (DPS)

DPS is the simplest coordination method. UE (User Equipment) chooses the best signal quality BS and neighboring cells are muted at temporarily.

Coordinated Scheduling/Coordinated Beamforming (CS/CB)

CS/CB is more complicated coordination than DPS. Coordinated BSs accumulate CSI (Channel State Information) of multiple UEs and choose the best combination of UEs and transmission beam which does not incur large interference to each other.

Joint Transmission (JT)

JT is the most effective and most complicated scheme. Coordinated BSs accumulate CSI in the same way as CS/CB. Then precoded signals are transmitted from multi points in order to be combined constructively at the receiving point. Consequently, interference from neighboring cells disappears and is turned into useful signal.

In any cases, an accurate coordination and advanced backhaul/fronthaul network are necessary to utilize CoMP.

In release 12, heterogeneous network became more flexible and more useful. Dual connectivity is supported in this release. Thanks to this function, UE can connect macro BS and smallcell BS simultaneously. This feature gives several benefits, here in particular focuses on the C/U (Control-plane/User-plane) splitting. If smallcell BS employs higher frequency band than that of macro BS, there are no inter cell interference between macro BS and smallcell BS and wider bandwidth can be used. However, the smallcell coverage becomes smaller and it may cause less mobility and frequent handover. C/U splitting can solve this problem. Large coverage macro BS maintains C-plane of all UEs within macro cell area even if the UE connects smallcell BS. On the other hand, smallcell BS only transmits U-plane data to achieve higher data rate. After finalizing release 13, finally the 5th generation (5G) standardization work will start. Figure 1.2 summarizes cellular network evolution from dawn to now.

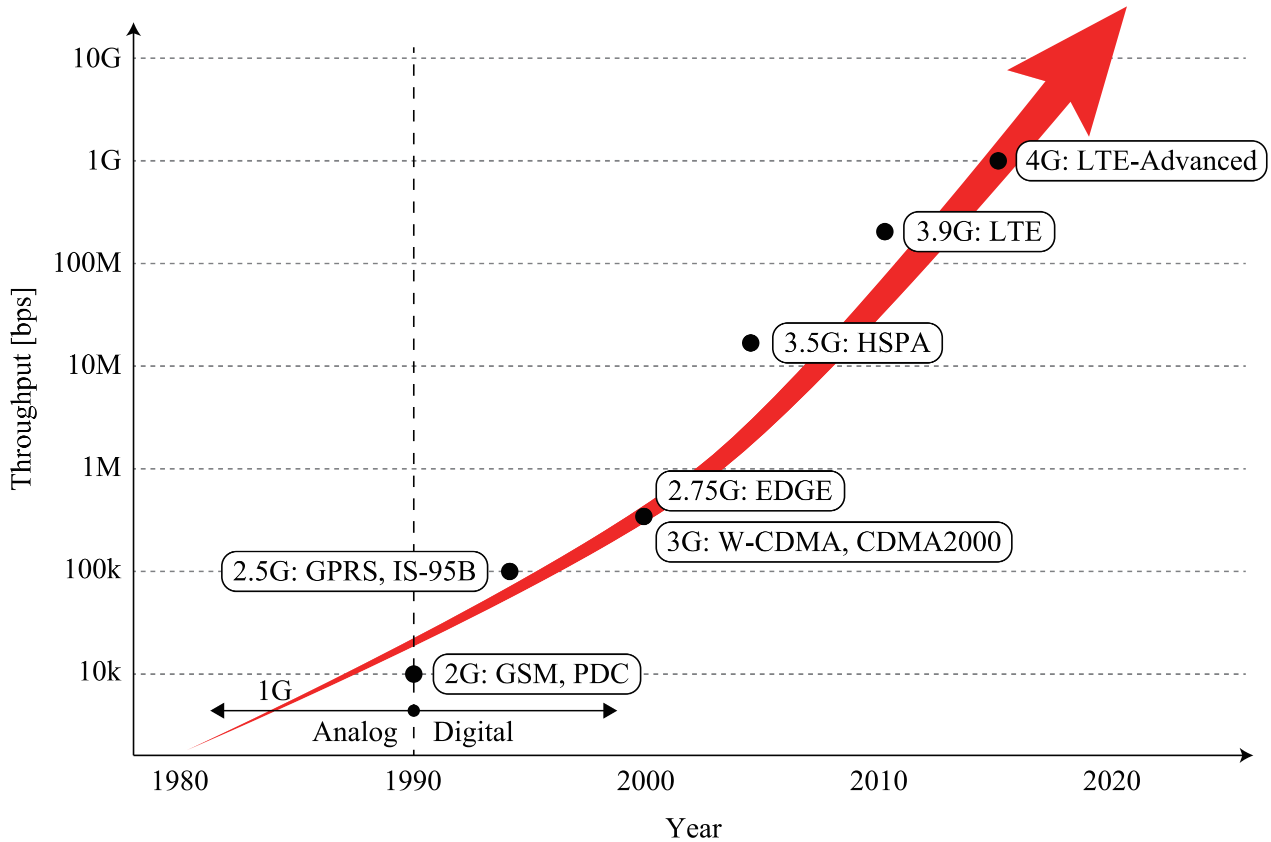

Figure 1.2 Cellular network evolution.

1.2 5G researches and developments

As mentioned in the previous section, the acceleration of mobile communication systems and the evolutions on mobile terminals is rapid. According to this evolution, large amount of data such as high resolution images or high-definition videos can be transmitted via wireless networks. On account of this rapid growth, the amount of mobile data traffic is exponentially increasing incomparable with that of the last decade. According to the Cisco Visual Network Index (VNI) [6], global mobile data traffic will grow at a CAGR (Compound Annual Growth Rate) of 53% from 2015 to 2020 and the number of connection of smart devices is also increasing. Moreover, Machine Type Communication (MTC) and Internet of Things (IoT) are expected to grow the number of connection more and more. Research and development of 5G cellular networks has been active all over the world to accommodate this huge mobile traffic.

In Japan, NTT DOCOMO published a white paper that describes technical concepts and requirements of 5G wireless access [7]. Also they are actively doing some experiments with other companies. 2020 and Beyond AdHoc Group (20B AH) also considers the concept and basic structure of the mobile communication system in 2020 and beyond and it is summarized in the white paper [8]. Additionally, 5GMF (The Fifth Generation Mobile Communication Promotion Forum) was established in 2014. They plan to hold integrated trials beginning in 2017.

In Europe, 7th Framework Programme for Research and Technological Development (FP7) [10] had been conducted by European Commission (EC) from 2007 to 2013 to improve the international competitiveness and technical strength. The famous 5G R&D projects e.g. METIS, 5GNow, MiWEBA, MiWaveS, iJOIN etc. are supported by this framework. In 2014, EC called the new framework program named "Horizon 2020" as a successor of FP7 [11]. Moreover, The 5G Infrastructure Public-Private partnership (5G PPP) [12] was established as a consortium in Horizon 2020.

In United States, New York University Polytechnic School of Engineering (NYU-Poly) has led 5G research and development with many companies. They have actively done outdoor propagation experiments and held the annual workshops called Brooklyn 5G summit. In China, three ministries of China jointly established "IMT-2020 (5G) promotion group" [13] in 2013 and they published four white papers about 5G.

ITU-R mentioned the requirements of 5G in the new report [14]. Figure 1.3 shows 5G requirements. ITU-R is now discussing how to utilize the frequency band above 6GHz for future IMT. Therefore investigations are necessary to find the best frequency band above 6GHz for future mobile communication networks. This thesis analyses the performance of CoMP and heterogeneous networks from lower frequency band to higher frequency band. According to this analysis results, this thesis proposes the best deployment strategy of CoMP and heterogeneous network for future cellular networks in each frequency band.

1.3 Thesis structure

This thesis aims to investigate the best deployment strategy of heterogeneous network and cooperative transmission to realize future cellular systems. Figure 1.4 shows the structure of the thesis.

Chapter 2 investigates the optimal smallcell BS deployment in heterogeneous cellular networks especially with the existence of hotspots. Smallcell BS locations are optimized together

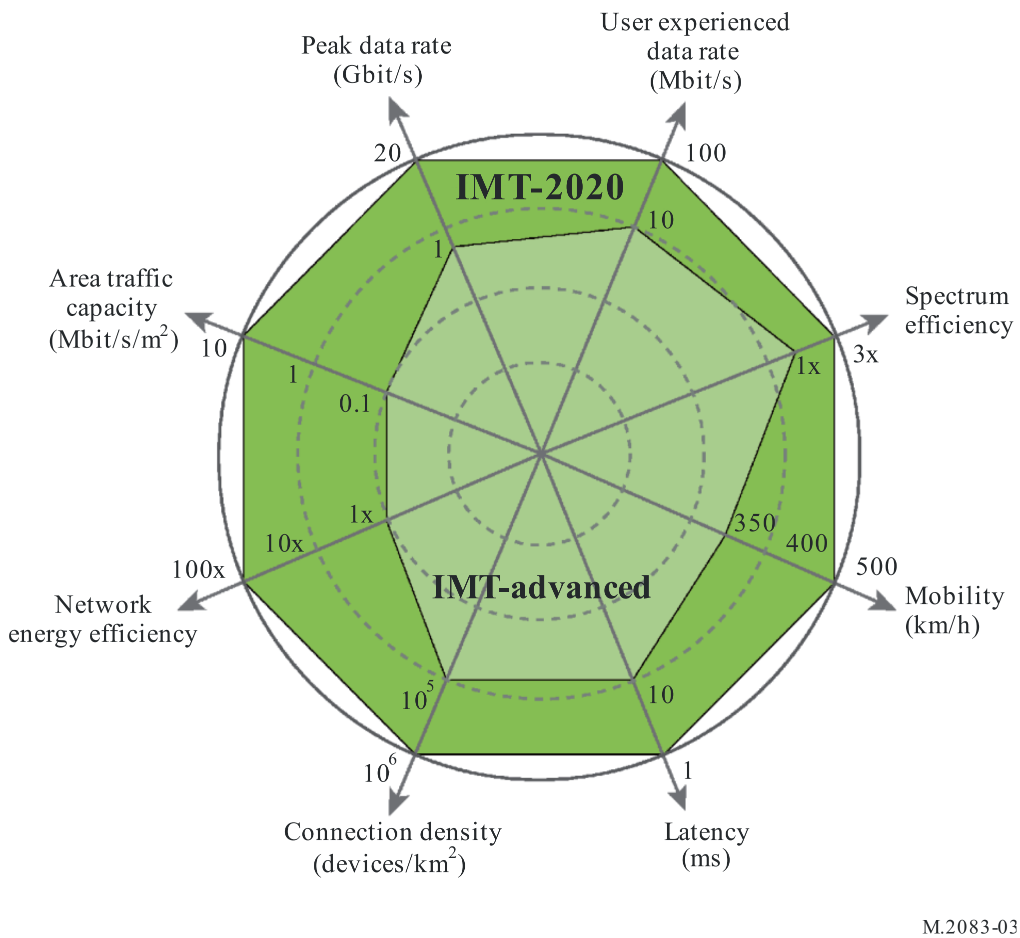

Figure 1.3 Enhancement of key capabilities from IMT-Advanced to IMT-2020 [14].

with other network parameters including spectrum resource allocation and smallcell size to maximize the fairness utility function, by considering two spectrum allocation strategies, i.e. spectrum overlapping and spectrum splitting. Numerical results show that the optimal small-cell BS locations depends on the hotspot user throughput and this optimization can improve the average user rate and outage user rate in heterogeneous cellular network with hotspots.

Chapter 3 analyses the relationship between CoMP scheme and frequency. In lower frequency band, the signal can be transmitted to wide area. However in higher frequency band, the signal is transmitted only within small area because large number of antenna elements are used for pathloss compensation by forming narrow beam. According to this nature, CoMP JT is more effective in lower frequency bands and CoMP CS/CB is more effective in higher frequency bands. This chapter reveals this relationship and proposes the best deployment strategy of cooperative transmissions in terms of frequency.

Chapter 4 introduces the best combination with CoMP and heterogeneous network in lower frequency band. Smallcell BSs are introduced to solve the cluster edge problem in CoMP cellular networks. In our novel cell topology, we derive the optimal locations of small cell BSs and the optimal resource allocation between the CoMP base station and small cell BSs to maximize the user fairness. By using the proposed architecture, in the case of perfect user scheduling, more than 150% improvement in 5% outage throughput is achieved, and in the case of successive proportional fair user scheduling, nearly 100% improvement of 5% outage throughput is achieved compared with conventional single cell networks.

Chapter 5 shows the performance of heterogeneous network with cooperative transmission in higher frequency band. In this scenario, the heterogeneous network becomes multiband therefore a novel cell association method which is suitable for multiband heterogeneous network is introduced. In the numerical evaluation, 28GHz, 60GHz, and 73GHz are analyzed and the performance of each band is indicated according to the numerical simulation results.

Finally, Ch. 6 concludes the thesis.

The results of Ch. 2 are published in

- H. Shimodaira, G.K. Tran, K. Sakaguchi, K. Araki, S. Kaneko, N. Miyazaki, S. Konishi, and Y. Kishi, "Optimization of Picocell Locations and Its Parameters in Heterogeneous Networks with Hotspots," in Proc. *IEEE PIMRC2012,*, pp. 124–129, Sep. 2012.
- H. Shimodaira, G.K. Tran, K. Sakaguchi, K. Araki, S. Kaneko, N. Miyazaki, S. Konishi, and Y. Kishi, "Optimization of Picocell Locations and Its Parameters in Heterogeneous Networks with Hotspots," *IEICE Trans. on Commun.,* Vol. E96-B, No. 6, pp.1338–1347, Jun. 2013.

The results of Ch. 4 are published in

- H. Shimodaira, G.K. Tran, K. Araki, K. Sakaguchi, S. Konishi, and S. Nanba, "Diamond cellular network –Optimal combination of small power basestations and CoMP cellular networks–," in Proc. *IEEE PIMRC2013,*, pp. 163–167, Sep. 2013.
- H. Shimodaira, G.K. Tran, K. Sakaguchi, K. Araki, S. Nanba, and S. Konishi, "Diamond cellular network –Optimal combination of small power basestations and CoMP cellular networks–," *IEICE Trans. on Commun.,* Vol. E99-B, No. 4, pp.917–927, Apr. 2016.

The results of Ch. 5 are published in

- H. Shimodaira, G.K. Tran, K. Araki, K. Sakaguchi, S. Nanba, T. Hayashi, and S. Konishi, "Cell Association Method for Multiband Heterogeneous Networks," in Proc. *IEEE PIMRC2014,* pp. 2209–2213, Sep. 2014.

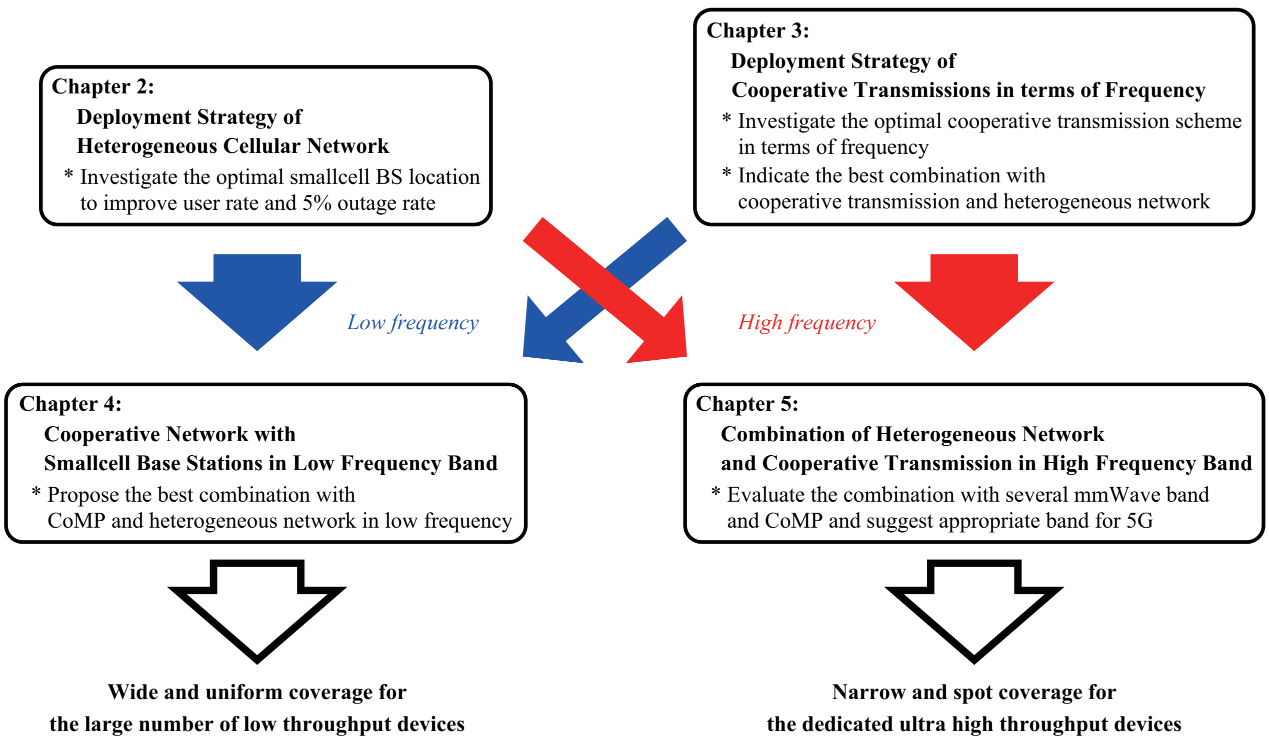

Figure 1.4 Structure of the thesis.

Chapter 2

Conclusion

2.1 Summary of the thesis

Heterogeneous network and CoMP transmission are key enablers to achieve uniform coverage and higher throughput than that of conventional homogeneous cellular network. In order to utilize these two technologies efficiently, the deployment strategy of smallcell BS and CoMP scheme in terms of frequency should be studied. This thesis investigated firstly the optimal deployment method of smallcell BSs with considering the hotspots existence. Then the performance of CoMP JT and CS/CB in several frequency bands from 3.5GHz to 73 GHz are evaluated and deployment strategy is suggested. According to this suggestion, we can conclude that CoMP heterogeneous network in low frequency band can construct the wide and uniform coverage for MTC or IoT network and CoMP heterogeneous network in high frequency band can construct the narrow but ultra high speed access coverage for heavy traffic demand users.

Chapter 2 showed the improvement of the average rate and the outage user rate made possible by introducing optimal smallcell BS locations and concluded that if macro BS has enough resources to serve all users, smallcell BSs should be deployed at the deadspot (capacity poor area) and if the user traffic exceeds the potential of macro BS, smallcell BSs should accommodate high traffic users or should be deployed near the hotspot whether macro BS and smallcell BS use a same frequency band or not.

Chapter 3 investigated the relationship between frequency band and the performance of CoMP schemes. For the evaluation, 6 frequency bands from 3.5GHz to 73GHz were chosen and different wireless channel condition and antenna configuration were employed. Through the numerical analysis, we revealed that CoMP JT is efficient if the system employs below 10GHz frequency band and CoMP CS/CB becomes more attractive in the case of above 10GHz systems. This result indicates that CoMP CS/CB should be employed in the mmWave 5G system rather than CoMP JT.

Chapter 4 proposed a novel heterogeneous network topology, the Diamond cellular network, in low frequency band. The numerical results showed that a significant improvement of 5% outage user rate is achieved. Of particular interest, the partial overlapping strategy provides the extraordinary gain of 150% in the outage user rate because it can effectively mitigate macro–smallcell interference at macro cell edge. Also in this case partial overlapping strategy achieves nearly 100% outage user rate improvement. In the case of lower frequency band, wide and uniform coverage can be realized by introducing this novel network topology and large number of devices can be accommodated.

Chapter 5 investigated the mmWave heterogeneous network for further enhancement toward future mobile network with CoMP CS/CB. Thorough system level analysis revealed that the key parameter to satisfy the huge traffic demand is system bandwidth regardless that the high frequency band is affected by significant path loss attenuation and path blocking. These results indicate that mmWave band which has large bandwidth can easily satisfy the user throughput requirements without concerning about the disadvantages of propagation characteristics. In the case of joint optimization, the high satisfaction ratio can be kept at all the time in all the cases while there are no significant differences between three candidates. These results indicate that mmWave band can provide ultra high speed access link with high QoS.

2.2 Suggestion for future works

There are still several remaining challenges to realize 5G system.

- Frequency allocation strategy:
  In the real situation, preferable frequency band is not always available. According to this study, 60GHz band is most useful because it has largest bandwidth. However, since the 60GHz band is unlicensed band, any types of wireless devices can use this band. Therefore a strict rule for coexistence must be established and agreed between all of users.

- Backhaul network:
  In order to use many smallcell BSs in the cellular network, backhaul problem should be resolved. Although mmWave backhaul system is proposed by many 5G researches, the problems that what is the best network configuration and how to coexist with access network have yet to be resolved. The real 5G system cannot be established until these problems are solved.

- Network delay:
  According to the results shown in Ch. 5, access delay requirement can be satisfied by applying the proposed resource optimization. However, network delay is an another problem. Since the amount of the traffic demand of each user is too large, conventional backhaul architecture becomes a bottleneck. Therefore, mobile edge computing technology should be introduced to each smallcell BSs. Also delayed offloading and prefetching techniques should be employed.

- Massive MIMO vs. distributed MIMO:
  One key technology to realize the 5G is Massive MIMO which uses several hundreds of antenna elements to attain large antenna gain and spatial multiplexing effect. On the other hand, distributed MIMO distributes antenna elements by using large number of smallcell BSs. According to the preliminary analysis in [75], this problem is also related to the frequency band. Overall system level analysis and cost effectiveness should be evaluated.

Appendix I

List of Publications

I.1 Journal papers

- H. Shimodaira, G.K. Tran, K. Sakaguchi, K. Araki, S. Kaneko, N. Miyazaki, S. Konishi, and Y. Kishi, "Optimization of Picocell Locations and Its Parameters in Heterogeneous Networks with Hotspots," *IEICE Trans. on Commun.,* Vol. E96-B, No. 6, pp.1338–1347, Jun. 2013.

- H. Shimodaira, G.K. Tran, K. Sakaguchi, K. Araki, S. Nanba, and S. Konishi, "Diamond cellular network –Optimal combination of small power basestations and CoMP cellular networks–," *IEICE Trans. on Commun.,* Vol. E99-B, No. 4, pp.917–927, Apr. 2016.

- K. Sakaguchi, G.K. Tran, H. Shimodaira, S. Namba, T. Sakurai, I. Siaud, K. Takinami, E.C. Strinati, A. Capone, I. Karls, R. Arefi and T. Haustein, "Millimeter-wave Evolution for 5G Cellular Networks," *IEICE Trans. Commun.,* Vol. E98-B, No. 3, Mar. 2015.

I.2 International conferences

- H. Shimodaira, G.K. Tran, K. Sakaguchi, K. Araki, S. Kaneko, N. Miyazaki, S. Konishi, and Y. Kishi, "Optimization of Picocell Locations and Its Parameters in Heterogeneous Networks with Hotspots," in Proc. *IEEE PIMRC2012,*, pp. 124–129, Sep. 2012.

- H. Shimodaira, G.K. Tran, K. Araki, K. Sakaguchi, S. Konishi, and S. Nanba, "Diamond cellular network –Optimal combination of small power basestations and CoMP cellular networks–," in Proc. *IEEE PIMRC2013,*, pp. 163–167, Sep. 2013.

- H. Shimodaira, G.K. Tran, K. Araki, K. Sakaguchi, S. Nanba, T. Hayashi, and S. Konishi, "Cell Association Method for Multiband Heterogeneous Networks," in Proc. *IEEE PIMRC2014,* pp. 2209–2213, Sep. 2014.

- H. Shimodaira, G.K. Tran, K. Sakaguchi, and K. Araki, "Investigation on Millimeter-wave Spectrum for 5G," in Proc. *CSCN2015,* pp. 143–148, Oct. 2015.

I.3 Domestic conferences

- H. Shimodaira, S. Tajima, G.K. Tran, K. Sakaguchi, K. Araki, S. Kaneko, N. Miyazaki, and Y. Kishi, "Design of Pico Cell Parameters in Heterogeneous Network," in Proc. *IEICE Society Conference,* BS-3-12, Sep. 2011.

- H. Shimodaira, G.K. Tran, K. Sakaguchi, K. Araki, N. Miyazaki, S. Kaneko, S. Konishi, and Y. Kishi, "Optimal Picocell Deployment in Heterogeneous Networks with Hotspots," in Proc. *IEICE Technical Report,* SR2012-17, vol. 112, no. 153, pp. 1–6, Jul. 2012.

- H. Shimodaira, G.K. Tran, K. Sakaguchi, K. Araki, S. Konishi, and N. Miyazaki, "Diamond Cellular Network –Combination of Small Power Basestations and CoMP Cellular Networks–," in Proc. *IEICE Technical Report,* RCS2012-336, vol. 112, no. 443, pp. 309–314, Mar. 2013.

- H. Shimodaira, G.K. Tran, K. Sakaguchi, K. Araki, S. Konishi, and T. Hayashi, "[MiWEBA] Cell Association Method for Multi Band Heterogeneous Networks," in Proc. *IEICE General Conference,* B-17-15, Mar. 2014.

- H. Shimodaira, G.K. Tran, K. Sakaguchi, and K. Araki, "Investigation on Millimeter-wave Spectrum for 5G," in Proc. *IEICE Technical Report,* SR2014-106, vol. 114, no. 435, pp. 75–80, Jan. 2015.

- H. Shimodaira, G.K. Tran, K. Sakaguchi, and K. Araki, "Cell Association Method for Millimeter Wave Heterogeneous Network with MU-MIMO," in Proc. *IEICE Technical Report,* SR2014-137, vol. 114, no. 491, pp. 157–162, Mar. 2015.

- H. Shimodaira, G.K. Tran, K. Sakaguchi, and K. Araki, “A Study on the Optimal Combination of Cooperative Transmission Scheme and Frequency Band for 5G,” in Proc. *IEICE Technical Report,* SR2016-53, vol. 116, no. 148, pp. 121–126, Jul. 2016.

I.4 Awards

- Best Paper Award from IEICE Technical Committee on Software Radio in 2015.

I.5 Others

- “Technical feasibility of IMT in bands above 6 GHz,” Report ITU-R M.2376-0, July 2015.

Reference

[1] K. Bullington, “Frequency economy in mobile radio bands,” in Transactions of the IRE Professional Group on Vehicular Communications, vol. 3, no. 1, pp. 4–27, Jun 1953.

[2] J.S. Engel, “The Effects of Cochannel Interference on the Parameters of a Small-Cell Mobile Telephone System,” in IEEE Transactions on Vehicular Technology, vol. 18, no. 3, pp. 110–116, Nov. 1969.

[3] R.H. Frenkiel, “A High-Capacity Mobile Radiotelephone System Model Using a Coordinated Small-Zone Approach,” in IEEE Transactions on Vehicular Technology, vol. 19, no. 2, pp. 173–177, May 1970.

[4] V.H. Mac Donald, ”Advanced Mobile Phone Service: The Cellular Concept,” in The Bell System Technical Journal, vol. 58, no. 1, pp. 15–41, Jan. 1979.

[5] ITU-R, “Framework and overall objectives of the future deelopment of IMT-2000 and system beyond IMT-2000,” Recommendation ITU-R M.1645, 2003.

[6] Cisco VNI Forecast, “Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2015–2020,” Cisco Public Information, Feb. 2016.

[7] NTT DOCOMO, INC., “5G Radio Access: Requirements, Concept and Technologies,” NTT DOCOMO 5G White paper, Jul. 2014.

[8] Association of Radio Industries and Business (ARIB), “Mobile Communications Systems for 2020 and beyond,” ARIB 2020 and Beyond Ad Hoc Group White Paper, Oct. 2014.

[9] “The Fifth Generation Mobile Communications Promotion Forum,” [Online]. Available: `http://5gmf.jp/en/`

[10] "FP7 Website," [Online]. Available: http://ec.europa.eu/research/fp7/index_en.cfm

[11] "Horizon 2020 Website," [Online]. Available: http://ec.europa.eu/programmes/horizon2020/

[12] "5G PPP Website," [Online]. Available: http://5g-ppp.eu/

[13] "IMT-2020 (5G) Promotion Group Website," [Online]. Available: http://www.imt-2020.cn/en/

[14] ITU-R, "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond," Recommendation ITU-R M.2083-0, 2015.

[15] V. Chandrasekhar, J. G. Andrews, and A. Gatherer, "Femtocell networks: a survey," IEEE Commun. Mag., vol. 46, no. 9, pp. 59–67, Sep. 2008.

[16] A. Khandekar, N. Bhushan, and V. Vanghi, "LTE-Advanced: Heterogeneous Network," European Wireless 2010, pp. 978–982, Apr. 2010.

[17] Ji-Hoon Yun, and K. G. Shin, "Adaptive Interference Management of OFDMA Femtocells for Co-Channel Deployment," IEEE Journal on Selected Areas in Communications, vol. 29, no. 6, pp. 1225–1241, Jun. 2011.

[18] D. López-Pérez, A. Valcarce, G. de la Roche, and J. Zhang, "OFDMA femtocells: a roadmap on interference avoidance," IEEE Commun. Mag., vol. 47, no. 9, pp. 41–48, Sep. 2009.

[19] Y. Shi, A. B. MacKenzie, L. A. DaSilva, K. Ghaboosi, and M. Latva-aho, "On Resource Reuse for Cellular Networks with Femto- and Macrocell Coexistence," Proc. IEEE Global Telecommunications Conference, GLOBECOM 2010, pp.1–6, Dec. 2010.

[20] B. Zubin, S. Andreas, A. Gunther, and H. Harald, "Dynamic Resource Partitioning for Downlink Femto-to-Macro-Cell Interference Avoidance," EURASIP Journal on Wireless Communications and Networking, vol. 2010, Jan. 2010.

[21] G.K. Tran, S. Tajima, R. Ramamonjison, K. Sakaguchi, K. Araki, S. Kaneko, N. Miyazaki, S. Satoshi, and Y. Kishi, "Study on Resource Optimization for Heterogeneous Networks," IEICE Trans. Commun., vol. E95-B, no. 4, pp. 1198–1207, Apr. 2012.

[22] M. Peng, X. Zhang, and W. Wang, “Performance of orthogonal and co-channel resource assignments for femto-cells in long term evolution systems,” IET Communications, vol. 5, Iss. 7, pp.996–1005, May 2011.

[23] J-M. Kelif, M. Coupechoux, and P. Godlewski, “A Fluid Model for Performance Analysis in Cellular Networks,” EURASIP Journal on Wireless Communications and Networking, Aug. 2010.

[24] 3GPP, TR 36.814 (V9.0.0), “Further advancements for E-UTRA physical layer aspects,” Mar. 2010.

[25] P. Vieira, P. Queluz, and A. Rodrigues, “Improving MIMO Spectral Efficiency in 4G Macro-Cellular Networks,” Proc. URSI Seminar of the Portuguese Committee, vol. 1, pp. 1–1, Nov. 2008.

[26] J. Sangiamwong, Y. Saito, N. Miki, T. Abe, S. Nagata, and Y. Okumura, “Investigation on Cell Selection Methods Associated with Inter-cell Interference Coordination in Heterogeneous Networks for LTE-Advanced Downlink,” Proc. European Wireless 2011, pp. 1–6, Apr. 2011.

[27] J. C. Lagrias, J. A. Reeds, M. H. Wright, and P. E. Wright, “Convergence properties of the Nelder–Mead simplex algorithm in low dimensions,” Tech. Rep. 96-4-07, AT&T Bell Laboratories, Apr. 1996.

[28] M. K. Karakayali, G. J. Foschini, and R. A. Valenzuela, “Network coordination for spectrally efficient communications in cellular systems,” IEEE Wireless Commun. Mag., vol. 13, no. 4, pp. 56–61, Aug. 2006.

[29] R. Irmer, H. Droste, P. Marsch, M. Grieger, G. Fettweis, S. Brueck, H.-P. Mayer, L. Thiele and V. Jungnickel, “Coordinated multipoint: Concepts, performance, and field trial results,” IEEE Commun. Mag., vol. 49, no. 2, pp. 102–111, Feb. 2011.

[30] N. Kusashima, I. D. Garcia, K. Sakaguchi, K. Araki, S. Kaneko and Y. Kishi, “Dynamic Fractional Base Station Cooperation Using Shared Distributed Remote Radio Units for Advanced Cellular Networks,” IEICE Trans. Commun., vol. E94-B, no. 12, pp. 3259–3271, Dec. 2011.

[31] 3GPP TR 36.819, “Coordinated multi-point operation for LTE physical layer aspects.”

[32] A. Maltsev, A. Sadri, A. Pudeyev and I. Bolotin, “Highly Directional Steerable Antennas: High-Gain Antennas Supporting User Mobility or Beam Switching for Reconfigurable Backhauling,” in IEEE Vehicular Technology Magazine, vol. 11, no. 1, pp. 32–39, Mar. 2016.

[33] 3GPP, TR 36.873 (V12.2.0), “Study on 3D channel model for LTE,” Jun. 2015.

[34] “QuaDRiGa –The Next Generation Channel Model–,” [Online]. Available: http://quadriga-channel-model.de/

[35] Federal Communications Commission, “Millimeter Wave Propagation: Spectrum Management Implications,” Jul. 1997.

[36] 3GPP TS 36.300 V10.11.0, “Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN), Overall description, Stage 2 (Release 10)”.

[37] A. Khandekar, N. Bhushan, and V. Vanghi, “LTE-Advanced: Heterogeneous Network,” European Wireless 2010, pp. 978–982, Apr. 2010.

[38] X. Gao, A. Li and H. Kayama, “Low-complexity Downlink Coordination Scheme for Multi-user CoMP in LTE-Advanced System,” Proc. IEEE PIMRC 2009, Sep. 2009

[39] D. Matsuo, R. Rezagah, G. K. Tran, K. Sakaguchi, K. Araki, S. Kaneko, N. Miyazaki, S. Konishi and Y. Kishi, “Shared Remote Radio Head Architecture to Realize Semi-Dynamic Clustering in CoMP Cellular Networks,” Proc. IEEE Global Telecommunications Conference, GLOBECOM 2012, Dec. 2012.

[40] P. Baracca, F. Boccardi and N, Benvenuto, “A dynamic clustering algorithm for downlink CoMP systems with multiple antenna UEs,” EURASIP Journal on Wireless Communications and Networking, 2014.

[41] L. Scalia, T. Biermann, S. Mizuta, “Coordinated multipoint multiuser-MIMO transmissions over backhaul-constrained mobile access networks,” Proc. IEEE PIMRC 2011, pp. 1336–1340, Sep. 2011.

[42] Y. Gao, Y. Li, H. Yu and S. Gao, “Performance Analysis of Dynamic CoMP Cell Selection in LTE-Advanced Heterogeneous Networks Scenario,” 2011 International Conference on Uncertainty Reasoning and Knowledge Engineering (URKE 2011), Aug. 2011.

[43] M. Shoeb, A. Ibrahim and H. Elgebaly, "Coordinated Multi-Point Algorithms in Pico Based Heterogeneous Networks," The 14th International Conference on Advanced Communication Technology (ICACT), Feb. 2012.

[44] B. Peng, W. Chen, Y. Zhang, M. Lei, Z. Cao and S. Zhou, "A Leakage-Aware CS/CB Scheme for Heterogeneous CoMP Network with Layered Limited Feedback," IEICE Trans. Commun., vol. E96-B, no.1, pp. 363–366, Jan. 2013.

[45] P. Viswanath, D. Tse, and R. Laroia, "Opportunistic beamforming using dumb antennas," IEEE Transactions on Information Theory, vol. 48, pp. 1277–1294, 2002.

[46] 3GPP TR 36.872, "Small cell enhancements for E-UTRA and E-UTRAN - Physical layer aspects"

[47] S. Emami, R.F. Wiser, E. Ali, M.G. Forbes, M.Q. Gordon, X. Guan, S. Lo, P.T. McElwee, J. Parker, J.R. Tani, J.M. Gilbert, and C.H. Doan, "A 60 GHz CMOS phased-array transceiver pair for multi-Gb/s wireless communications," IEEE ISSCC Dig. Tech. Papers, Feb. 2011.

[48] A. Siligaris, O. Richard, B. Martineau, C. Mounet, F. Chaix, R. Ferragut, C. Dehos, J. Lanteri, L. Dussopt, S.D. Yamamoto, R. Pilard, P. Busson, A. Cathelin, D. Belot, and P. Vincent, "A 65 nm CMOS fully integrated transceiver module for 60 GHz wireless HD applications," IEEE ISSCC Dig. Tech. Papers, Feb. 2011.

[49] K. Okada, K. Kondou, M. Miyahara, M. Shinagawa, H. Asada, R. Minami, T. Yamaguchi, A. Musa, Y. Tsukui, Y. Asakura, S. Tamonoki, H. Yamagishi, Y. Hino, T. Sato, H. Sakaguchi, N. Shimasaki, T. Ito, Y. Takeuchi, N. Li, Q. Bu, R. Murakami, K. Bunsen, K. Matsushita, M. Noda, and A. Matsuzawa, "A full 4-channel 6.3 Gb/s 60 GHz direct-conversion transceiver with low power analog and digital baseband circuitry," IEEE ISSCC Dig. Tech. Papers, Feb. 2012.

[50] T. Tsukizawa, N. Shirakata, T. Morita, K. Tanaka, J. Sato, Y. Morishita, M. Kanemaru, R. Kitamura, T. Shima, T. Nakatani, K. Miyanaga, T. Urushihara, H. Yoshikawa, T. Sakamoto, H. Motozuka, Y. Shiraka, N. Yosoku, A. Yamamoto, R. Shiozaki, and N. Saito, "A fully integrated 60 GHz CMOS transceiver chipset based on WiGig/IEEE802.11ad with built-in self calibration for mobile applications," IEEE ISSCC Dig. Tech. Papers, Feb. 2013.

[51] ITU-R WP5D, "Workplan, timeline, process and deliverables for the future development of IMT"

[52] "Tentative 3GPP timeline for 5G," [Online]. Available: http://www.3gpp.org/news-events/3gpp-news/1674-timeline_5g

[53] M. Mueck, W. Jiang, G. Sun, H. Cao, E. Dutkiewicz and S. Choi, "Novel Spectrum Usage Paradigms for 5G," IEEE ComSoc, TCCN, White Paper, Nov. 2014.

[54] "METIS Website," [Online]. Available: https://www.metis2020.com/

[55] "MiWaveS Website," [Online]. Available: http://www.MiWaveS.eu/

[56] "D5.1: Intermediate description of the spectrum needs and usage principles," ICT-317669-METIS/D5.1, Aug. 2013.

[57] K. Sakaguchi, G.K. Tran, H. Shimodaira, S. Namba, T. Sakurai, I. Siaud, K. Takinami, E.C. Strinati, A. Capone, I. Karls, R. Arefi and T. Haustein, "Millimeter-wave Evolution for 5G Cellular Networks," IEICE Trans. Commun., Vol. E98-B, No. 3, Mar. 2015.

[58] "METIS II introduction," [Online]. Available: https://5g-ppp.eu/metis-ii/

[59] "mmMAGIC introduction," [Online]. Available: https://5g-ppp.eu/mmmagic/

[60] NTT DOCOMO, INC., "DOCOMO's 5G Outdoor Trial Achieves 4.5Gbps Ultra-high-speed Transmission – Aiming at 5G launch by Tokyo 2020 Olympic and Paralympic Games –," NTT DOCOMO press release, Mar. 2015.

[61] K. Son, H. Kim, Y. Yi, and B. Krishnamachari, "Base station operation and user association mechanisms for energy-delay tradeoffs in green cellular networks," IEEE J. Sel. Areas Commun. vol. 29, no. 8, pp. 1525–1536, Sep. 2011.

[62] H. Kim, G. Veciana, X. Yang and M. Venkatachalam, "Distributed α-Optimal User Association and Cell Load Balancing in Wireless Networks," IEEE/ACM Transactions on Networking, vol.20, no.1, pp.177-190, Feb. 2012.

[63] 3GPP TS 23.203 V13.6.0, "Policy and charging control architecture (Release 13)"

[64] J. Choi, Ji-Won Choi and Seong-Cheol Kim, “An Improved Throughput Estimation Method and Dynamic User Association in Multi-Cell Networks,” 2013 IEEE 24th International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC), Sep. 2013.

[65] A. Sang, X. Wang, M. Madihian, and R. D. Gitlin, “Coordinated load balancing, handoff/cell-site selection, and scheduling in multi-cell packet data systems,” Wireless Networks, vol. 14, no. 1, pp. 103–120, Jan. 2008.

[66] P. Hande, S. Patil, and H. Myung, “Distributed load-balancing in a multi-carrier system,” in Proc. IEEE WCNC2009, Budapest, Hungary, Apr. 2009.

[67] K. Son, S. Chong, and G. de Veciana, “Dynamic association for load balancing and interference avoidance in multi-cell networks,” IEEE Trans. Wireless Commun. vol. 8, no. 5, pp. 3566–3576, Jul. 2009.

[68] S. Corroy, L. Falconetti and R. Mathar, “Cell Association in Small Heterogeneous Networks: Downlink Sum Rate and Min Rate Maximization,” 2012 IEEE Wireless Communications and Networking Conference (WCNC), Apr. 2012.

[69] Q. Ye, B. Rong Y. Chen, M. Al-Shalash, C. Caramanis and J.G. Andrews, “User Association for Load Balancing in Heterogeneous Cellular Networks,” IEEE Transactions on Wireless Communications, vol.12, no.6, pp.2706-2716, Jun. 2013.

[70] K. Shen and W. Yu, “Downlink Cell Association Optimization for Heterogeneous Networks via Dual Coordinate Descent,” 2013 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), May 2013.

[71] R. Han, C. Feng and H. Xia, “Optimal User Association Based on Topological Potential in Heterogeneous Networks,” 2013 IEEE 24th International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC), Sep. 2013.

[72] Q. Kuang, J. Speidel, and H. Droste, “Joint base-station association, channel assignment, beamforming and power control in heterogeneous networks,” in Proc. IEEE VTC2012-Spring, Yokohama, Japan, May 2012.

[73] H. Shimodaira, G.K. Tran, K. Araki, K. Sakaguchi, S. Nanba, T. Hayashi, and S. Konishi, "Cell Association Method for Multiband Heterogeneous Networks," in Proc. IEEE PIMRC2014, pp. 2209–2213, Sep. 2014.

[74] D.S. Baum, J. Salo, M. Milojevic, P. Kyösti and J. Hansen, "MATLAB implementation of the interim channel model for beyond-3G systems (SCME)," `http://www.tkk.fi/Units/Radio/scm/`, May 2005.

[75] R.W. Heath Jr, "Comparing Massive MIMO at Sub-6 GHz and Millimeter Wave Using Stochastic Geometry (Keynote speech)," in IEEE ICC2015, Jun. 2015