ISTANBUL TECHNICAL UNIVERSITY ★ INFORMATICS INSTITUTE

JOINT TRANSMISSION COORDINATED MULTIPOINT TECHNIQUE IN MULTI DRONE CELLS

M.Sc. THESIS

Serdar TORUN

Applied Informatics Department

Information and Communications Engineering Programme

JUNE 2019

ISTANBUL TECHNICAL UNIVERSITY ★ INFORMATICS INSTITUTE

JOINT TRANSMISSION COORDINATED MULTIPOINT TECHNIQUE IN MULTI DRONE CELLS

M.Sc. THESIS

Serdar TORUN
(708151017)

Applied Informatics Department

Information and Communications Engineering Programme

Thesis Advisor: Prof. Dr. Lütfiye DURAK ATA

JUNE 2019

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ BİLİŞİM ENSTİTÜSÜ

ORTAK İLETİM EŞGÜDÜMLÜ ÇOKLU NOKTA TEKNİĞİNİN ÇOKLU DRON HÜCRELERİNDE KULLANIMI

YÜKSEK LİSANS TEZİ

Serdar TORUN
(708151017)

Bilişim Uygulamaları Anabilim Dalı

Bilgi ve Haberleşme Mühendisliği Programı

Tez Danışmanı: Prof. Dr. Lütfiye DURAK ATA

HAZİRAN 2019

Serdar TORUN, a M.Sc. student of ITU Informatics Institute student ID 708151017 successfully defended the thesis entitled "JOINT TRANSMISSION COORDINATED MULTIPOINT TECHNIQUE IN MULTI DRONE CELLS", which he/she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Prof. Dr. Lütfiye DURAK ATA**	....
Jury Members :	**Assoc. Prof. Dr. Berk CANBERK** Istanbul Technical University	....
	Assist. Prof. Dr. Eylem ERDOĞAN Istanbul Medeniyet University	....

Date of Submission : 5 May 2019
Date of Defense : 10 June 2019

FOREWORD

I would like to express my sincere gratitude to my supervisor, Prof. Dr. Lütfiye Durak Ata for giving me valuable advice during my graduate education. Her guidance have pushed me beyond my expectations. It is a great chance to have the opportunity to work with her.

Besides my thesis advisor, my sincere thanks must also go to Dr. Mehmet Başaran for his great support. I would like to thank the members of the examining committee for their valuable discussion, comments and suggestions.

To my mother, my father and my sister, I am greatly indebted to their encouragement, emotional support, and prayers.

June 2019 Serdar TORUN

TABLE OF CONTENTS

Page

FOREWORD .... **vii**
TABLE OF CONTENTS .... **ix**
ABBREVIATIONS .... **xi**
LIST OF TABLES .... **xiii**
LIST OF FIGURES .... **xv**
SUMMARY .... **xvii**
ÖZET .... **xix**
1. INTRODUCTION **1**
1.1 Literature Review 2
1.2 Problem Statement and Hypothesis 4
1.3 Contributions 5
1.4 Thesis Organisation 5
2. THEORETICAL BACKGROUND **7**
2.1 Heterogeneous Networks 7
2.2 Interference Mitigation 9
2.2.1 Intercell interference coordination 10
2.2.2 Enhanced ICIC 12
2.2.3 Coordinated multipoint 13
2.3 Airborne Communication Network Model 15
3. SYSTEM MODEL **19**
3.1 Poisson Point Process Model for UE Distribution 19
3.2 Line of Sight Probability 19
3.3 Path Loss Model For Drone Networks 20
3.4 Reference Signal Received Power Calculations for DBSs 22
3.5 Signal to Interference Noise Ratio for CoMP-Applied UEs 23
3.6 COMP Clustering Algorithm 24
3.7 Throughput Difference under CoMP 25
3.8 The 5th-Percentile Spectral Efficiency for the UEs under CoMP 26
3.9 Outage Probability for CoMP Users 26
4. SIMULATION RESULTS **29**
4.1 Numerical Results 29
4.2 Conclusion Remarks 32
5. CONCLUSION **35**
REFERENCES **37**
CURRICULUM VITAE **41**

ABBREVIATIONS

ABS	: Aerial base station
ABSF	: Almost blank subframe
BS	: Base station
CDF	: Cumulative distribution function
COMP	: Coordinated multipoint
CRE	: Cell range extension
DBS	: Drone base station
DL	: Downlink
eICIC	: Enhanced intercell interference coordination
feICIC	: Further enhanced intercell interference coordination
FSO	: Free space optics
HAP	: High altitude platform
HetNet	: Heterogenous network
ICIC	: Intercell interference coordination
ITU	: International Telecommunication Union
JT-COMP	: Joint transmission coordinated multipoint
LAP	: Low altitude platform
LoS	: Line of sight
LTE	: Long term evolution
NLoS	: Non-line of sight
QoS	: Quality of services
PDF	: Probability density function
RSRP	: Reference signal received power
SDN	: Software defined network
SE	: Spectral efficiency
SINR	: Signal to interference and noise ratio
UAV	: Unmanned aerial vehicle
UAV-BS	: Unmanned aerial vehicle base station
UE	: User equipment
UL	: Uplink
3GPP	: 3rd generation partnership project

LIST OF TABLES

Page

Table 2.1 : Components of heterogenous networks. 8
Table 2.2 : Feature summary of interference mitigation techniques..................... 15
Table 2.3 : Feature comparison of airborne network components........................ 16
Table 3.1 : Requirements for the 5th-percentile SE in 5G................................... 26
Table 4.1 : Simulation parameters.. 29

LIST OF FIGURES

Page

Figure 1.1 : Multi drone cell deployment.. 2
Figure 2.1 : An heterogeneous network consisting of different components........ 7
Figure 2.2 : Demonstration of network deployment models: a) Base station centric network model, b) User centric network model...................... 9
Figure 2.3 : Interference mitigation techniques in 3GPP releases. 10
Figure 2.4 : Bandwidth usage with FFR technique in hexagonal cell deployments. 11
Figure 2.5 : Almost blank subframes in a macrocell and in a small cell. 12
Figure 2.6 : Power reduced subframes in the macrocell with reduce factor α. 13
Figure 2.7 : Joint transmission in subframes: Both transmission points transmits in each subframe... 14
Figure 2.8 : An airborne communication network model containing a satellite layer, a HAP layer and a LAP layer. 16
Figure 3.1 : UE distribution and DBS locations in the field 20
Figure 3.2 : Line-of-sight probability as a function of altitude............................ 21
Figure 3.3 : Path loss as a function of altitude for different distances to DBS. 22
Figure 3.4 : Path loss as a function of altitude for different frequencies. 22
Figure 4.1 : CoMP and non-CoMP users in different PLDs 30
Figure 4.2 : The PDF of throughput difference with different PLDs................... 31
Figure 4.3 : The CDF of throughput difference with different PLDs. 31
Figure 4.4 : The PDF of 5th-percentile SE 32
Figure 4.5 : The CDF of 5th-percentile SE 33
Figure 4.6 : Outage Probability of DBSs 33

JOINT TRANSMISSION COORDINATED MULTIPOINT TECHNIQUE IN MULTI DRONE CELLS

SUMMARY

Next generation communication technologies offer users high data rate in every environment. Macrocells may be insufficient where the number of users instantaneously increases or on the occurrence of extraordinary situations like natural disasters. Therefore, drone cells are going to be a part of heterogeneous networks in 5G thanks to their mobile capabilities.

Through drone cells, service quality and network capacity can be improved in the fields with a high amount of users. Having the ability to fly beyond line of sight (LoS), there is a remarkable decrease in the path loss of the signal transmitted from drone base station (DBS). LoS probability in a network consisted of multi drone cells is analysed and the path loss derived from the LoS probability as a function of altitude is presented. The optimum flying height and operating frequencies are presented.

Using multiple drones close to each other in the same spectrum band and coverage area creates interference problems. With the joint transmission coordinated multipoint (JT-CoMP) technique introduced by 3GPP, it is both aimed to improve the performance of cell edge users and to increase the capacity for them while mitigating interference. Preventing and exploiting from interference, it is possible to effectively utilize it for the DBSs flying close to each other. Accordingly, in this thesis, the user equipments (UEs) are clustered whether they utilize CoMP or not regarding their received power level difference (PLD) from different DBSs. JT-CoMP technique is used to increase the system performance for cell edge users that are identified according to their PLD values.

In the simulations, the Poisson point process is used to distribute the UEs in the simulation area. Signal-to-interference-noise-ratio (SINR) of each UE, that is receiving service from a DBS, is calculated. Based on the SINR calculations, the throughput difference and the 5th-percentile spectral efficiency of the users with and without CoMP are presented. Furthermore, we analyze the outage probability performance of multi drone-cells as a function of SINR treshold with and without CoMP.

ORTAK İLETİM EŞGÜDÜMLÜ ÇOKLU NOKTA TEKNİĞİNİN ÇOKLU DRON HÜCRELERİNDE KULLANIMI

ÖZET

Yeni nesil haberleşme teknolojileri, kullanıcılarına her ortamda yüksek veri hızı sağlamayı hedeflemektedir. Makro baz istasyonları, kullanıcı sayılarının anlık arttığı veya doğal afet gibi olağandışı durumlarda haberleşme ihtiyacını karşılayamayarak yetersiz kalabilmektedir. Bundan dolayı, dron hücreleri 5G'de heterojen ağlara dahil olacaktır. Bu hücreler ile yüksek kullanıcılı sahalarda servis kalitesi ve ağ kapasitesi arttırılabilecektir. Aynı frekans bandının dron baz istasyonu (DBS) dahil birden çok baz istasyonu tarafından kullanılması ve bu baz istasyonlarının birbirinin etkileşim alanı içerisinde bulunması girişim sorunlarını doğurmaktadır. Girişim sorunlarını engellemek için 3GPP tarafından önerilen yöntemlerden olan ortak iletim eşgüdümlü çoklu nokta tekniği (JT-CoMP) ile hücre kıyısında bulunan kullanıcılar için girişimin engellenmesi ve performans arttırımı amaçlanmaktadır.

Dronların hareket yetenekleri sayesinde bu araçların gezgin (taşınabilen) baz istasyonları olarak servis sağlaması yaygınlaşmaktadır. Doğal afetlerden sonra devre dışı kalabilen sabit baz istasyonlarının yerine servis devamlılığını sağlayabilmek için kullanım alanları mevcuttur. Dron sistemlerinin haberleşme alanının yanında askeri, özel ve ticari kullanım alanları da bulunmaktadır. İçerisinde birden çok dron barındıran çoklu dron şebekeleri daha verimli, kullanışlı ve güvenilirdir. Şebekede bozulan veya zarar gören bir dronun yerine diğer dronlar servis sunabilir. DBS'nin en uygun performansta servis verebilmesi için uçma yüksekliği, kullanıcı cihazlarına (UE) uzaklığı ve hareket algoritmalarını belirleyen çalışmalarda DBS'lerin etkili servis verebilmesi için üç boyutlu optimum konumlandırılması hem yükseklik hem de UE'ye uzaklık açısından incelenmiştir.

Tek bir DBS sınırlı sayıda kullanıcıya servis verebilir. Daha fazla UE'ye servis verebilmek için birden çok DBS aynı anda uçurulmaktadır. DBS'ler birbirlerinin kapsama alanına girdiklerinde girişim sorunları oluşmaktadır. 3GPP tarafından girişim sorunlarının çözülmesi amacıyla girişim engelleme teknikleri önerilmiştir. Hücrelerarası girişim eşgüdümü tekniği (ICIC), hücre içi ve hücre dışı kullanıcılarına farklı frekans alt bantlarını tahsis ederek girişimi engellemeyi hedefler. Geliştirilmiş hücrelerarası girişim eşgüdümü tekniğinde (eICIC), neredeyse boş alt zaman dilimlerinde hücreler veri içeren işaret göndermez, bu dilimlerde komşu hücrenin kullanıcıya işaret göndermesine imkan tanır. Daha fazla geliştirilmiş hücrelerarası girişim eşgüdümü tekniğinde (feICIC) ise gücü azaltılmış alt dilimler sayesinde hücre kıyılarında bulunan UE'ler girişimden etkilenmezler. Önerilen girişim engelleme tekniklerinden sonuncusu olan eşgüdümlü çoklu nokta (CoMP) tekniğinde, UE'nin işaretini yakaladığı baz istasyonlarından aynı frekansta servis alınabilmesi mümkündür. Bu şekilde girişime sebep olan işaret, anlamlı ve kullanılabilir işarete çevrilir. İşaret-girişim-gürültü-oranı (SINR), girişime sebep olan sinyalin azalması sayesinde artar.

CoMP metodunun amacı girişim sorununu engellemek ve girişime sebep olan işaretten faydalanarak bu işareti kullanmaktır. CoMP tekniğinde UE, işaret aldığı istasyonların her birinden aynı anda ve aynı frekansta servis alır. Veri paketlerinin farklı noktalardan gönderilmesinden dolayı eş zamanlama konusu çok önemlidir. Eş zamanlamayı kaybeden noktalar CoMP metodunun çalışmamasına ve iletilen verinin anlamını yitirmesine sebep olabilir.

Baz istasyonları kendi aralarında gönderilen paketlerin eş güdümünü sağlamak amacıyla haberleşirler. Bu haberleşme, taşıma kaynak kullanımının artmasına sebep olur. Taşıma işaretleşmesi için yüksek kaynak kullanım ihtiyacı, CoMP metodunun sadece belirli hücrelerde ve belirli kullanıcılar için yapılması zorunluluğunu doğurmuştur. CoMP yöntemi kaynak yetmeyeceği ve bazı kullanıcılara faydası olmayacağı için hücre içerisinde bulunan tüm kullanıcılara uygulanamaz, genellikle hücre kıyısı kullanıcıları için uygulanır. Kısıtlı kaynaklar dolayısıyla kullanıcılar, belirli durumlara göre kümelendirilerek CoMP yapanlar ve yapmayanlar olarak ayrıştırılabilir. Bu çalışmada CoMP yapan kullanıcıları belirleme yöntemi, UE'nin iletim noktalarından aldığı işaret güçlerinin farkına göre seçilmiştir. İletim noktalarından alınan işaretlerin güçleri ardışık sıralanır. Güç farkı seviyesi belli bir eşik değerin altında ise kullanıcıların noktalara olan mesafesi yakındır ve bu durumdaki kullanıcılar CoMP yapan kullanıcılar kümesi olarak belirlenir. Ayrıca, güç farkı seviyesi eşik değerin altında olan kullanıcıların hücre kıyısında olduğu anlaşılmaktadır.

Literatürdeki mevcut çalışmalarda CoMP modelinin DBS'ler tarafından kullanılmasını analiz eden bir çalışma bulunmamaktadır.

Bu tezde, içerisinde dron hücreleri barındıran bir şebekede görüş çizgisi (LoS) modeli ile yol kayıpları hesaplanmıştır. CoMP tekniği kullanılarak hücre kıyısı kullanıcıları için performans arttırımı amaçlanmış ve bu yöntemden yararlanmak için alınan işaret gücü temelli bir yapı önerilmiştir. DBS'lerin JT-CoMP tekniğiyle işaret girişiminin engellenip kullanıcıya sunulan performansın arttırılması amaçlanmıştır. DBS'lerin kullanıcının doğrudan görüş hizasında bulunmasının avantajıyla LoS olasılığına bağlı hesaplanan bir yol kaybı modeli kullanılmıştır. Havadan zemine kanal modeli (air-to-ground), karasal modellerden farklılık göstermektedir. Havadan zemine yol kaybını hesaplarken LoS olasılığı önem taşımaktadır. Dron hücresinin havada bulunmasından dolayı LoS bağlantısı şansı, karasal modellere göre daha yüksektir. Yol kaybı, LoS olasığı ile hesaplanarak UE'lerin alınan güç değerleri hesaplanmıştır. CoMP kümeleri alınan güç temelli kümelendirme metodunda farkların belli eşik değerden düşük olmasına göre oluşturulmuştur.

Benzetimlerde UE'ler belli bir alan içerisine Poisson nokta süreci uygulanarak dağıtılmıştır. Merkezde birbirlerine belli mesafede ve birbirlerinin kapsama alanında hareketsiz duran iki DBS'den, kullanıcı cihazlarının alınan güçleri hesaplanmıştır. Farklı iletim noktalarından alınan güçlerin seviye farkına göre kullanıcılar CoMP uygulanılan veya uygulanılmayan kullanıcılar olarak kümelendirilmiştir.

Kullanıcıların CoMP uygulanılan ve CoMP uygulanılmadığı durumdaki performansları veri hacmi, yüzde beşinci spektral verim, kapsama alanı dışında kalma olasılıkları açısından karşılaştırılmıştır. Veri hacmi farkının ve yüzde beşinci spektral verimin, olasılık yoğunluk fonksiyonları (probability density function, PDF) ve birikimsel dağılım fonksiyonları (cumulative distribution function, CDF) incelenmiştir. CoMP yapılan durumlarda veri hacmi farkının ve spektral verimin arttığı gözlemlenmiştir. CoMP tekniğinin SINR değerini arttırması ile kapsama alanı dışında kalma olasılığının da azaldığı incelenmiştir.

1. INTRODUCTION

Drones are expected to be important components of 5G networks due to their mobility and ease of use on extraordinary occasions. Owing to their ability both to fly beyond LoS and to decrease the path loss, the role of DBSs in 5G is going to be essential. Through a DBS, it is possible to improve the coverage. Due to the high cost of covering rarely intense areas with terrestrial networks, it is an advantage for mobile network operators to use DBSs time to time when an area exceeds over a certain user amount.

Since a drone's power is not capable enough to carry powerful and heavy transmitters, multiple drones or drone swarms could be used at the same time to enhance the capacity of the drone network. Flying in their coverage area and operating in the same spectrum expose interference issues for cell-edge users. If the number of DBS and transmitting nodes used in a network gets higher, the number of cell-edge users affected by interference increases. To mitigate the interference, 3GPP has proposed various intercell interference mitigation methods including coordinated multipoint (CoMP) technique. While the method is preventing interference and exploiting it, it is going to be effective with the DBSs flying close to each other. CoMP tecnique has different variants and implementations. In joint transmission type of the CoMP technique, user equipments (UE) are enabled to receive service from different transmitting nodes at the same time simultaneously.

Providing service to the user equipment from different base stations (BS) requires resources because of the coordination needed between serving BSs. Since the spectrum sources are limited, the UEs should be clustered carefully if CoMP technique is applied to them. There are different clustering methods that optimize performance. In this thesis, we define a received power strength based joint transmission coordinated multi point (JT-CoMP) clustering algorithm special for drone networks. The UEs are clustered according to the difference of their power levels received from the connected multi points.

In Figure 1.1 the received powers by cell-edge users are sorted in a descending way. If the difference of the levels is over a certain treshold, the UE is supposed to be applied

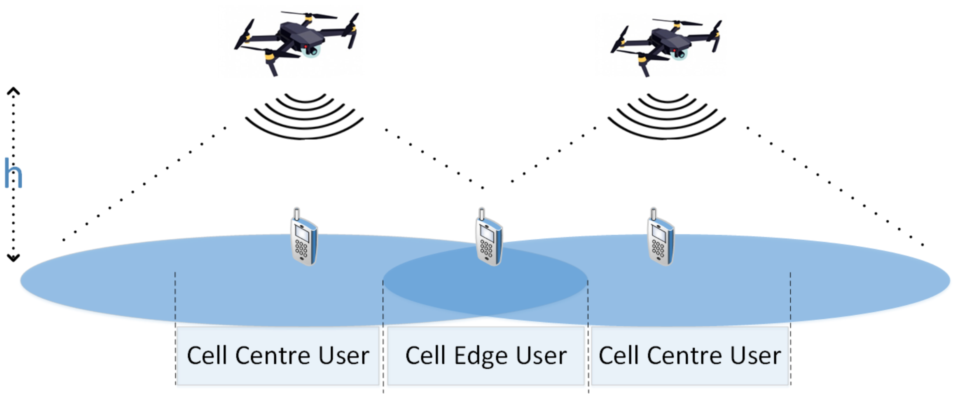

Figure 1.1 : Multi drone cell deployment

the CoMP technique by the DBSs. We aim to increase throughput, spectral efficiency and outage probability with JT-CoMP technique while mitigating interference. Since the drones are classified as low altitude flying platforms, LoS path loss model is used. Using the advantages of drones being beyond the LoS and CoMP technique mitigating the interference, performance improvements have been achieved.

1.1 Literature Review

Drone deployment in mobile networks becomes increasing thanks to its mobile feature and ability to fly beyond LoS. After natural disasters, drones can be served as BSs for ensuring service continuity if many network components are disabled or out of use [1], [2]. In crowded areas, they can also be used to assist the existing network. Besides, drone systems are mainly used for military, private and commercial purposes. Drone networks, consisting of multiple drones, are more reliable, effective and easy to use. If a single drone gets out of use in drone networks, other drones can continue to provide service [3].

There are many works that analyse flying height, distance to the UE and moving algorithms for the best service performance of DBS. In [4], three-dimensional positioning including height and distance to UE is analysed for the effective usage of DBS. Usage of several drones and the investigation of interference effect are named as future work [4]. In [5], three dimensional positioning of unmanned aerial vehicle base station (UAV-BS) is analysed regarding energy efficiency and covering maximum users with minimum required power. In [6], a location optimization algorithm for aerial BS is studied to get the minimum path loss for the users. The outage probabilities for

LoS and non-LoS is driven. In [7], an effective particle swarm optimization algorithm is offered to make use of both backhaul signaling between DBS and macro BS (MBS) and increased coverage area of drones.

Regarding the capacity of a single DBS, a limited number of UEs can be served. To increase the number of served UEs and expand the coverage area, multiple drones as drone swarm can be deployed. When DBSs fly in coverage areas of each other, interference problems may occur in the cell-edges of DBSs. In 1.1, the network model of multi drone cell deployment is illustrated where the coverage areas of two drone cells, cell-centre users and cell-edge users exposed to interference are demonstrated.

Although moving algorithms, backhaul signaling and capacity problems of DBS systems are discussed in [1]- [7], studies about CoMP technique for DBS networks are mainly ignored.

To mitigate the interference problems for the cell-edge users, several interference mitigation techniques are introduced by 3GPP including intercell interference coordination (ICIC) and coordinated multipoint (CoMP) [8]. In [9] further enhanced ICIC (feICIC) is optimized for spectral and energy efficiency in heterogeneous networks. Using range expansion and power reduced subframes, the trade-offs between energy efficiency and spectral efficiency are optimized. In [10], a genetic algorithm for positioning of UAV-BSs is presented utilizing feICIC parameters as the fitness function. The performance of reduced power subframes from feICIC is compared with the performance of almost blank subframes from eICIC. The interference between UAV-BS and terrestrial BSs are studied. In [11], eICIC and feICIC for the aerial and terrestrial networks are studied. For an aerial network, UAV-BSs are used with LoS probability based path loss model. It is concluded that feICIC returns better coverage probability and spectral efficiency than eICIC.

CoMP technique is introduced in Release 11 by 3GPP [12]. In this technique, UEs can receive service from the BS they are attached, as long as the connected BSs are coordinated with each other. For the cell-edge users and CoMP clusters, the signal causing interference is exploited. The necessity for the coordination of the points brings backhaul signaling load which reduces the service capacity of the system.

The BSs should be coordinated with each other and this communication among BSs requires allocated capacity from the existing bandwidth [13]. In a network, all UEs cannot function under CoMP mode. Due to the limited capacity for a specific bandwidth, the cluster of CoMP users should be decided carefully. In our work, the CoMP method is selected according to the received power level difference (PLD) from connected points.

The aim of the joint transmission CoMP (JT-CoMP) method is to exploit the interfering signal and convert it to a useful signal [13]. There are uplink and downlink types of JT-CoMP referring the way of data packages sent. In the downlink JT-CoMP method, UE receives service simultaneously at the same frequency from all coordinated points. It is highly important for the cells to be synchronised for backhaul signaling. Losing synchronization may cause the transmitted data packages to be meaningless. In [14], the authors studied α-fair function based CoMP clustering and resource scheduling in heterogenous ultra dense networks. A two-step joint clustering scheme is proposed to improve the average throughput in cell-edges. In [15], a dynamic and user-centric CoMP clustering method is offered. CoMP technique is applied to the users regarding their received PLD from different cells and the throughput gain is determined with varied PLD values. An expression for outage capacity in Rayleigh fading with a CoMP downlink transmission are proposed in [16]. In [17], goodput and outage probabilities are analysed for CoMP applied UEs that are active in heterogeneous ultra-dense networks. Summarizing, the application of CoMP technique to DBS networks is mainly neglected.

1.2 Problem Statement and Hypothesis

One of the main issues in 5G and beyond communication systems is providing enough coverage having low latency and high speed. To achieve the minimum coverage requirements everywhere with the existing terrestrial network is going to be impossible. Therefore, low altitude platforms (LAP) are going to be used in these networks. LAPs consisting of unmanned aerial vehicles (UAV) and drones may have operational difficulties related to flying time. The BS attached to the drone cannot be as large as a macrocell and can provide service to a limited number of UEs. The solution to these problems is flying of multi drone cells together and mitigating the interference with JT-CoMP. The method allows receiving service from each DBS at the same time and in the same spectrum. To summarize, the aim is to increase the capacity while using multiple drones together and applying JT-CoMP to exclude the interference.

1.3 Contributions

The motivation in this thesis is to analyze the benefits of CoMP method for drone cells within a given realistic network scenario. Our aim is to serve more user equipments using multiple drones and apply JT-CoMP between DBSs to mitigate the interference. We first analyse path loss model based on the LoS probability, then calculate the received powers for each UE and use PLD for CoMP clustering algorithm. While clustering the UEs for JT-CoMP, a user-centric dynamic clustering algorithm is developed. In this algorithm, the UEs are clustered according to their received power difference level from each DBSs. Through LoS probability and path loss model, the received powers are calculated and users are clustered as either a CoMP user or a non-CoMP user. We show that there is a significant improvement in the throughput and the 5th-percentile spectral efficiency (SE) under CoMP with drone cells. The outage probability of DBS systems is expressed as a function of the SINR threshold. This work also presents that there are lower outage probability rates for DBS systems with higher signal-to-interference-plus-noise ratio (SINR) under CoMP.

1.4 Thesis Organisation

The rest of the thesis is organised as follows. In the next section, we present a theoretical background for heterogeneous networks, interference mitigation techniques and a general overview of airborne communication networks. Afterwards, we provide the proposed system model and express PPP distribution for UEs, the LoS probability and the path loss. In Section 3, the CoMP clustering method based on PLDs and SINR for CoMP applied UEs are also defined. The throughput difference, the 5th-percentile SE and outage probability analyses are presented. In Section 4, we provide the simulation results with significant improvements under CoMP method. Finally, we conclude our work with the outcomes and future work as discussed in the Section 5.

2. THEORETICAL BACKGROUND

Increasing capacity needs let the operators use existing sources in an optimum way while enlarging it with new components. Since the bandwidth allocated for operators is a scarce source; it brings out the issue of solving interference problems in heterogeneous networks. In the first part of this chapter, a brief summary is presented about heterogeneous networks and interference mitigation techniques are explained. In the second part, drone networks, that is going to be an important part of 5G and beyond, are presented.

2.1 Heterogeneous Networks

The rapid development in communication technologies has brought different types of techniques and components to wireless networks. On each improvement, a new type of node is added to the network. A network consisting of macrocells and low power nodes is called heterogeneous network (HetNet) [18]. Some components of the network may have closed access to the public, yet they may transmit the signal in same bandwidth with open access networks. A simple demonstration of a HetNet is presented in Figure 2.1.

The components called differently according to the strength of radiated power. **Macrocells** are installed by mobile network operators (MNO) and transmit signal with

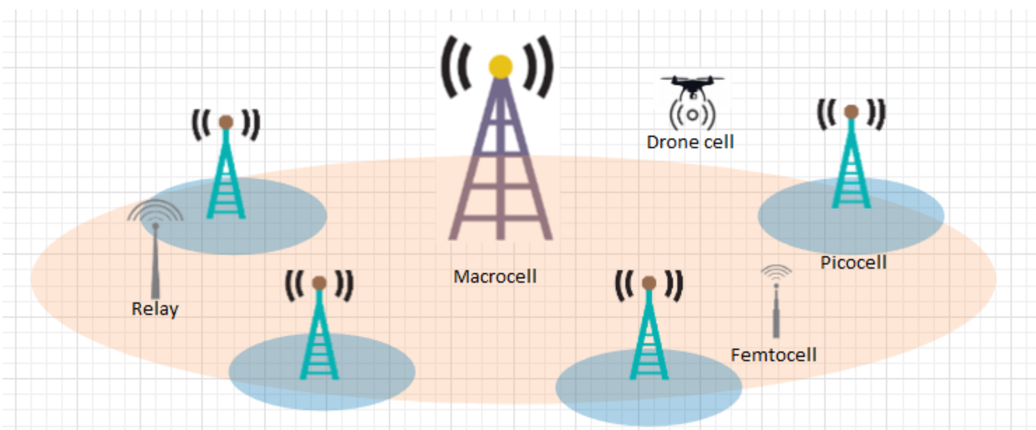

Figure 2.1 : An heterogeneous network consisting of different components.

46dBm. Their coverage area is a few kilometers. **Picocells** transmit a signal between 23dBm and 30 dBm and affects an area smaller than 300m.

To serve more UEs from a picocell, cell range extension (CRE) technique is used [19]. The CRE technique lets the UE get service from the picocell continuously. CRE has also the advantage of offloading UEs from a microcell to a picocell. It brings an additive bias value to the signal-to-interference-noise (SINR) ratio to the transmission of picocell. Therefore, the UE attaches to the picocell, although the strength of the signal transmitting from the microcell is higher. Macrocells and picocells are open to the use of public and have dedicated backhaul resource.

Femtocells are usually deployed in indoor locations like shopping malls or train stations. They can be installed by the operator and also by the users themselves. MNOs deploy relays to route data between a macrocell and UEs. A remote radio head (**RRH**) is connected to the macrocell and takes part in distribution. The transmit power and summary of the features of different types of nodes are given in Table 2.1.

Deploying many macrocells and low power nodes is increasing the number of cell-edge areas. In a cell-edge area, the UE gets mainly multiple signals from different transmitting nodes. The signal from serving base station interferes with the one from a neighbour cell. Since the interference decreases the quality of services the UE gets, the deployment of base stations should be well deployed. For the very low latency requirements of 5G, the BS deployment models are shifted from traditional BS centric network to the user centric and small cell network models [20]. In Figure 2.2, the BS centric and UE centric deployment models can be seen.

In [21], a futuristic concept called converged cell-less communication network for heterogeneous networks in 5G is presented. In this concept, all the serving transmitting nodes are connected to a software defined network (SDN). SDN controllers manages

Table 2.1 : Components of heterogenous networks.

Types of nodes	Transmit power	Coverage	Backhaul	Installation
Macrocell	46 dBm	>1 km	S1 Interface	Operator installed
Picocell	23-30 dBm	<300m	X2 Interface	Operator installed
Drone cell	30 dBm	<300m	Wireless	Operator installed
Femtocell	<23 dBm	<50m	Internet IP	Operator/user installed
Relay	30 dBm	300m	Wireless	Operator installed
RRH	46 dBm	>1 km	Fiber	Operator installed

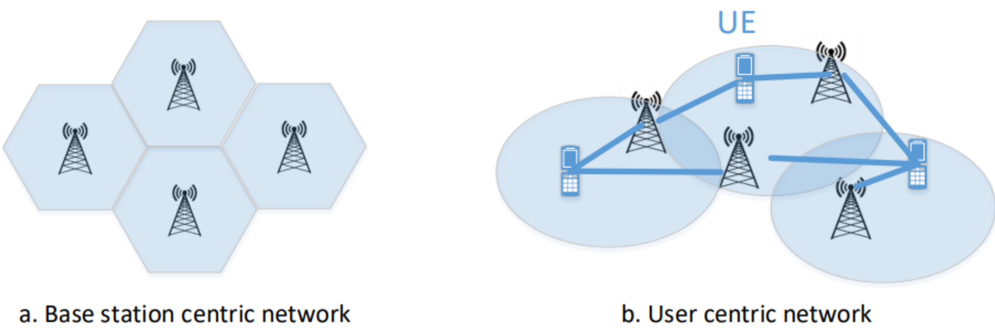

Figure 2.2 : Demonstration of network deployment models:
a) Base station centric network model, b) User centric network model

resource allocation and traffic scheduling. The aim of this concept is to reduce frequent handovers, improve the coverage and save the energy. Although the concept is promising, the complexity of SDN is a bottleneck. Since all the work of traffic scheduling and resource allocation works from each BS in HetNet is loaded to a centralized SDN, the reliability of the system is questionable.

2.2 Interference Mitigation

In order to provide high-quality performance in HetNets, it is extremely necessary to solve interference issues. If the different BSs are deployed in their coverage areas at the same frequency, interference occurs. Mostly, cell-edge users are effected from the interference. To mitigate interference, the deployment of transmitters should be well planned. There are certain reasons that are the root cause of interference as follows [22]:

- **Unplanned deployment:** MNOs usually plan and deploy the nodes very well. Due to geographical challenges, the planning could be extremely difficult. An uncalculated hill or a tall building may reduce coverage. Adding more nodes to extend the coverage creates interference in cell-edges. In some areas, user deployed transmitters radiate signal in the same band with the one that is deployed by the MNO. Since the operator does not control user deployed cells, network planning and optimization may become insufficient.

- **Closed subscriber group access:** Some networks may be operated only for a private group of users. The public access is not granted to these groups, however, the UEs in the coverage areas of these both networks may catch both signals or the serving signal interferes with the one of the open access networks.

- **Power Difference Between Nodes:** The power difference between nodes occurs in a topology, where macrocell and picocell (or a drone cell) are deployed in each other's coverage areas. Operators deploy picocells to offload and manage the traffic, decrease the load of the macrocells. In crowded areas, the intensity of the nodes is increased. Being in their each other's coverage areas at the same spectrum, creates interference.

- **Range Expanded Users:** Range expansion techniques are used to enlarge coverage area of the nodes to give better service in cell-edges. With expanded coverage, the signal may interfere with other signal radiating from another base station.

Interference mitigation will be a major challenge in 5G. Due to the increasing number of BSs in the network, the issue should be dealt with carefully. The 3rd Generation Partnership Project (3GPP) released many methods in order to reduce interference as illustrated in Figure 2.3. In Release 8, intercell interference coordination (ICIC) method has been proposed. In Release 10 the method is upgraded to enhanced ICIC (eICIC) and in Release 11 to further enhanced ICIC (FeICIC). In Release 11 there is also coordinated multipoint technique introduced and improved in Release 12.

2.2.1 Intercell interference coordination

The idea with basic ICIC is to partition existing resources and let the BSs use a different part of the bandwidth. At cell-edges, neighbour cells do not use same frequency band.

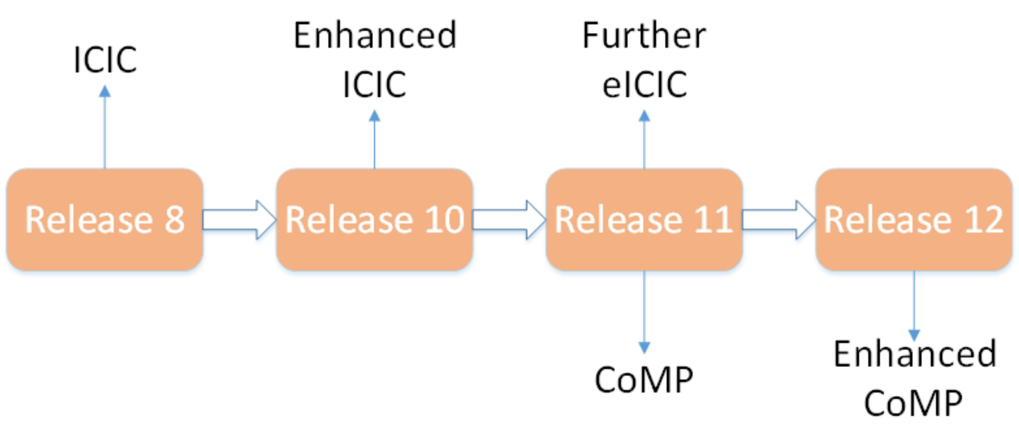

Figure 2.3 : Interference mitigation techniques in 3GPP releases.

There are well-known approaches to apply spectrum allocation under ICIC. **The fractional frequency reuse (FFR)** method allows the same subbands to cell-centre users and different subbands to cell-edge in neighbour cells. The problem with FFR is not using the whole available spectrum in the field. Since resources are not getting used, the capacity is reduced and in crowded areas, this may create capacity problems. **The soft frequency reuse (SFR)** lets the whole spectrum to be used in a single cell. It does not let any neighbour cell-edge to have the same frequency. In Figure 2.4, the FFR method in the hexagonal cell can be seen. The cell-center users have the subband f_1 in each cell. The other subbands f_2, f_3 and f_4 that are less than f, are distributed to the cell-edges as in Figure 2.4.

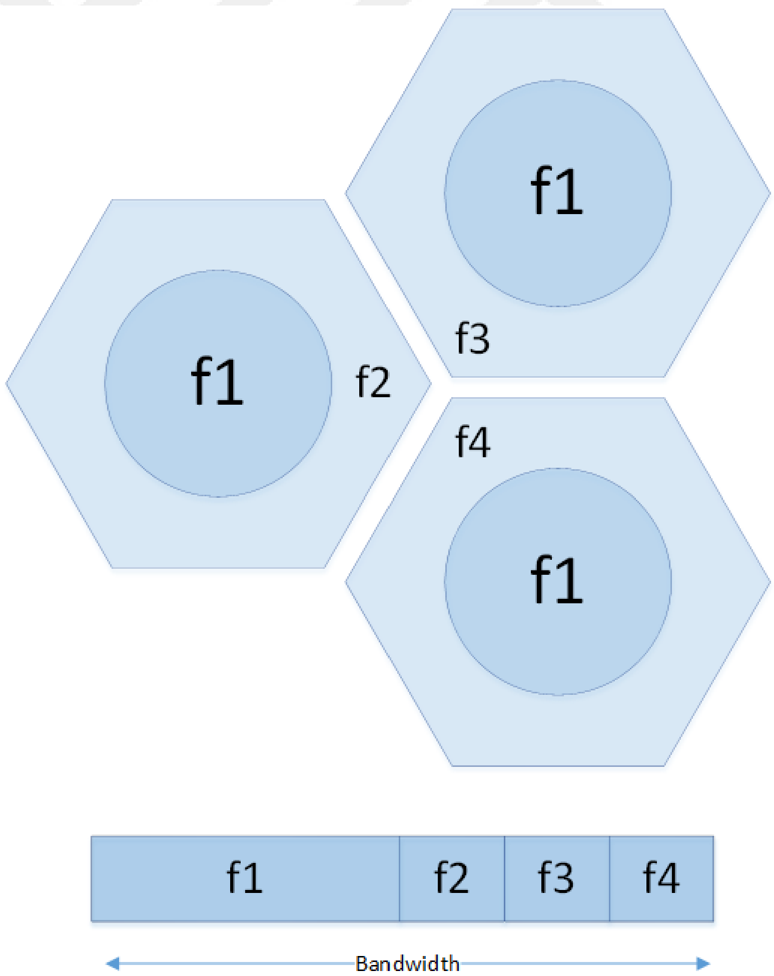

Figure 2.4 : Bandwidth usage with FFR technique in hexagonal cell deployments.

2.2.2 Enhanced ICIC

Enhanced intercell interference coordination (eICIC) techniques are presented in Release 10 [10]. There are three main types of this method: time domain, frequency domain and power control domain.

- **In time-domain** eICIC, resource scheduling is performed on the time domain. Subframes in time-domain are being aligned to the victim user. The subframes which do not contain control and data signals, but only contain reference signals, are called Almost blank subframes (ABSF). Once a victim macrocell user enters the transmitting area of small cell and gets effected by it, the ABSFs of the small cell can be scheduled for the macrocell user. Sharing of ABSFs can be on both ways. If subbands of macrocells have ABSFs, the small cells can transmit data in these frames. In Figure 2.5 the demonstration of ABSFs can be seen.
- **In the frequency domain** eICIC method, resource scheduling is planned on the frequency domain. Similar to ICIC, the frequency bands are scheduled differently. The allocation may change dynamically in case a victim user is detected.
- **In the power domain** eICIC method, reduced power subframes are used. It is also called further enhanced ICIC method in Release 11 [10]. In the cell-edges, the transmitting power of small cells is reduced by a factor α in some subframes.

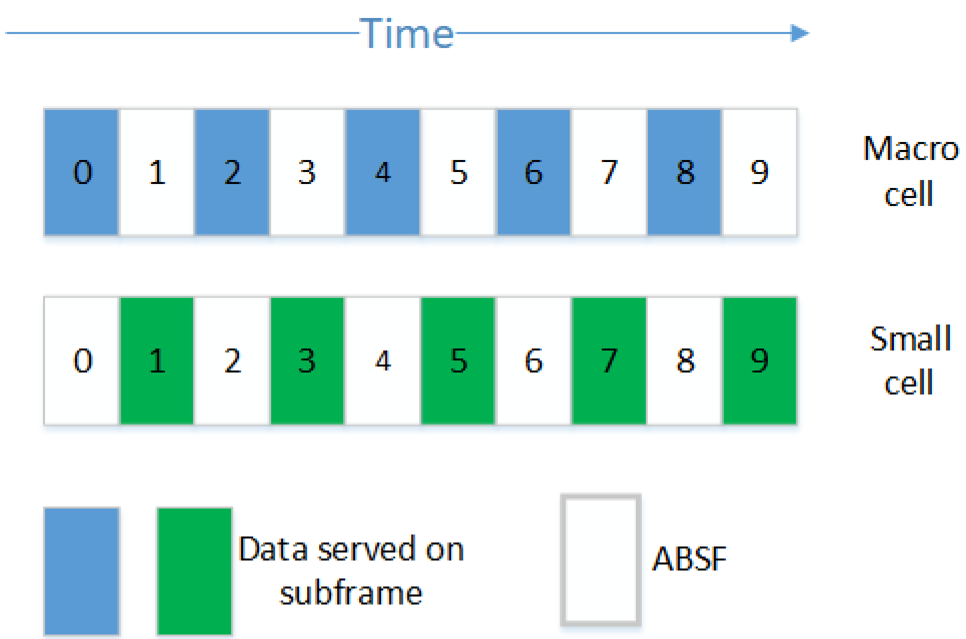

Figure 2.5 : Almost blank subframes in a macrocell and in a small cell.

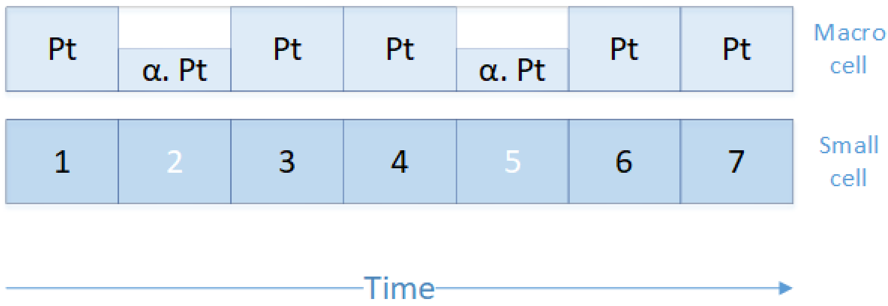

Figure 2.6 : Power reduced subframes in the macrocell with reduce factor α.

While small cell reduces power, the UE can receive service from the other cell without interference. In Figure 2.6, power reduced subframes are illustrated as 2. and 5. subframes.

2.2.3 Coordinated multipoint

The aim of the CoMP (JT-CoMP) method is to exploit the interfering signal and convert it to a useful signal. While exploiting interfering signal, the method aims to increase the performance of cell-edge users. In this case, a UE may be located in an area where it can receive multiple signals from different nodes. Without CoMP and ICIC methods, the signals are used to interfere with each other. Through the CoMP method, it is enabled to receive data over these signals at the same frequency and at the same time. The method has different implementations in downlink (DL) and uplink (UL) communications. In this thesis, our focus is mainly DL-CoMP schemes. There are three approaches in DL-CoMP method according to the transmission type:

- **Coordinated Beamforming or Coordinated Scheduling (CS/CB):** In this method the UE gets service only from the serving cell as if there is no CoMP. The aim of this type is the dynamic coordination of scheduling and beamforming activities between cells for the purpose of controlling interference.
- **Dynamic Point Selection (DPS):** The UE gets service by a single transmission node. However, the nodes are being changed in subframes dynamically according to their load and readiness. The UE is not being served at the same time by different nodes.
- **Joint Processing/Joint Transmission (JP/JT):** The UE is being served by different nodes simultaneously across cell sites. The multi-points should be very well

coordinated with each other. In order to achieve synchronization and coordination, there is a need for backhaul communication. In Figure 2.7, the transmission from both macrocells at the same time is illustrated.

For joint transmission, there are stringent backhaul transport requirements. In Release 11, it is decided that the backhaul transport is made through a direct fiber connection [12]. For **eCoMP** defined in Release 12, it is allowed to use non-ideal backhaul without the fiber [8]. For the UL CoMP technique, there are two approaches, which are explained as follows.

- **Joint Reception (JR):** In joint reception, the data sent from UE is received by different BSs in different sites. The BSs should be coordinated with each other after receiving data packages at the same time. This coordination requires large amount of capacity for the backhaul transport between BSs.
- **Coordinated Scheduling and Beamforming (CS/CB):** In this scheme, the coordination between BSs are scheduled to mitigate the interference. The data is received from only one point. For coordinated scheduling, lesser transport between BSs is required since only scheduling information needs to be transferred.

In Table 2.2, a brief summary and comparison of the features of interference mitigation methods are presented.

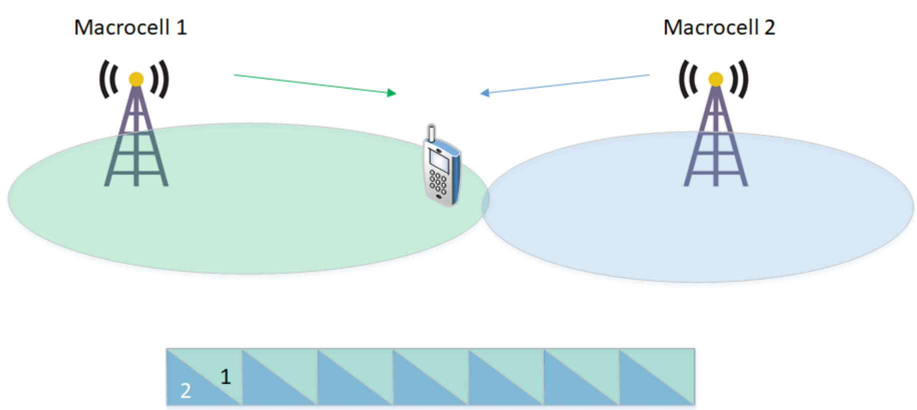

Figure 2.7 : Joint transmission in subframes: Both transmission points transmits in each subframe.

Table 2.2 : Feature summary of interference mitigation techniques

	ICIC	**eICIC**	**CoMP**	**eCoMP**
3GPP Release	Rel. 8	Rel. 10 for eICIC Rel. 11 for feICIC	Rel. 11	Rel.12
Operating in	Frequency domain	Time domain	Additionally spatial domain (antennas)	Additionally spatial domain (antennas)
Operating principle	According to channel quality indicator (CQI) feedback	Time-domain resource sharing	Multi-cell transmission and reception	Fast multi-cell coordination over non-ideal backhaul
Time syncronization between base stations	Not needed	Needed	Needed	Needed
Backhaul transport between cells	Not needed	Only control plane	High requirements for joint transmission	Low requirements

2.3 Airborne Communication Network Model

The coverage problem is getting more important with the increasing demand for low latency and high-speed data. In order to solve the coverage problem, an efficient way is to use aerial vehicles and satellites. As aerial vehicles, high altitude platforms (HAP), low altitude platforms (LAP), and drones can be used. A transmitter is being attached to the platforms to radiate signal for service to UE. Due to their ability to fly beyond LoS, the path loss is stringently low in comparison to terrestrial networks. The path loss of the signal transmitted from a DBS is presented in Section 3.3. Aircraft and balloons can be categorized as HAPs. They operate in the range of 17-22 km above the ground. Their advantage is the wide area coverage and rapid deployment. LAPs are more mobile than HAPs, and LAP category consists of UAV and drones. The size of UAVs are bigger and faster than drones and they can stay in the air longer due to their capacity to hold bigger batteries. Drones are flexible, more mobile, and can move as swarms. In Figure 2.8, an airborne network model including HAPs, UAV-BSs, DBSs are illustrated over a terrestrial network. In this illustration, the satellite, HAPs and LAPs are connected via satellite-HAP, inter-HAP, LAP-HAP, inter-LAP and drone

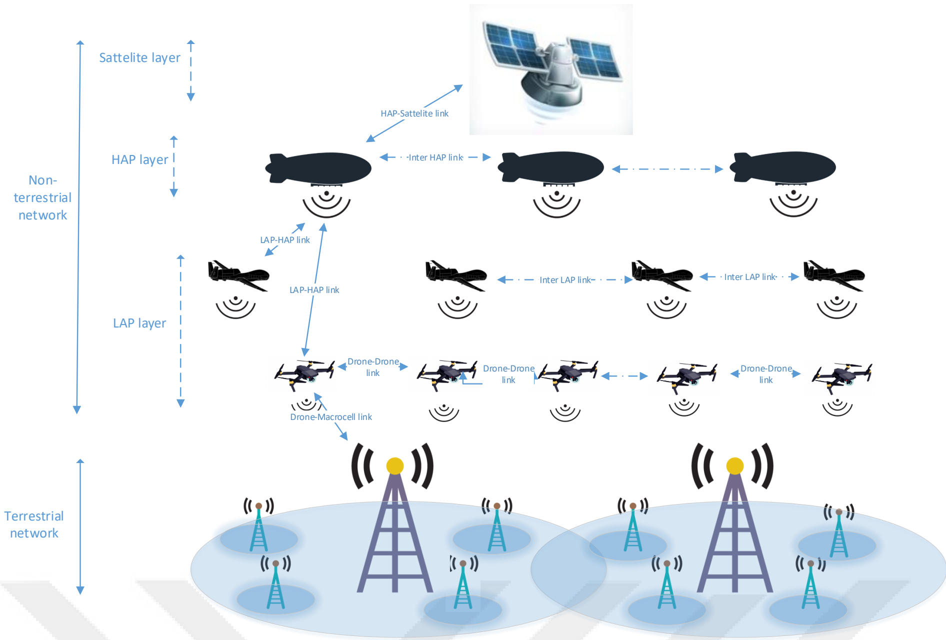

Figure 2.8 : An airborne communication network model containing a satellite layer, a HAP layer and a LAP layer.

to drone links. Over the links backhaul transfer is possible. Free space optical communication (FSO) is considered for the implementation of these links.

All components of the aerial network could be linked either to the satellite through free space optical communication or radio links. The UAV-BSs and DBSs should be connected to the terrestrial network, especially to macrocells. Since their connectivity cannot be achieved with fiber, they are connected through transmitters. In [23], a survey about all type of airborne communication components are studied. In Table 2.3, a brief summary of the features is presented.

Table 2.3 : Feature comparison of airborne network components

Performance	**Satellite**	**HAP**	**LAP (UAVs/Drones)**
Footprint	superiority	large	small
Overflight	superiority	restricted	restricted
Flexibility	slow	medium	rapid
Communication persistence	long	long	short
Propagation delay	long	short	short
Cost	high	medium	low

In our work, we assume that backhaul transport is made through a different band than the one that is used for the service to UEs. Although there are promising studies optimizing backhaul transport for the CoMP scheme [24], [25], in our work we seperate the operation of backhaul transport from the serving spectrum to preserve capacity.

3. SYSTEM MODEL

In this thesis, the network model of multi-drone cell deployment is introduced where two DBSs serving with CoMP method is considered. Drones fly stable and stationary without moving any direction. UEs are distributed with the Poisson point process (PPP) model in a field with the width and length of 2000m. PPP-based model is feasible for capturing real UE locations since there are various UE intensities in the process. We assume all DBSs have the same transmit power p^t_{in}. PPP intensity λ parameter can be varied to increase or decrease the number of UEs in our model. In Figure 3.1, PPP-distributed UEs and the DBSs are demonstrated.

3.1 Poisson Point Process Model for UE Distribution

Since UE locations have a direct effect on service quality, the UEs should be located as possible as they are in real life to achieve reliable results. The PPP model is commonly used to locate base stations and UEs in the simulations. There are three types of PPP categories including independent homogenous PPP, repulsive point process (RPS) and clustered point process [26]. Independent homogenous PPP distributes the points randomly. In RPS, the points push each other and create distance. In clustered PPP, the points push each other and create clusters. The models can be used according to the type of area criteria. For the shopping malls, concerts and areas where users gather together, clustered PPP is a more realistic approach. For a network where BSs should have distance between each other, RPP could be ideal. In our work, we assume that the user equipments in the network should be homogeneously distributed, therefore the random PPP has density, λ_u [27]. The density can be tuned in order to increase the number of UEs in the simulation area.

3.2 Line of Sight Probability

Air to ground path loss model differs from conventional terrestrial models than the aerial networks. Since aerial base stations (ABS) flies beyond the LoS, the path loss

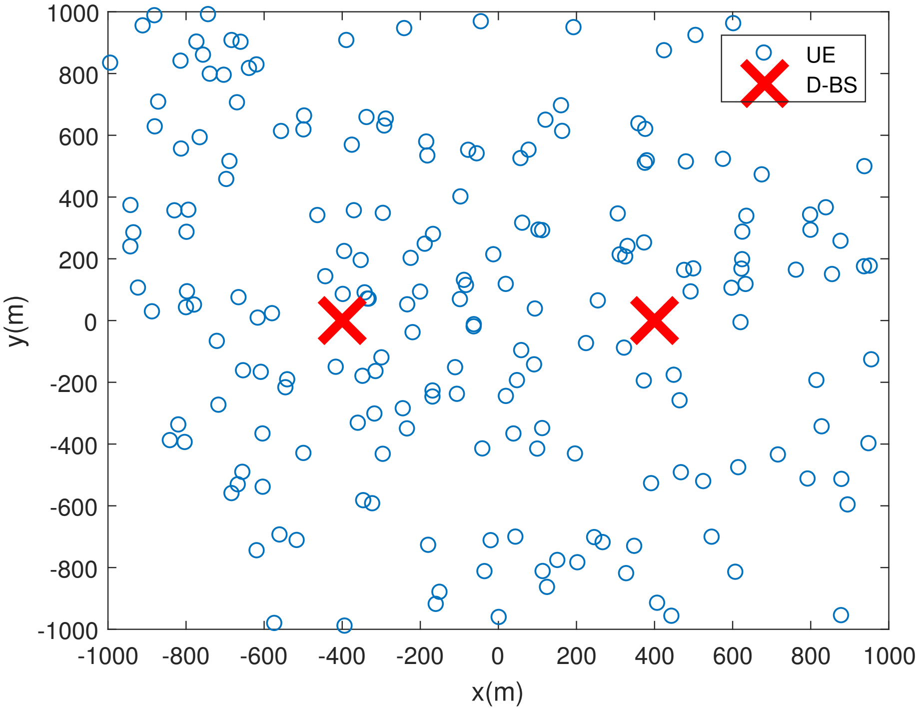

Figure 3.1 : UE distribution and DBS locations in the field

and the power received from ABSs should be calculated based on the LoS probability $P_{LoS}(r,h)$. The LoS probability depends on the UE's distance to LAP and the altitude of the LAPs as [28]

$$P_{LoS}(r,h) = \frac{1}{(1+a\exp(-b(\frac{180}{\pi}\arctan(\frac{h}{r})-a)))}, \tag{3.1}$$

where r is the distance between a UE and its DBS, h is the altitude, a and b are constant values (for rural areas $a=9.61$, $b=0.16$). Since the drones in UE's LoS and there are no obstacles between them, the path loss is expected to be lower. In Figure 3.2, the LoS probability in different altitudes is presented. It is seen that the LoS probability increases in higher altitudes.

3.3 Path Loss Model For Drone Networks

The path loss is calculated with its corresponding probability as given below:

$$\begin{aligned} PL(r,h) =& 20\log(\frac{4\pi f_c\sqrt{h^2+r^2}}{c}) + P_{LoS}(r,h)\eta_{LoS} \\ &+(1-P_{LoS}(r,h)) + \eta_{NLoS}, \end{aligned} \tag{3.2}$$

where f_c, c, η_{LoS} and η_{NLoS} represent frequency, speed of light, average additional losses for LoS and non-LoS, respectively. By changing the altitude of DBSs, the LoS

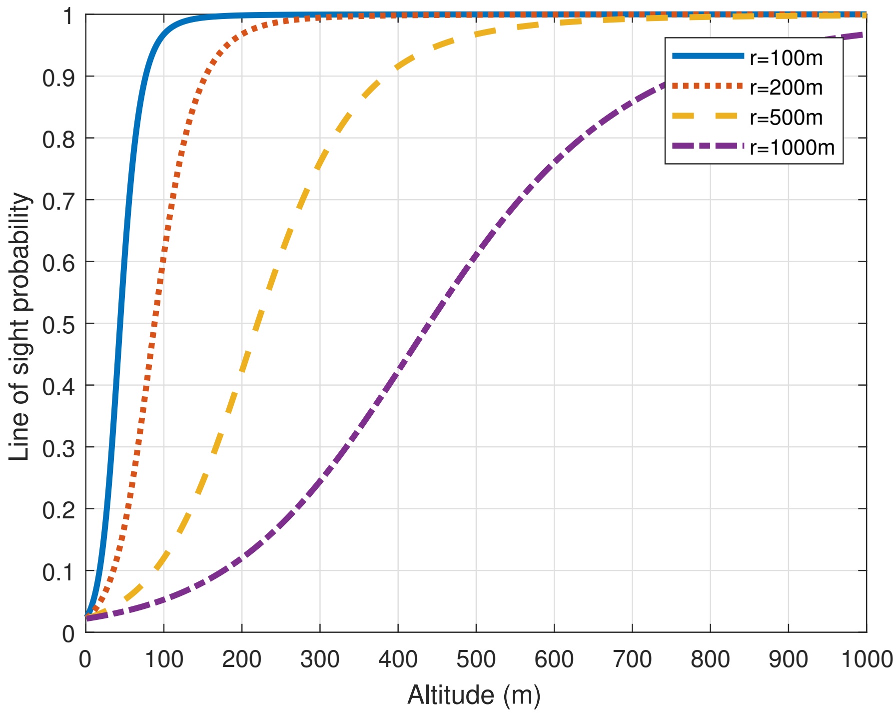

Figure 3.2 : Line-of-sight probability as a function of altitude.

probability also changes. In Figure 3.3, the path loss from different distances between UE and DBS with increasing altitude can be seen. In 900 MHz band, path loss takes its minimum value around 180 m altitude from any distance to DBS. Each curve falls until 180 m and then increases monotonically. In the distance of 500 m to the DBS, the path loss differs from 105 dB to 87 dB. The 18 dB difference shows that it is very crucial to position the DBSs in an optimum way since 18 dB can create a great advantage in the quality of services (QoS).

For the different operating frequencies, the path loss value also changes. In 3.4, the path loss from 200 m distance to the DBS is demonstrated for the different LTE frequency bands, i.e., 800 MHz, 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz. While the path loss is higher in high frequencies, the difference of path loss values between 800MHz and 2600 MHz is around 10 dB. In terrestrial networks, the operators use mainly 900 MHz band for their services in order to have lower path loss. Due to the limited capacity and drained resources in this band, higher bands can be used for DBS networks. Although the path loss is higher in these bands, there is still the advantage of flying below LoS ability of DBS systems against terrestrial networks.

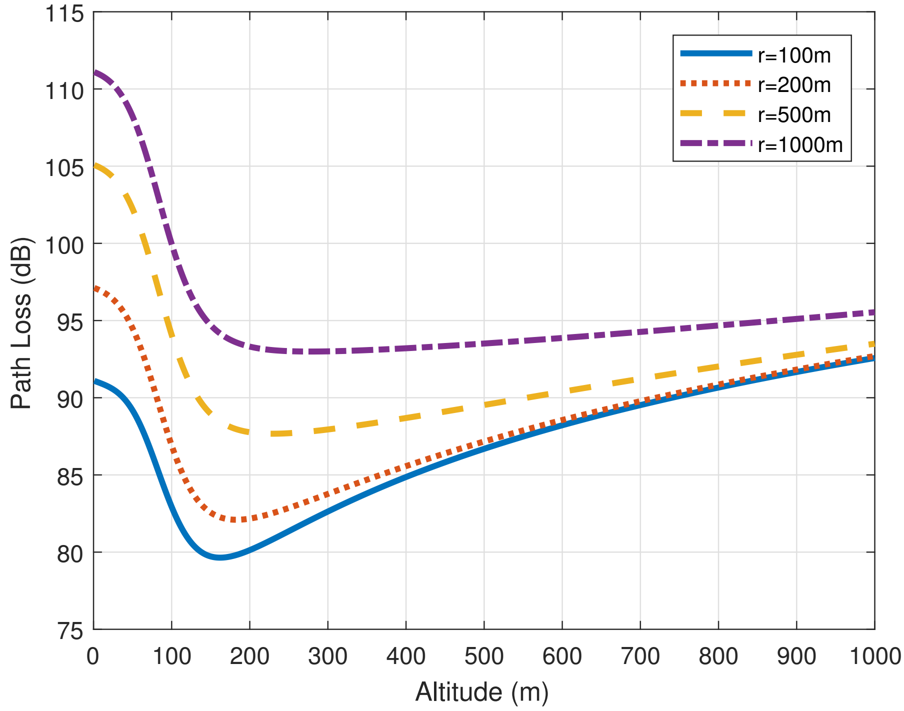

Figure 3.3 : Path loss as a function of altitude for different distances to DBS.

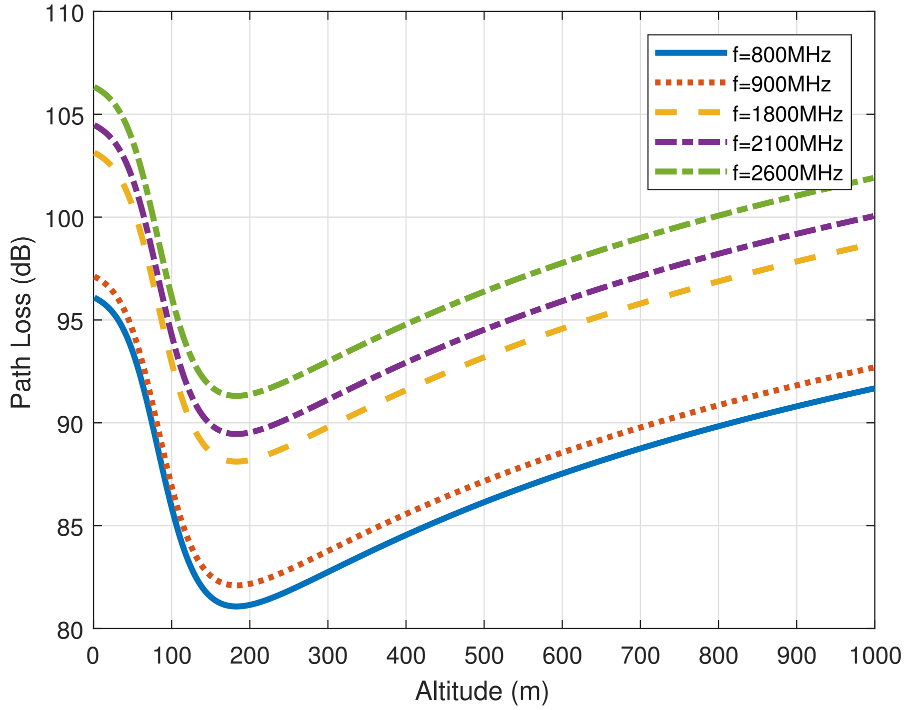

Figure 3.4 : Path loss as a function of altitude for different frequencies.

3.4 Reference Signal Received Power Calculations for DBSs

Reference signal received power (RSRP) value is assumed to be known by the UE and the serving BS. It is one of the parameters which is included in the decision of handover to the most convenient BS. In our work, it is also used to decide for CoMP clusters defined in Section 3.4.

RSRP is defined by subtraction of path loss that is determined with the LoS probability from the transmitting power from DBS as defined below:

$$p_{in}^{r}(dB) = p_{in}^{t}(dB) - PL(dB) \quad \textbf{(3.3)}$$

where p_{in}^{r} is the received power by UE from DBS and p_{in}^{t} is transmit power from DBS.

$$\begin{aligned} p_{in}^{r}(dB) =& p_{in}^{t}(dB) - 20\log(\frac{4\pi f_c \sqrt{h^2+r^2}}{c}) + P_{LoS}(r,h)\eta_{LoS} \\ &+ (1 - P_{LoS}(r,h)) + \eta_{NLoS}, \end{aligned} \quad \textbf{(3.4)}$$

where f_c, c, η_{LoS} and η_{NLoS} represent frequency, speed of light, average aditional losses for LoS and non-LoS, respectively.

$$\begin{aligned} p_{in}^{r}(dB) =& p_{in}^{t}(dB) - 20\log(\frac{4\pi f_c \sqrt{h^2+r^2}}{c}) + \frac{1}{(1 + a\exp(-b(\frac{180}{\pi}\arctan(\frac{h}{r}) - a)))}\eta_{LoS} \\ &+ (1 - \frac{1}{(1 + a\exp(-b(\frac{180}{\pi}\arctan(\frac{h}{r}) - a)))}) + \eta_{NLoS}. \end{aligned} \quad \textbf{(3.5)}$$

where f_c, c, η_{LoS} and η_{NLoS} represent frequency, speed of light, average aditional losses for LoS and non-LoS, respectively. The RSRP value depends on the height and distance of the UE to DBS. The f_c, c values and LoS constants a, b, η_{LoS} and η_{NLoS} are other factors that effects the path loss and change the RSRP value.

3.5 Signal to Interference Noise Ratio for CoMP-Applied UEs

CoMP technique exploits the interfering signal and uses it as a meaningful signal. Therefore, SINR (γ) is directly affected by the CoMP users. The interfering signal of other DBS normally is in the denominator and decreases the SINR. After the appliance of the CoMP to the UEs, the interference is removed. The interfering signal is used as a serving signal and it becomes a nominator term in the SINR equation. A general definition of SINR value for CoMP-applied and normal users is expressed as:

$$\gamma = \frac{\sum_{k \in C_N^i} p_{in}^{r}}{\sum_{m \in N/C_N^i} p_{in}^{r} + \sigma^2}, \quad \textbf{(3.6)}$$

where p^r_{in} is the received power from DBS, N is the DBS cluster in the network, C^i_N is the cluster of received powers from all DBSs for CoMP users and non-CoMP users and σ^2 is the noise level.

In a network consisting of two DBS, assuming there are no other actively interfering BS, simple definition of SINR for non-CoMP users is expressed as

$$\gamma_{NonCoMP} = \frac{p^r_{DBS1}}{p^r_{DBS2} + \sigma^2}, \tag{3.7}$$

where p^r_{DBS1} is the received power from the serving BS and p^r_{DBS2} is the received power from a neighbour cell that is interfering. With the appliance of CoMP, and using both DBSs as serving cell, the simple definition changes as

$$\gamma_{CoMP} = \frac{p^r_{DBS1} + p^r_{DBS2}}{\sigma^2}. \tag{3.8}$$

SINR value of CoMP users and non-CoMP users will be used through outage probability, spectral efficiency and throughput calculations in the following sections.

3.6 COMP Clustering Algorithm

CoMP technique should be applied to limited cells or a limited number of users due to the extensive traffic load of backhaul transmission. Therefore, the UEs should be clustered in an optimum way. There are static, dynamic or hybrid cluster types in networks that indicates if the cluster size and formation changes in case of network status change. The static clusters are easy to implement, however, the advantages of CoMP cannot always be applied with static clusters.

The dynamic cluster types are also categorized as network-based (i.e. network centric), user-based (i.e. user-centric), and hybrid clusters referring to how the users selected to cluster. In the user based clusters, the users are selected individually to the CoMP cluster. In network-based models, all users in the network together are allocated to the cluster. The hybrid model consists of network-based and user-based cluster types. In our model, we used the user base, a dynamic clustering algorithm that depends on RSRP difference from each cell.

To identify CoMP users, the RSRPs from different DBSs are sorted in descending order and the PLD is identified to decide whether it is under a threshold or above it. Being under the threshold means that the difference between all RSRP values from different cells small, the UE is near the cell-edge area, and is suitable for operating under the CoMP mode. If PLD exceeds the threshold, the user is allocated as a non-CoMP user. This relationship is expressed below as

$$\begin{array}{rl} \text{Non-CoMP user:} & \frac{p^r_{i1}}{p^r_{i2}} > \beta, \\ \text{CoMP user:} & \frac{p^r_{i1}}{p^r_{i2}} < \beta \ , \end{array} \quad \textbf{(3.9)}$$

where p^r_{i1} is the highest RSRP, p^r_{i2} is the second highest RSRP and β denotes the PLD threshold.

The capacity required for backhaul signalling is normally reserved from the fibre network in macrocells as defined in 3GPP Rel.11 [12]. For DBS systems, the backhaul signalling cannot be made through a fiber network due to mobility reasons. The backhaul transmission and drone-to-drone (D2D) communications should occur in the spectrum that may create complex capacity allocation problems. In this work, it is assumed that the backhaul signalling between DBSs is carried out in a different spectrum from the one that is used for the service to UEs.

3.7 Throughput Difference under CoMP

The throughput that a single UE gets, is calculated according to the truncated Shannon bound (TSB) model [29]:

$$R = \begin{cases} 0 & \gamma < \gamma_{min}, \\ \phi \ \log_2(1+\gamma) & \gamma_{min} < \gamma < \gamma_{max}, \\ \mathrm{R}_{max} & \gamma > \gamma_{max}, \end{cases} \quad \textbf{(3.10)}$$

where R is the throughput, γ_{min} is minimum SINR level that guarantees minimum service requirement for the UE, R_{max} is the maximum throughput, γ_{max} is the maximum SINR value that can reach maximum throughput R_{max}. TSB parameters are selected as $\gamma_{min} = 1.8$ dB, $\gamma_{max} = 21$ dB, $\phi = 0.65$ [29].

In order to analyze how the throughput increases under the CoMP technique, the throughput without CoMP technique is calculated and the difference between them is presented as

$$\Delta R = R_{CoMP} - R_{NonCoMP}, \quad \textbf{(3.11)}$$

where R_{CoMP} is the throughput of the UE under CoMP mode, $R_{NonCoMP}$ is the throughput of the non-CoMP UE.

3.8 The 5th-Percentile Spectral Efficiency for the UEs under CoMP

The 5th-percentile spectral efficiency (SE) is the 5% value of the cumulative distribution function (CDF) of the average user throughput. This value is used to measure the performance of cell-edge users and service quality. The minimum requirements of the International Telecommunication Union's (ITU) in 5G for the 5th-percentile SE is presented in Table 3.1 [30]

Considering Shannon's capacity formula, the spectral efficiency C_n of a single UE receiving service from DBS is given by

$$C_n = \frac{\log_2(1+\gamma)}{N}, \tag{3.12}$$

where γ is the SINR and N is the number of UEs. The same expression is used for a UE that is clustered either CoMP or non-CoMP, since SINR value differs in each circumstance.

3.9 Outage Probability for CoMP Users

The outage probability of the CoMP users is expected to be increased since the interference is mitigated and SINR value is increased. The SINR outage probability $P(\gamma(c_i^b))$ of a network that consists of CoMP users and non-CoMP users, is expressed as [14]

$$\begin{aligned} P\{\gamma(c_i^b) < \delta_{th}\} =& 1 - \sum_{b\in B_\Omega} c_i^b \Bigg(e^{-\frac{\Gamma\sigma_z^2}{P_b l_i^b}} \prod_{j\in B_\Omega \backslash b} \left(\frac{P_b l_i^b}{P_b l_i^b - P_j l_i^j}\right)^{c_i^j} \\ &\times \prod_{m\in B_\Omega} \left(\frac{P_b l_i^b}{P_m l_i^m \Gamma + P_b l_i^b}\right)^{1-c_i^m} \Bigg), \end{aligned} \tag{3.13}$$

Table 3.1 : Requirements for the 5th-percentile SE in 5G

Environment	Downlink (bit/s/Hz)	Uplink (bit/s/Hz)
Indoor hotspot	0.3	0.21
Dense urban	0.225	0.15
Rural	0.12	0.045

where B_Ω is the set of DBSs, c_i^b indicates whether DBS b provides service to the user i and $c_i^b \in \{0,1\}$. If the DBS provide service, then $c_i^b = 1$. If it is not able to provide service, then $c_i^b = 0$. δ_{th} is the minimum SINR value which is required to realize communications and l_i^b is the channel gain between DBSs. Rayleigh fading channel model is considered with Chi-squared distribution of order two and centered on l_b^i [14].

4. SIMULATION RESULTS

In the simulations, the RSRP values of PPP distributed UEs are calculated with regard to their path loss based on the LoS probability of DBS. The working mode of UEs if they function in CoMP mode or in non-CoMP mode is decided according to the PLD values. Monte Carlo simulations are repeated over 10000 times. SINR values of all UEs are calculated with respect to the CoMP technique. Simulation parameters are given in Table 4.1.

4.1 Numerical Results

In this section, the results from simulations are demonstrated. The performance gains in throughput, the 5th-percentile SE, and outage are analysed.

In Figure 4.1, the percentage of CoMP users and non-CoMP users regarding PLD values is shown. Increasing the PLD threshold means the difference between received powers is increasing. High PLD value means that the user is located close to the cell-center. The percentage of non-CoMP users decreases on the contrary. In low PLD value, CoMP user percentage is close to zero. With the increasing PLD value, the number of CoMP users in the network also increases. When the PLD value gets higher, CoMP has applied also to cell-center users. After 13 dB, all users in the network are expected to function under CoMP. For fairness and resource efficiency, PLD value should be chosen carefully for each network.

Table 4.1 : Simulation parameters

Parameter	Value
Line of sight constants (rural) (a, b, η_{LoS}, η_{NLoS})	$\{9.61, 0.16, 1, 20\}$
Repetitions	100000
Transmition power (p^t_{in})	30 dBm
Number of UEs	200
Noise level	-174 dBm
Frequency (f_c)	900 MHz
Simulation area	2000 m^2
UE density	50 UEs/km

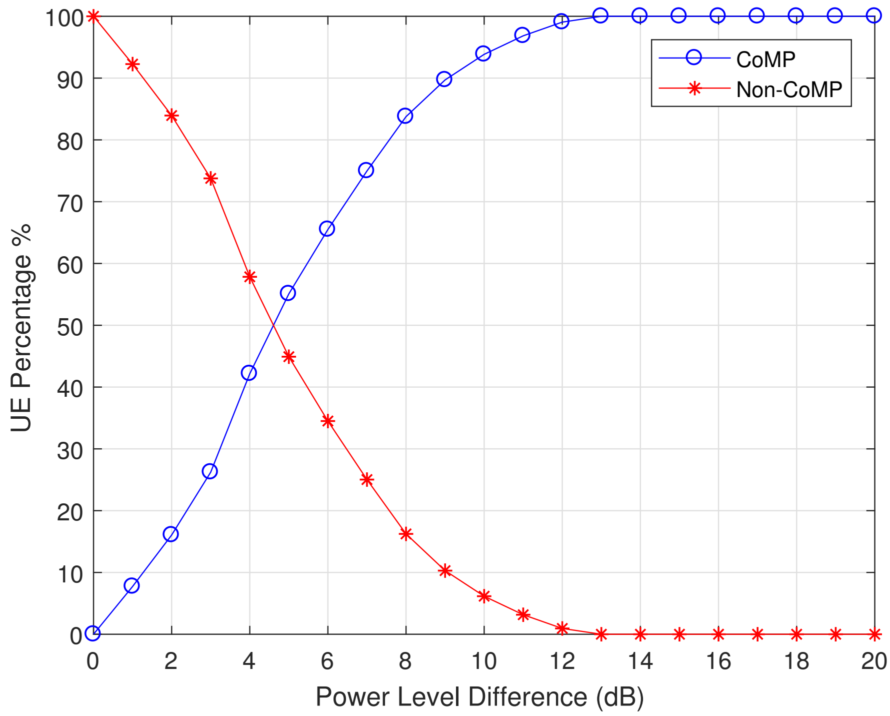

Figure 4.1 : CoMP and non-CoMP users in different PLDs

In Figure 4.2, the probability density function of throughput difference between between CoMP mode and non-CoMP mode is presented. At 3 dB PLD value, the PDF is 33% higher at 2.5 bps/Hz than the PLD at 6 dB. In higher PLD values the PDF gets smaller. In previous section, it is presented that higher PLDs let the number of cell-edge users get increasing. The gain in throughput varies from 0 bps/Hz until 4.5 bps/Hz with 3 dB PLD value and from -1 bps/Hz until 5.8 bps/Hz with 6 dB PLD value.

In Figure 4.3 the CDF of throughput difference between CoMP mode and non-CoMP mode is presented. The CDF is demonstrated from PDF in Figure 4.2. The clustering method for the CoMP is defined based on the received PLD. The CDF is presented with two types of PLD values.

When the threshold is increased, the percentage of CoMP users also increases with the result of a slight decrease in the throughput difference. As a result, it is clearly seen that the CoMP technique is effective on increasing throughput received by the UE.

The PDF of the 5th-percentile SE is presented in Figure 4.4. After this value, the PDF of SE for non-CoMP users gets higher. The 5th-percentile spectral efficiency differs from $5.7x10^-3$ bps/Hz to 9.5 bps/Hz when CoMP applied to users. This result is

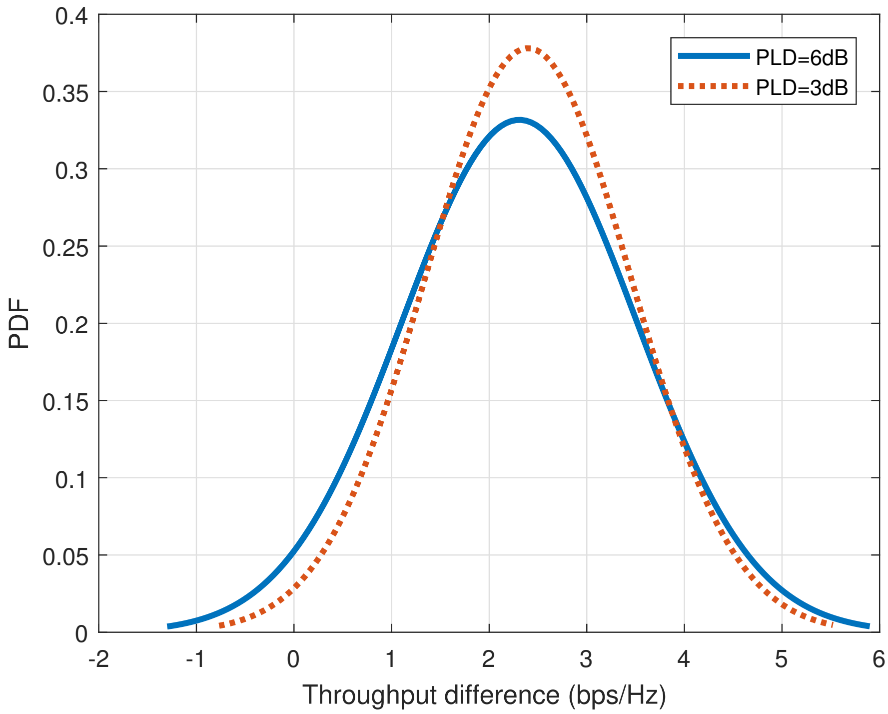

Figure 4.2 : The PDF of throughput difference with different PLDs.

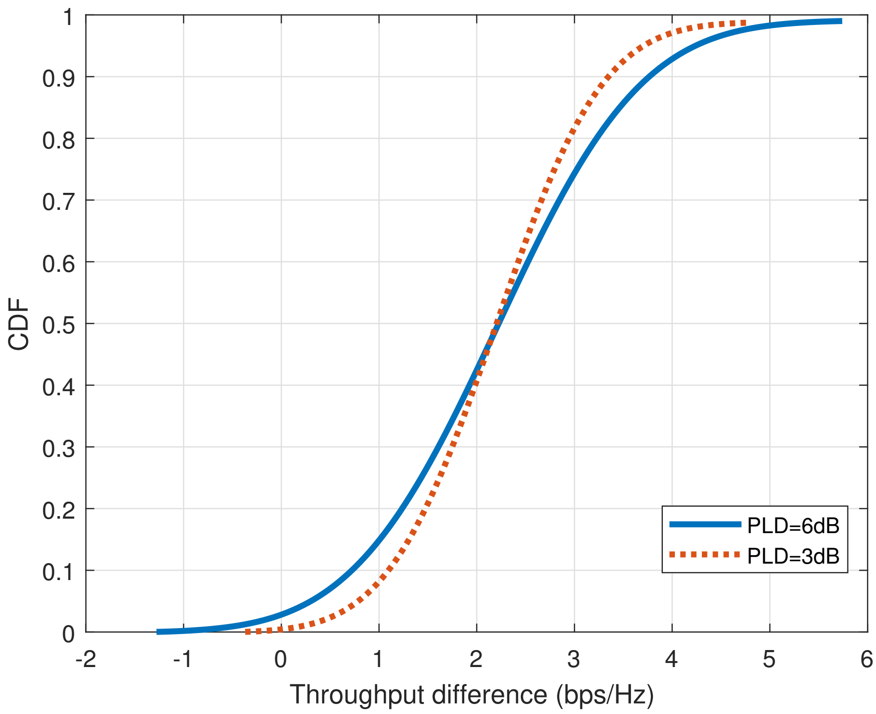

Figure 4.3 : The CDF of throughput difference with different PLDs.

above minimum required 5th-percentile efficiency in 5G [30]. The reason of this is the advantage of flying beyond LoS and increased SINR through CoMP technique.

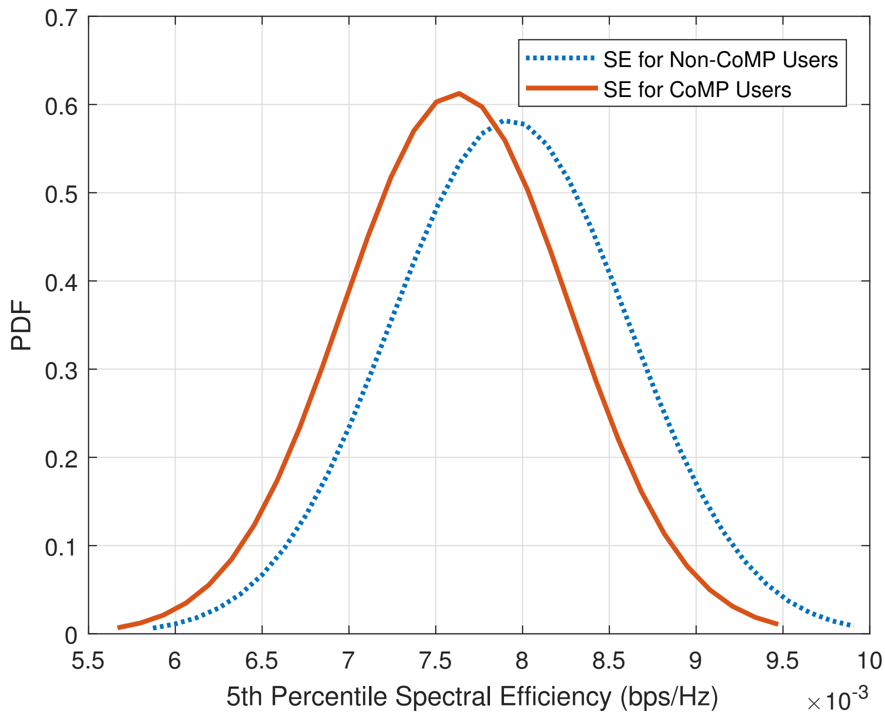

Figure 4.4 : The PDF of 5th-percentile SE

In Figure 4.5, the CDF of the 5th-percentile SE is shown for CoMP and non-CoMP users. In general, the SE for the UEs under CoMP is higher than that of the non-CoMP since the interference power is mitigated and exploited under CoMP. Therefore, the UEs have higher SINR value that results in higher SE for CoMP users.

In Figure 4.6, outage probability is demonstrated as a function of SINR threshold. The outage probability depends on the minimum value that needs to be provided for reliable communications. It is seen that under CoMP, the outage probability is lower than under non-CoMP case. At 1 dB SINR threshold, the outage probability is 50% higher under non-CoMP due to the interfering signal power. For high threshold values, the gap between the outage probabilities gets smaller, since CoMP method loses its efficiency in higher thresholds.

4.2 Conclusion Remarks

In this section, the simulation results of the performance CoMP applied to UEs are evaluated via numerical results. Since a received power clustering algorithm is used, the UE percentages in CoMP clusters are determined. With higher PLD values, the cluster for CoMP method increases. The advantage of CoMP is seen through exploited

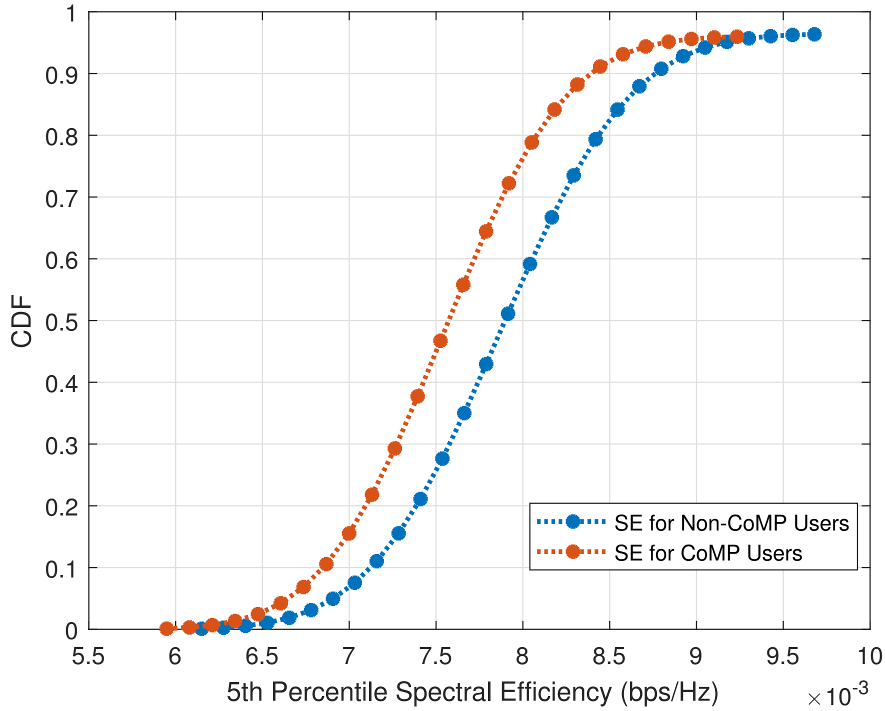

Figure 4.5 : The CDF of 5th-percentile SE

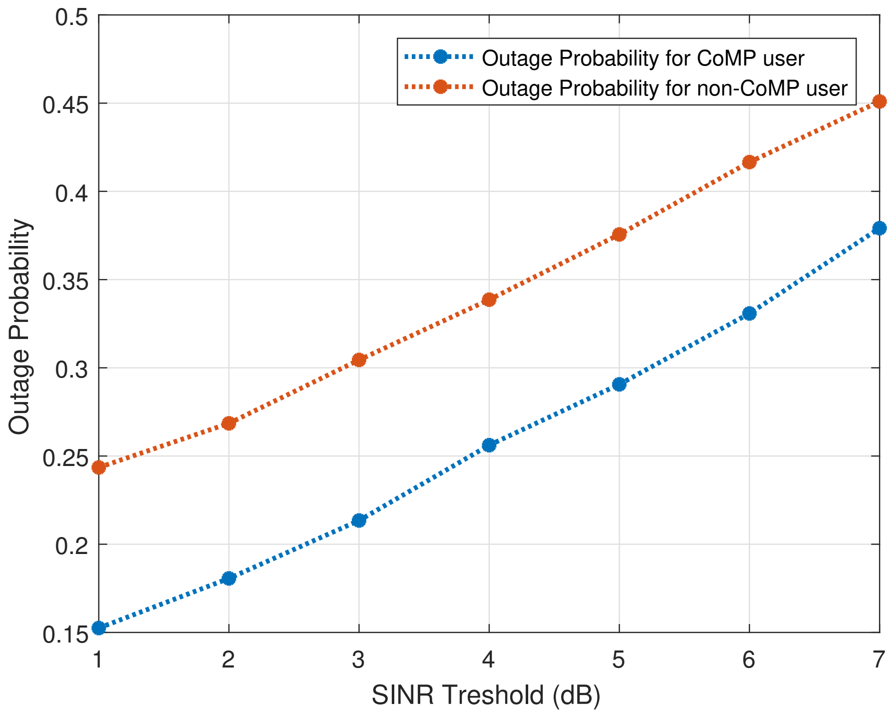

Figure 4.6 : Outage Probability of DBSs

interference and increased SINR. Increasing SINR value effects to the throughput, increases it up to 5.8 bps/Hz under 6dB PLD value. It is demonstrated that the 5th-percentile SE is above minimum reqirements of 5G when CoMP applied and DBSs are used. Furthermore, it is presented that the SINR outage probability is 50% lower at 1 dB SINR treshold under CoMP technique. The performance gains are stemmed from the ability of flying beyond line of sight, accordingly decreased path loss for DBSs and CoMP technique.

5. CONCLUSION

In this thesis, we showe that the JT-CoMP technique is significantly effective for interference mitigation in networks consisted of multiple drone base stations. Among the interference mitigation techniques, CoMP method is convenient for drone swarms.

For that purpose, we utilize LoS probability in different heights and altitudes to calculate optimum positioning. A path loss model derived from LoS probability is presented. The UEs are clustered based on a user-centric, dynamic clustering model for CoMP. The received PLD from all transmitting nodes are sorted in a descending order and the difference of sequent received powers are evaluated if they are over a threshold. In simulations, the UEs are distributed with a PPP.

Through Monte Carlo simulations, it is demonstrated that the percentage of CoMP users is increasing with higher PLD values. Increasing PLD value is expanding cell-edge area and therefore rising the amount of CoMP applied users. SINR value of a single UE changes when it is served under the CoMP mode. Due to exploited interference, the value gets higher if CoMP is applied. Based on the SINR value, throughput, spectral efficiency and SINR outage probabilities are evaluated.

Accordingly, we show that the throughput difference of UEs are higher under CoMP in the DBS network. There are significant gains of throughput per user under CoMP mode that is going to increase data speed and decrease the latency. Furthermore, the 5th percentile SE of CoMP and Non-CoMP users are demonstrated, compared with ITU 5G requirements. Furthermore, we present that the outage probability is notably lower for CoMP users. It is also shown that by changing SINR threshold the outage probability increases and the difference between outage probabilities for CoMP and non-CoMP users get smaller in higher SINR threshold values.

Our main contribution to this thesis is the usage of JT-CoMP technique to DBS systems. While utilizing received PLD based CoMP clustering scheme, we present that there are effective gains in the throughput and the 5th percentile SE. The dependence of CoMP user percentage to the PLD value is demonstrated. This work also presents that SINR outage probability decreases for DBS systems under CoMP.

Future directions of this research may be creating a positioning algorithm for drone swarms regarding the benefits of the CoMP technique such as higher throughput, SE and lower outage probability from our work, and studying backhaul capacity and the usage of backhaul signalling in service spectrum, or incorporating free space optical communications for CoMP-applied moving drone networks.

REFERENCES

[1] **Merwaday, A.**, **Tuncer, A.**, **Kumbhar, A. and Guvenc, I.**, 2016. Improved Throughput Coverage in Natural Disasters: Unmanned Aerial Base Stations for Public-Safety Communications, *IEEE Vehicular Technology Magazine*, **11(4)**, 53–60.

[2] **Gupta, L.**, **Jain, R. and Vaszkun, G.**, 2016. Survey of Important Issues in UAV Communication Networks, *IEEE Communications Surveys Tutorials*, **18(2)**, 1123–1152.

[3] **Hayat, S.**, **Yanmaz, E. and Muzaffar, R.**, 2016. Survey on Unmanned Aerial Vehicle Networks for Civil Applications: A Communications Viewpoint, *IEEE Communications Surveys Tutorials*, **18(4)**, 2624–2661.

[4] **Bor-Yaliniz, R.I.**, **El-Keyi, A. and Yanikomeroglu, H.**, 2016. Efficient 3-D placement of an aerial base station in next generation cellular networks, 2016 IEEE International Conference on Communications (ICC), pp.1–5.

[5] **Alzenad, M.**, **El-Keyi, A.**, **Lagum, F. and Yanikomeroglu, H.**, 2017. 3-D Placement of an Unmanned Aerial Vehicle Base Station (UAV-BS) for Energy-Efficient Maximal Coverage, *IEEE Wireless Communications Letters*, **6(4)**, 434–437.

[6] **Helmy, M.**, **Baykaş, T. and Arslan, H.**, 2015. Optimization of aerial base station location in LAP for disaster situations, 2015 IEEE Conference on Standards for Communications and Networking (CSCN), pp.240–244.

[7] **Shi, W.**, **Li, J.**, **Xu, W.**, **Zhou, H.**, **Zhang, N.**, **Zhang, S. and Shen, X.**, 2018. Multiple Drone-Cell Deployment Analyses and Optimization in Drone Assisted Radio Access Networks, *IEEE Access*, **6**, 12518–12529.

[8] **Holma, H.**, **Toskala, A. and Reunanen, J.**, 2016. LTE Small Cell Optimization: 3GPP Evolution to Release 13, John Wiley & Sons Ltd.

[9] **Merwaday, A. and Güvenç, I.**, 2016. Optimisation of FeICIC for energy efficiency and spectrum efficiency in LTE-advanced HetNets, *Electronics Letters*, **52(11)**, 982–984.

[10] **Kumbhar, A.**, **Güvenç, I.**, **Singh, S. and Tuncer, A.**, 2018. Exploiting LTE-Advanced HetNets and FeICIC for UAV-Assisted Public Safety Communications, *IEEE Access*, **6**, 783–796.

[11] **Kumbhar, A.**, **Binol, H.**, **Guvenç, and Akkaya, K.**, 2019. Interference Coordination for Aerial and Terrestrial Nodes in Three-Tier LTE-Advanced HetNet, 2019 IEEE Radio and Wireless Symposium (RWS), pp.1–4.

[12] **3GPP**, 2013. Coordinated multi-point operation for LTE physical layer aspects, Technical Report.

[13] **Jungnickel, V.**, **Manolakis, K.**, **Zirwas, W.**, **Panzner, B.**, **Braun, V.**, **Lossow, M.**, **Sternad, M.**, **Apelfrojd, R. and Svensson, T.**, 2014. The role of small cells, coordinated multipoint, and massive MIMO in 5G, *IEEE Communications Magazine*, **52(5)**, 44–51.

[14] **Liu, L.**, **Zhou, Y.**, **Garcia, V.**, **Tian, L. and Shi, J.**, 2018. Load Aware Joint CoMP Clustering and Inter-Cell Resource Scheduling in Heterogeneous Ultra Dense Cellular Networks, *IEEE Transactions on Vehicular Technology*, **67(3)**, 2741–2755.

[15] **Shami, T.M.**, **Grace, D.**, **Burr, A. and Zakaria, M.D.**, 2018. Radio Resource Management for User-Centric JT-CoMP, 2018 15th International Symposium on Wireless Communication Systems (ISWCS), pp.1–5.

[16] **Garcia, V.**, **Lebedev, N. and Gorce, J.**, 2011. Capacity Outage Probability for Multi-Cell Processing Under Rayleigh Fading, *IEEE Communications Letters*, **15(8)**, 801–803.

[17] **Garcia, V.**, **Zhou, Y. and Shi, J.**, 2014. Coordinated Multipoint Transmission in Dense Cellular Networks With User-Centric Adaptive Clustering, *IEEE Transactions on Wireless Communications*, **13(8)**, 4297–4308.

[18] **Damnjanovic, A.**, **Montojo, J.**, **Wei, Y.**, **Ji, T.**, **Luo, T.**, **Vajapeyam, M.**, **Yoo, T.**, **Song, O. and Malladi, D.**, 2011. A survey on 3GPP heterogeneous networks, *IEEE Wireless Communications*, **18(3)**, 10–21.

[19] **Ghosh, A.**, **Mangalvedhe, N.**, **Ratasuk, R.**, **Mondal, B.**, **Cudak, M.**, **Visotsky, E.**, **Thomas, T.A.**, **Andrews, J.G.**, **Xia, P.**, **Jo, H.S.**, **Dhillon, H.S. and Novlan, T.D.**, 2012. Heterogeneous cellular networks: From theory to practice, *IEEE Communications Magazine*, **50(6)**, 54–64.

[20] **Agiwal, M.**, **Roy, A. and Saxena, N.**, 2016. Next Generation 5G Wireless Networks: A Comprehensive Survey, *IEEE Communications Surveys Tutorials*, **18(3)**, 1617–1655.

[21] **Han, T.**, **Ge, X.**, **Wang, L.**, **Kwak, K.S.**, **Han, Y. and Liu, X.**, 2017. 5G Converged Cell-Less Communications in Smart Cities, *IEEE Communications Magazine*, **55(3)**, 44–50.

[22] **Lopez-Perez, D.**, **Guvenc, I.**, **de la Roche, G.**, **Kountouris, M.**, **Quek, T.Q.S. and Zhang, J.**, 2011. Enhanced intercell interference coordination challenges in heterogeneous networks, *IEEE Wireless Communications*, **18(3)**, 22–30.

[23] **Cao, X.**, **Yang, P.**, **Alzenad, M.**, **Xi, X.**, **Wu, D. and Yanikomeroglu, H.**, 2018. Airborne Communication Networks: A Survey, *IEEE Journal on Selected Areas in Communications*, **36(9)**, 1907–1926.

[24] **Zhao, J.**, **Quek, T.Q.S. and Lei, Z.**, 2013. Coordinated Multipoint Transmission with Limited Backhaul Data Transfer, *IEEE Transactions on Wireless Communications*, **12(6)**, 2762–2775.

[25] **Xia, P.**, **Liu, C. and Andrews, J.G.**, 2013. Downlink Coordinated Multi-Point with Overhead Modeling in Heterogeneous Cellular Networks, *IEEE Transactions on Wireless Communications*, **12(8)**, 4025–4037.

[26] **Lagum, F.**, 2018. Stochastic Geometry-Based Tools for Spatial Modeling and Planning of Future Cellular Networks: Opportunistic Cell Switch-off and Strategic Deployment of Flying Base Stations, Ph.D. thesis, Carleton University.

[27] **Turgut, E. and Gursoy, M.C.**, 2018. Outage Probability Analysis in D2D-Enabled mmWave Cellular Networks with Clustered Users, 2018 IEEE 88th Vehicular Technology Conference (VTC-Fall), pp.1–5.

[28] **Al-Hourani, A.**, **Kandeepan, S. and Lardner, S.**, 2014. Optimal LAP Altitude for Maximum Coverage, *IEEE Wireless Communications Letters*, **3(6)**, 569–572.

[29] **T.Jiang, A. Papadogiannis, A.G. and Burr, D.**, 2011. Bungee deliverable: D4. 1.1 interim simulation, Technical Report, University of York.

[30] **Mohyeldin, E.**, 2016. Minimum Technical Performance Requirements for IMT-2020 radio interface(s), Technical Report, ITU.

CURRICULUM VITAE

Name Surname: Serdar TORUN

Place and Date of Birth: Kadıköy, Istanbul, 12th August 1989

E-mail: torun15@itu.edu.tr

EDUCATION:

- **B.Sc.:** 2012, Karlsruhe Institute of Technology, Germany, Electrical Engineering and Information Technology

PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

- S. Torun, M.Basaran, L. Durak-Ata, 'Performance Analysis of Multi Drone Cell Deployment with JT-CoMP' in *27th Signal Processing and Communications Applications Conference (SIU)*, Sivas, Turkey, April 2019.