NON-ORTHOGONAL MULTIPLE ACCESS FOR CELLULAR-CONNECTED UNMANNED AERIAL VEHICLES

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DEDICATION

To my family;

New Ah Lek, How Mui Hiong, New Eugene, and New Siew Ching.

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ABSTRACT

Cellular-connected unmanned aerial vehicles (UAVs) have been introduced for 5th Generation (5G) and beyond cellular networks to enable various UAVs' operations which require real-time and ubiquitous connectivity. Existing solutions are relying on orthogonal multiple access (OMA) to support existing terrestrial users (TUs) and UAVs as new aerial users (AUs). However, OMA is unable to provide an efficient network performance because each orthogonal resource block can only be utilised by a single user. To address this limitation, non-orthogonal multiple access (NOMA) can be employed. NOMA enables AUs and TUs to share the same orthogonal resource block. By leveraging their downlink asymmetry, NOMA could efficiently serve the AUs and TUs. Nevertheless, concurrently serving the AUs and TUs in cellular networks introduces new challenges. Specifically, reverse successive interference cancellation (SIC) policy and inappropriate NOMA power allocation might occur if the AUs are moving in three dimensional space and perfect channel state information (CSI) is unavailable. These issues will result in spectral inefficiency and unreliable communications. Due to high altitude, AUs also suffer strong inter-cell interference (ICI) that causes the pairing of AUs and TUs in NOMA to be inefficient. Therefore, this thesis investigates the performance of NOMA which concurrently serves a mobile AU and a TU in the absence of perfect CSI. Results show that pairing a mobile AU and a TU is more beneficial than pairing TUs only. Furthermore, NOMA provides up to 99% rate of improvement and lower outage probability as compared to OMA. Performance analysis for AUs and TUs in multi-cell networks is also carried out by using stochastic geometry. The analysis highlights the effects of different network parameters and reveals that the network performance can be affected by user association, receiving antenna configuration and ICI mitigation technique. This thesis proposes and provides an important insight about an efficient combination of user association, transmitting and receiving strategies known as aerial-terrestrial network NOMA. The proposed scheme outperforms existing schemes up to 91% in terms of sum-rate and its analytical outage probability can be as low as the order of 10^{-17}. This thesis concludes that NOMA can efficiently serve the AUs and TUs in downlink cellular networks.

ABSTRAK

Pesawat tanpa pemandu (UAV) bersambung selular telah diperkenalkan untuk rangkaian generasi kelima (5G) dan seterusnya untuk membolehkan pelbagai operasi UAV yang memerlukan keterhubungan masa nyata dan di mana-mana pada masa yang sama. Penyelesaian kini bergantung pada capaian berbilang ortogon (OMA) untuk menyokong pengguna darat (TU) sedia ada dan UAV sebagai pengguna udara (AU) baru. Namun, OMA tidak dapat memberikan prestasi rangkaian yang cekap kerana setiap blok sumber ortogon hanya dapat diguna oleh satu pengguna. Untuk mengatasi pengehadan ini, capaian berbilang bukan ortogon (NOMA) dapat digunakan. NOMA dapat menyokong AU dan TU dengan blok sumber ortogon yang sama. Dengan memanfaatkan asimetri laluan menurun, NOMA dapat melayani AU dan TU dengan cekap. Walaupun begitu, AU dan TU yang disokong secara serentak dalam jaringan selular berdepan dengan cabaran yang baru. Khususnya, dasar pembatalan gangguan berturutan (SIC) balikan dan peruntukan kuasa NOMA yang tidak sesuai mungkin berlaku jika AU bergerak di dalam ruang tiga dimensi dan maklumat keadaan saluran sempurna (CSI) tidak ada. Isu-isu ini akan menyebabkan ketidakcekapan spektrum dan komunikasi yang tidak boleh dipercayai. Oleh kerana altitud tinggi, AU juga mengalami gangguan antara sel yang kuat (ICI) yang menyebabkan ketidakcekapan pasangan AU dan TU dalam NOMA. Lantaran, tesis ini menyiasat prestasi NOMA yang melayani AU bergerak dan TU secara serentak tanpa adanya CSI sempurna. Keputusan menunjukkan bahawa pasangan AU bergerak dan TU lebih bermanfaat daripada pasangan TU sahaja. Selanjutnya, NOMA memberikan kadar pembaikan sehingga 99% dan kebarangkalian keluaran yang lebih rendah berbanding OMA. Analisis prestasi untuk AU dan TU dalam rangkaian berbilang sel juga dilakukan dengan menggunakan geometri stokastik. Analisis ini menekankan pengaruh parameter rangkaian yang berbeza dan mendedahkan bahawa prestasi rangkaian dapat dipengaruhi oleh pertalian pengguna, konfigurasi antena penerima dan teknik pengurangan ICI. Tesis ini mengusulkan dan memberikan pandangan yang penting berkaitan gabungan pertalian pengguna, strategi penerimaan dan transmisi yang cekap dikenali sebagai rangkaian udara-daratan NOMA. Skim yang dicadangkan mengatasi skim yang sedia-ada sehingga 91% dari segi jumlah kadar dan kebarangkalian keluaran analisis serendah 10^{-17}. Tesis ini menyimpulkan bahawa NOMA dapat melayani AU dan TU dengan cekap dalam rangkaian selular laluan menurun.

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LIST OF ABBREVIATIONS

2D	–	Two Dimensional
3D	–	Three Dimensional
3GPP	–	3rd Generation Partnership Project
5G	–	5th Generation
a.k.a.	–	also known as
AWGN	–	Additive White Gaussian Noise
AT-NOMA	–	Aerial-Terrestrial Non-Orthogonal Multiple Access
AT-NOMA-PC	–	Aerial-Terrestrial Non-Orthogonal Multiple Access with Perfect Channel State Information
AT-NOMA-SC	–	Aerial-Terrestrial Non-Orthogonal Multiple Access with Statistical Channel State Information
ATN-NOMA	–	Aerial-Terrestrial Network Non-Orthogonal Multiple Access
ATN-NOMA-P	–	Aerial-Terrestrial Network Non-Orthogonal Multiple Access with Perfect Channel State Information
ATN-NOMA-S	–	Aerial-Terrestrial Network Non-Orthogonal Multiple Access with Statistical Channel State Information
AU	–	Aerial User
BS	–	Base Station
BVLOS	–	Beyond Visual Line-of-Sight
CB-NOMA	–	Coordinated Beamforming Non-Orthogonal Multiple Access
CS-NOMA	–	Coordinated Scheduling Non-Orthogonal Multiple Access
CSI	–	Channel State Information
C&C	–	Command and Control
CCDF	–	Complementary Cumulative Distribution Function

CDF	–	Cumulative Distribution Function
CoMP	–	Coordinated Multi-Point
e.g.	–	for example
FB-FNOMA	–	Fixed Beamwidth and Fixed Power Allocation Network Non-Orthogonal Multiple Access
FB-NOMA	–	Fixed Beamwidth and Optimal Power Allocation Network Non-Orthogonal Multiple Access
FB-OMA	–	Fixed Beamwidth Joint Transmission Coordinated Multi-Point Orthogonal Multiple Access
FDMA	–	Frequency-Division Multiple Access
i.e.	–	that is
i.i.d.	–	independent and identically distributed
ICI	–	Inter-Cell Interference
ICIC	–	Inter-Cell Interference Coordination
i.n.i.d.	–	independent non-identical distributed
IoT	–	Internet-of-Things
IRS	–	Intelligent Reflecting Surface
JT-NOMA	–	Joint Transmission Non-Orthogonal Multiple Access
LOS	–	Line-of-Sight
LTE	–	Long-Term Evolution
MRT	–	Maximum Ratio Transmission
MGF	–	Moment Generating Function
MIMO	–	Multiple-Input Multiple-Output
MUST	–	Multi-User Superposition Transmission
NOMA	–	Non-Orthogonal Multiple Access
NLOS	–	Non Line-of-Sight
NP-hard	–	Non-deterministic Polynomial-time Hard

OB-FNOMA	–	Optimal Beamwidth and Fixed Power Allocation Network Non-Orthogonal Multiple Access
OB-OMA	–	Optimal Beamwidth Joint Transmission Coordinated Multi-Point Orthogonal Multiple Access
OFDMA	–	Orthogonal Frequency-Division Multiple Access
OMA	–	Orthogonal Multiple Access
PPP	–	Poisson Point Process
PDF	–	Probability Density Function
PGFL	–	Probability Generating Functional
PMF	–	Probability Mass Function
RSMA	–	Rate-Splitting Multiple Access
SNR	–	Signal-to-Noise Ratio
SCA	–	Successive Convex Approximation
SIC	–	Successive Interference Cancellation
SIR	–	Signal-to-Interference Ratio
SINR	–	Signal-to-Interference-plus-Noise Ratio
TDMA	–	Time-Division Multiple Access
TS	–	Terrestrial Station
TN-NOMA	–	Terrestrial Network Non-Orthogonal Multiple Access
TT-NOMA	–	Terrestrial-to-Terrestrial Non-Orthogonal Multiple Access
TU	–	Terrestrial User
UAV	–	Unmanned Aerial Vehicle
w.r.t.	–	with respect to

LIST OF SYMBOLS

x	–	Scalar parameters/variables or points
$\boldsymbol{x}$	–	Vectors, e.g., $\boldsymbol{x} = [x_1, \ldots, x_n]^T$
$(\cdot)^T$	–	Transpose
$(\cdot)^H$	–	Conjugate transpose
$C(x, c)$	–	A circle centred at point x with a radius of c
$\text{Bino}(n, p)$	–	Binomial distributed random variable with n trials and probability of p
$\mathcal{CN}(\mu, \sigma^2)$	–	Circularly symmetric complex Gaussian random variable with mean μ and variance σ^2
$\text{Gamma}(m, \theta)$	–	Gamma distributed random variable with rate m and scale θ
$\lvert\cdot\rvert$	–	Absolute value
$\lVert\cdot\rVert$	–	Euclidean norm
$\mathbb{E}[\cdot]$	–	Statistical expectation
$\exp(\cdot)$	–	Exponent
$\{\cdot, \cdot\}$	–	A set of
$\{\cdot \mid \cdot\}$	–	A set determined by a condition on the elements
$\text{card}(C)$	–	The cardinality of set C
$\mathbf{1}_c\{\cdot\}$	–	Indication function for condition c
$\in$	–	Is an element of
$\sim$	–	Is distributed as
$\approx$	–	Approximately equal to
$\log(\cdot)$	–	Logarithm with base 2
$\ln(\cdot)$	–	Natural logarithm
$\max(\cdot)$	–	The maximum of an argument

$\min(\cdot)$	–	The minimum of an argument
$\sup(\cdot)$	–	The supremum of an argument
$\tan^{-1}(\cdot)$	–	Inverse tangent
$\tan_2^{-1}(\cdot,\cdot)$	–	Fourth quadrant inverse tangent
$[\cdot]_c^+$	–	Argument is lower bounded by c
$[\cdot]_c^-$	–	Argument is upper bounded by c
$\mathbb{P}\{X\}$	–	The probability of event X
$\mathbb{P}\{X\|Y\}$	–	The conditional probability of event X given Y
$I_0(\cdot)$	–	Zero order modified Bessel function
$\bar{B}(z,x,y)$	–	Beta upper incomplete function
$B_i(\cdot)$	–	Complete Bell polynomial
$B_{i,j}(\cdot)$	–	Incomplete Bell polynomial
$\mathcal{J}^{(i)}(\cdot)$	–	The ith derivative of an arbitrary function $\mathcal{J}(\cdot)$
$Q_1(\cdot,\cdot)$	–	First order Marcum Q-function
$M_{(\cdot,\cdot)}(\cdot)$	–	Whittaker M function

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CHAPTER 1

INTRODUCTION

1.1 Background

Unmanned aerial vehicle (UAV), also known as drone, is an aircraft without any human pilot onboard. It has increasingly become a promising tool in the field of wireless communications. On one hand, UAV can be used as an aerial communication platform such as aerial base station or aerial relay to provide wireless communications. On the other hand, UAV can be employed as an aerial user (AU) to perform arbitrary operations. Both of these applications are broadly termed as UAV communications but this thesis centres mainly on the latter application.

Due to wide market availability and affordable price, employing UAV as an AU is no longer an enviable practice. It has instead become rather common these days. For example, common people have been employing UAVs for aerial photography and drone racing. In the industry, engineers and technicians have also been using UAVs for inspection and monitoring purposes. Compared to existing terrestrial users (TUs), AUs exhibit unique characteristics in the communication system due to their ability to move in the three dimensional (3D) space. Because of the nature of their applications, AUs also have different characteristics in uplink and downlink communications. This thesis focusses on the downlink communications.

Most of the commercial UAVs are controlled via point-to-point links over the unlicensed spectrum. Such a solution is workable but it also limits the UAVs' operation range to line-of-sight (LOS). To enable beyond visual line-of-sight (BVLOS) operations, the concept of cellular-connected UAVs has been introduced in the 5th Generation (5G) and beyond cellular networks. The key idea of cellular-connected UAVs is to serve the UAVs as AUs via existing cellular networks. This solution is very attractive to the telecommunication industry because this new service can help to create new revenues.

More importantly, existing cellular networks are now widely deployed, and therefore no significant financial investment is required to serve the new AUs.

Companies such as Qualcomm, Nokia, Ericsson, NTT Docomo, Huawei, and ZTE have conducted field tests and performed simulations to support the new AUs. Existing studies mainly rely on orthogonal multiple access (OMA) schemes to support both AUs and TUs. Examples of the OMA schemes are frequency-division multiple access (FDMA), time-division multiple access (TDMA), and orthogonal frequency-division multiple access (OFDMA). In OMA, each orthogonal radio resource/resource block is assigned to only a single user to prevent co-channel interference. Because of this, OMA is unable to achieve high spectral efficiency nor large number of concurrent connectivity.

To address these limitations, non-orthogonal multiple access (NOMA) can be employed. NOMA has been proposed for beyond 5G cellular networks primarily to improve the spectral efficiency and enable massive connectivity. In general, there are two classes of NOMA: power-domain NOMA and code-domain NOMA. In this thesis, only power-domain NOMA is considered. Thus, for brevity, power-domain NOMA is also referred to as NOMA throughout this thesis. Unlike OMA, NOMA enables multiple users (e.g., AU and TU) to share the same orthogonal radio resource/resource block by employing superposition coding at the transmitter(s) and successive interference cancellation (SIC) at the receivers. The users' messages are superimposed by using superposition coding and broadcast with an orthogonal radio resource/resource block. The co-channel interference induced by the superposition coding is then cancelled at the receivers by using SIC.

Intuitively, employing NOMA for AUs and TUs can improve the spectral efficiency and number of concurrent connectivity of the cellular networks. Previous studies have also shown that NOMA performs well if the user channels are asymmetric. Thus, by further leveraging the downlink asymmetricity between AUs and TUs, the applications of NOMA for AUs and TUs could provide additional gains than that of NOMA for TUs only. Nevertheless, the applications of NOMA for the co-existing of

AUs and TUs introduces new challenges. This thesis aims to address some of the key challenges.

1.2 Problem Statements

This thesis identifies several open problems in efficiently serving AUs and TUs using NOMA in downlink communications. The problem statements are detailed in the following.

1.2.1 Reverse SIC Policy and Inappropriate NOMA Power Allocation

Efficiently serving a mobile AU and a TU over a time-varying channel using NOMA remains an open problem because reverse SIC policy and inappropriate NOMA power allocation issues might frequently occur. In particular, the superiority of NOMA over OMA is only guaranteed if the strong user and weak user are distinguishable. It is inefficient for the weak user to perform SIC and strong user to treat the co-channel interference as noise, i.e., the reverse SIC policy. In existing terrestrial NOMA, this issue can be addressed by using distance-based ranking [1] or classifying the types of links [2], if perfect channel state information (CSI) is unavailable. Nevertheless, these solutions cannot be applied to the AU due to its unique 3D mobility effect. Furthermore, in downlink communications, typical TU expects high data rate whilst a minimum data rate must be delivered to the AU to ensure its safe operation. Specifically, the command and control (C&C) messages used for controlling the AU's 3D mobility are delivered in downlink communications. Therefore, inappropriate NOMA power allocation does not only lead to spectral inefficiency of the TU, but also high AU's outage probability. The high AU's outage probability would cause unreliable communications and subsequently affect the safe operation of the AU.

1.2.2 Effects of Various Network Parameters in NOMA-Enabled Cellular-Connected UAVs

Existing cellular networks are mainly designed to serve the TUs only. Thus, to better serve the new AUs, it is important to consider the co-existence of AUs and TUs in multi-cell networks. Existing works have shown that the AUs can experience stronger communication links than the TUs due to the availability of LOS links. But this also leads to two contrasting effects: i) a stronger link to its associated base station (BS), and ii) a stronger inter-cell interference (ICI) from neighbouring BSs. Unfortunately, various studies conclude that the former is unable to compensate the latter [3, 4, 5, 6, 7, 8, 9, 10]. Thus, the pairing of AUs and TUs using NOMA might be inefficient in the multi-cell networks. This motivates the necessity to analyse the effects of different network parameters on the performance of a typical AU and a TU using NOMA in multi-cell networks. Thanks to recent advancements, the average performance of a typical user in multi-cell networks can be analysed using the tools of stochastic geometry [11]. Nevertheless, a stochastic geometry framework that considers the co-existing of AUs and TUs over NOMA is still missing in the literature. Furthermore, existing frameworks cannot be directly applied to evaluate the performance of NOMA for co-existing of AUs and TUs in multi-cell networks.

1.2.3 Strong Inter-Cell Interference in Cellular-Connected UAVs

Strong ICI of the AUs remains as a major impediment to an efficient NOMA system. In fact, using NOMA in existing terrestrial multi-cell networks is also challenged by the ICI problem. This is because the SIC at the receivers can only be used to cancel the co-channel interference induced by the superposition coding, not the ICI. Several efficient solutions have been proposed to mitigate the ICI of cell-edge TUs but existing solutions such as [12, 13, 14, 15, 16, 17, 18, 19, 20, 21] require coordination among the BSs. For cell-edge TUs, a coordination among two to three adjacent BSs is sufficient to address the ICI of the cell-edge TUs because adjacent BSs are the dominant interferers and the ICI from BSs that are far away can be suppressed by the severe terrestrial path loss. Nevertheless, AUs that hover at high altitudes establish strong LOS links with many other terrestrial BSs. Depending on the AU's altitude and the environment, the AUs might detect up to thirty terrestrial BSs [22]. Coordination among these terrestrial BSs is required to fully mitigate the strong ICI of AUs. Nonetheless, this is not an appealing solution for the AUs because coordination among a large number of BSs leads to high system complexity and extreme backhaul requirements [23].

1.3 Research Objectives

This thesis aims to address the open problems discussed in Section 1.2. Based on the same order, the corresponding research objectives of this thesis are to:

1. Design a robust aerial-terrestrial NOMA (AT-NOMA) scheme that maximises the TU's rate over a time-varying wireless channel subject to the AU's rate requirement.
2. Develop a stochastic geometric framework to analyse the effects of different network parameters on the performance of AT-NOMA in multi-cell networks.
3. Design an aerial-terrestrial network NOMA (ATN-NOMA) scheme that can efficiently mitigate the strong ICI of AU, and maximise the TUs' sum-rate subject to the AU's rate requirement.

1.4 Research Scope

This thesis focuses on the theoretical network performance for the co-existence of an AU and a TU in downlink communications. Specifically, this research is carried out based on the principles of wireless communication theory, optimisation theory, stochastic geometry, probability and statistics, and by using computer software such as MATLAB and Mathematica. In each research study, the system model considers only certain parts of the wireless communication process which are major players in the analysis. These parts include path loss, multipath fading, multiple access scheme, and user rate.

Throughout this thesis, a two-user NOMA is considered. In two-user NOMA, the transmitter (e.g., terrestrial station (TS)/BS) pairs only two users over an orthogonal radio resource/resource block using NOMA. The proposed schemes can be extended to serve multiple AUs and TUs by using a multi-carrier NOMA system[1]. Specifically, an AU and a TU can be paired over an orthogonal radio resource/resource block. Then, each pair of AU and TU can be served using different orthogonal radio resource/resource block.

In NOMA, the receivers are required to perform SIC and, for simplicity, this thesis assumes that the SIC is perfect. The implementation, aviation matters, meteorological conditions, side information, network protocols, and backhaul communications are assumed to be in perfect, proper, and working conditions. In addition, all the nodes (e.g., TS, BS, AU, and TU) in the system are equipped with a single antenna.

1.5 Research Contributions

The original contributions of this thesis are summarized as follows. In Chapter 4, a robust AT-NOMA scheme that considers the pairing of a mobile AU and a TU is proposed. An optimisation problem that maximises the TU's rate over a time-varying wireless channel by optimal SIC policy and power allocation subject to the AU's rate requirement is formulated. Both perfect CSI and partial CSI cases are considered. The solution of the perfect CSI case is used to provide useful insights to that of partial CSI case. In the partial CSI case, the probabilities of AU/TU channel order are derived in closed-form expressions. These expressions enable the recognition of strong user and weak user, and thereby allow the proposed AT-NOMA scheme with partial CSI to achieve a higher TU's rate. The AU's mobility effect is also considered, and

[1]A multi-carrier NOMA system is a combination of OMA and NOMA schemes. Specifically, users are divided into multiple groups, each group is assigned with an orthogonal radio resource/resource block, and users in each group are served using NOMA [24].

suboptimal power allocation is obtained in closed-form expressions. Due to the AU's mobility effect, the proposed suboptimal power is dynamically allocated, and it exploits the complementary cumulative distribution function (CCDF) of the AU's channel gain in each time slot to ensure the AU's rate requirement is satisfied across time. In the absence of perfect CSI, there is also a tradeoff between the TU's rate and the reliability of satisfying the AU's rate requirement. To address this tradeoff, suboptimal SIC policy and appropriate targeted probability are suggested to strike a balance between rate and reliability.

In Chapter 5, a novel stochastic geometric framework is proposed, where the terrestrial BSs are spatially distributed according to a homogeneous Poisson point process (PPP) and each AU is paired with a TU using NOMA. Different features such as minimum-distance and maximum-signal-to-interference-plus-noise ratio (SINR) based user associations, directional and omni-directional antennas, and also inter-cell interference coordination (ICIC) are incorporated into the proposed framework. Tractable expressions for the coverage probabilities and average rates of a typical AU and a TU are derived. Using the derived analytical expressions, the effects of various network settings and parameters are further analysed. The discussions of the analysis provide intuitive insights on the system characteristics at a fundamental level and practical guidelines for efficient system design. To efficiently serve the AUs and the TUs, an interference-aware AT-NOMA scheme that combines the use of maximum-SINR based user association, directional antenna with fixed beamwidth, and ICIC is proposed. Analytical and simulation results are presented to verify the superiority of the proposed interference-aware AT-NOMA scheme as compared to other schemes based on different combinations.

In Chapter 6, a novel ATN-NOMA scheme for the co-existence of AUs and TUs is proposed. Specifically, each BS pairs the AU and TU in a NOMA setting to leverage their asymmetric channel and rate demand characteristics. The proposed ATN-NOMA scheme further employs elevation-angle based user association, the use of a directional antenna with adjustable beamwidth at the AU, and network NOMA to address the strong ICI issue at the AU. An optimisation problem is formulated to maximise the sum-rate of the TUs by optimal beamwidth and power allocation subject to the AU's rate requirement, and a local optimal solution is subsequently obtained. By leveraging the unique properties of the proposed scheme and the statistical CSI, the probability density function (PDF) and cumulative distribution function (CDF) of the aggregated ICI experienced at the AU are derived. Deriving the statistical properties is a challenging task because the aggregated ICI is generally the sum of independent non-identical gamma random variables conditioned by the number of LOS/non-LOS (NLOS) links. Utilizing the derived statistical properties, the aggregated ICI at the AU can be estimated reliably. Furthermore, a criterion where AU experiences zero ICI is outlined. Specifically, AU experiences zero ICI when there are no interfering BSs having the same elevation angle as the coordinated BSs. In such cases, the AU's outage probability is approximated. This analytical result helps to verify the superiority of the proposed ATN-NOMA scheme in terms of outage probability, and confirms that the proposed ATN-NOMA scheme is able to support reliable communications for the AU's links. Simulation results with different network parameters and settings are presented. The simulation results provide quantitative insights on the effects of AU's interference, and more importantly reveal the key factors that determine the performance of the proposed scheme at a fundamental level.

1.6 Organization

The rest of this thesis is organized as follows: Chapter 2 presents the literature review, while Chapter 3 describes the research methodology. In Chapter 4, a robust AT-NOMA scheme that considers the pairing of a mobile AU and a TU is proposed. In Chapter 5, a novel stochastic geometry framework is developed, a comprehensive performance analysis is made, and an interference-aware AT-NOMA scheme is proposed. Then, a novel ATN-NOMA scheme which can fully eliminate the ICI of the AUs with limited number of coordinated BSs is proposed in Chapter 6. Lastly, conclusions are made and some promising future directions are outlined in Chapter 7.

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3. New, W. K., Leow, C. Y., Navaie, K. Sun, Y. and Ding, Z, “Application of NOMA for Cellular-Connected UAVs: Opportunities and Challenges”, in Journal of Science China Information Sciences, vol. 64, no. 4, pp. 140302:1-140302:14, April 2021, doi: 10.1007/s11432-020-2986-8.

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1. New, W. K., Leow, C. Y., Navaie, K. Sun, Y. and Ding, Z, "Downlink NOMA for Coexistence of Aerial and Terrestrial Users: Stochastic Geometry Analysis," GLOBECOM 2020 - 2020 IEEE Global Communications Conference, 2020, pp. 1-6, doi: 10.1109/GLOBECOM42002.2020.9322605.
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