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YANSHAN UNIVERSITY

硕 士 学 位 论 文

MASTER'S DISSERTATION

（ 学 术 学 位 ）

论文题名　无人机辅助的车联网络任务卸载与资源分配的研究

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无人机辅助的车联网络任务卸载与资源分配的研究

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Joint Robust Optimal Allocation and Communication Resources Under High Dynamic Vehicular Heterogeneous Networks

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By

xxx

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燕山大学硕士学位论文原创性声明

本人郑重声明：此处所提交的硕士学位论文《无人机辅助的车联网络任务卸载与资源分配的研究》，是本人在导师指导下，在燕山大学攻读硕士学位期间独立进行研究工作所取得的成果。论文中除已注明部分外不包含他人已发表或撰写过的研究成果。对本文的研究工作做出重要贡献的个人和集体，均已在文中以明确方式注明。本声明的法律结果将完全由本人承担。

作者签字：　　　　　　　日期：　　　年　　月　　日

燕山大学硕士学位论文使用授权书

《无人机辅助的车联网络任务卸载与资源分配的研究》系本人在燕山大学攻读硕士学位期间在导师指导下完成的硕士学位论文。本论文的研究成果归燕山大学所有，本论文的研究内容不得以其它单位的名义发表。本人完全了解燕山大学关于保存、使用学位论文的规定，同意学校保留并向有关部门送交论文的复印件和电子版本，允许论文被查阅和借阅。本人授权燕山大学，可以采用影印、缩印或其它复制手段保存论文，可以公布论文的全部或部分内容。

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无人机辅助的车联网络任务卸载与资源分配的研究

摘要：近年来，随着道路交通车辆密度的不断增大，道路交通安全以及车辆通信拥堵等问题日益凸显。随着智能化、联网化程度的不断发展，智能交通系统 (Intelligent Traffic Systems, ITS) 正在世界各地得到广泛开发和部署。纵观前四代移动通信技术，仅仅实现了人与人之间的信息交互，并未真正转变到人与物、物与物之间的互联。而 5G 的出现，使得万物互联不再停留在概念阶段。5G 具有大容量、高速率、低时延、高带宽和高移动性等特点。借助多路访问边缘计算 (Multi-Access Edge Computing, MEC)，端到端延迟缩短至 1 毫秒。因此，作为一项实现智慧城市、智能交通的重要手段，车联网被寄予厚望。万物互联的提出，使得越来越多的设备加入车联网成为可能，更加多样化的车联网场景相继提出，本文聚焦于无人机作为空中基站辅助车辆与路边单元的通信与任务卸载，并制定了有效的功率控制及轨迹优化策略，通过联合优化方案提升车联网的系统性能。

$$\tilde{g}_{i,j}^{k} = L_{i,j}^{2}\widetilde{h}_{i,j}^{2}\xi_{i,j}^{2}$$

首先，针对空地一体化的大规模通信异构的车联网络，提出了一种基于博弈的鲁棒资源分配算法，该方案通过构建用户间的博弈关系，制定了实时功率分配和定价策略，在该优化方案中实现了用户利益的最大化。引入了概率约束，以确保用户服务的可靠性和稳定性。仿真结果表明，所提算法在复杂多用户干扰和信道不确定性的空地一体化异构车联网通信场景下是有效的。

其次，针对车辆网络越来越高的低延迟高数据计算的需求，提出了云辅助 MEC 的鲁棒功率控制和任务卸载的新方法。根据系统模型构建了鲁棒性功率控制和任务卸载调度的优化问题，由于信道存在不确定性，优化问题受到传输速率、计算通信延迟和概率形式的限制。应用了连续凸近似 (Successive Convex Approximation, SCA) 技术，将变量耦合的 NP 难问题 (Non-deterministic Polynomial-time hard problem, NP-hard problem) 转化为可处理的凸问题。仿真结果表明，所提出的算法得到了近似最优解。与现有方法相比，系统平均卸载效用得到显著改善。

最后，考虑了将无人机辅助通信与任务卸载相结合的物理场景，提出了一种天地一体化的无人机辅助双向车道的车辆通信方案。设计了车辆通信时的吞吐量最大化与通信及无人机飞行能耗最小化的平衡方案。通过优化车辆的发射功率与无人机的飞行轨迹以及时隙的分配，可以使得系统的能效最大化，数值仿真表明，该方案在能效方面的性能明显高于其他方法并可显著提升车联网通信效率。

关键词： 车联网；无人机通信；吞吐量最大化；中断概率；边缘计算；轨迹优化；任务卸载

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Joint Robust Optimal Allocation and Communication Resources Under High Dynamic Vehicular Heterogeneous Networks

Abstract: In recent years, the density of road vehicles has increased, leading to prominent issues of traffic safety and vehicle communication congestion. Intelligent Traffic Systems (ITS) are being widely developed and deployed worldwide due to the continuous development of intelligence and networking. During the first four generations of mobile communication technology, it facilitated information exchange solely between people, without enabling connections between people and things, or things and things. However, with the advent of 5G, the concept of interconnectivity will become a reality. 5G boasts high capacity, speed, bandwidth, and mobility, as well as low latency. Multi-Access Edge Computing (MEC) can reduce end-to-end latency to 1 millisecond, making telematics a crucial component in the realization of smart cities and intelligent transportation. This proposal introduces the concept of the Internet of Everything. This paper focuses on the use of UAVs as airborne base stations to support communication and task offloading between vehicles and roadside units. It formulates power control and trajectory optimization schemes to improve the system performance of vehicle networking. The paper aims to achieve an all-round improvement in the system's performance.

Firstly, a game-based resource allocation algorithm is proposed for air-ground integrated large-scale communication heterogeneous vehicular networks. The algorithm centers on the game relationship between users and formulates real-time power allocation and pricing strategies to maximize user benefits in a novel optimization scheme. To ensure the reliability and stability of user services, probabilistic constraints are introduced. The simulation results demonstrate the effectiveness of the proposed algorithm in air-ground integrated heterogeneous vehicular communication scenarios, even in the presence of complex multi-user interference and channel uncertainty.

Secondly, a new approach to robust power control and task offloading for cloud-assisted MEC is proposed to address the increasing demand for low-latency, high-data computation in vehicular networks. The optimization problem is limited by the form of transmission

rate, computational communication delay, and co-channel interference probability due to the presence of channel uncertainty. The optimization problem is initially formulated as a robust power control and task offloading scheduling problem using the Successive Convex Approximation (SCA) technique to transform the variable-coupled NP-hard problem into a tractable convex problem. Simulation results demonstrate that our proposed algorithm achieves a Compared to the existing methods, the average utility of system offloading has significantly improved.

Finally, this paper considers a more realistic physical scenario that combines UAV-assisted communication with task offloading. The authors propose an efficient UAV-assisted vehicular communication scheme for two-way lanes. A balancing scheme is constructed to measure the basic throughput, communication, and UAV flight energy consumption during vehicular communication. By optimizing the transmit power of the vehicle and the flight trajectory of the UAV, as well as the allocation of time slots, the energy efficiency of the system can be maximized. Numerical simulations show that this scheme significantly outperforms other methods in terms of energy efficiency and can greatly improve vehicular communication efficiency.

Keywords: UAV Communication; Throughput Maximisation; Outage Probability; Edge Computing; Trajectory Optimisation; Task Offloading

Classification: 623.1

目　次

参考文献

[1] Liu W, Hua M, Deng Z, et al. A Systematic Survey of Control Techniques and Applications in Connected and Automated Vehicles [J]. IEEE Internet of Things Journal, 2023, 10(24): 21892–21916.

[2] Haydari A, Yılmaz Y. Deep Reinforcement Learning for Intelligent Transportation Systems: A Survey [J]. IEEE Transactions on Intelligent Transportation Systems, 2022, 23(1): 11–32.

[3] Kiran B R, Sobh I, Talpaert V, et al. Deep Reinforcement Learning for Autonomous Driving: A Survey [J]. IEEE Transactions on Intelligent Transportation Systems, 2022, 23(6): 4909–4926.

[4] Lai C, Lu R, Zheng D, et al. Security and Privacy Challenges in 5G-Enabled Vehicular Networks [J]. IEEE Network, 2020, 34(2): 37–45.

[5] 刘雪娇, 曹天聪. 区块链架构下高效的车联网跨域数据安全共享研究 [J]. 通信学报, 2023, 44(3): 186–198.

[6] Noor-A-Rahim M, Liu Z, Lee H, et al. 6G for Vehicle-to-Everything (V2X) Communications: Enabling Technologies, Challenges, and Opportunities [J]. Proceedings of the IEEE, 2022, 110(6): 712–734.

[7] Kuutti S, Bowden R, Jin Y, et al. A Survey of Deep Learning Applications to Autonomous Vehicle Control [J]. IEEE Transactions on Intelligent Transportation Systems, 2021, 22(2): 712–733.

[8] Katare D, Perino D, Nurmi J, et al. A Survey on Approximate Edge AI for Energy Efficient Autonomous Driving Services [J]. IEEE Communications Surveys & Tutorials, 2023, 25(4): 2714–2754.

[9] Liu S, Liu L, Tang J, et al. Edge Computing for Autonomous Driving: Opportunities and Challenges [J]. Proceedings of the IEEE, 2019, 107(8): 1697–1716.

[10] Wu M, Yu F R, Liu P X. Intelligence Networking for Autonomous Driving in Beyond 5G Networks with Multi-Access Edge Computing [J]. IEEE Transactions on Vehicular Technology, 2022, 71(6): 5853–5866.

[11] Zhou Z, Feng J, Chang Z, et al. Energy-Efficient Edge Computing Service Provisioning for Vehicular Networks: A Consensus Admm Approach [J]. IEEE Transactions on Vehicular Technology, 2019, 68(5): 5087–5099.

[12] Dai P, Hu K, Wu X, et al. A Probabilistic Approach for Cooperative Computation Offloading in MEC-Assisted Vehicular Networks [J]. IEEE Transactions on Intelligent Transportation Systems, 2022, 23(2): 899–911.

[13] Tan L T, Hu R Q. Mobility-Aware Edge Caching and Computing in Vehicle Networks: A Deep Reinforcement Learning [J]. IEEE Transactions on Vehicular Technology, 2018, 67(11): 10190–10203.

[14] Wang Y, Lang P, Tian D, et al. A Game-based Computation Offloading Method in Vehicular Multiaccess Edge Computing Networks [J]. IEEE Internet of Things Journal, 2020, 7(6): 4987–4996.

[15] Wang J, Zhu K, Chen B, et al. Distributed Clustering-Based Cooperative Vehicular Edge Computing for Real-Time Offloading Requests [J]. IEEE Transactions on Vehicular Technology, 2022, 71(1): 653–669.

[16] Li Z, Yang C, Huang X, et al. Coor: Collaborative Task Offloading and Service Caching Replacement for Vehicular Edge Computing Networks [J]. IEEE Transactions on Vehicular Technology, 2023.

[17] Nemirovski A, Shapiro A. Convex Approximations of Chance Constrained Programs [J]. SIAM Journal on Optimization, 2007, 17(4): 969–996.

[18] Bertsekas D. Nonlinear Programming (athena Scientific, Nashua, Nh) [J]. 1999.

[19] Zhou H, Xu W, Bi Y, et al. Toward 5G Spectrum Sharing for Immersive-Experience-Driven Vehicular Communications [J]. IEEE Wireless Communications, 2017, 24(6): 30–37.

[20] Tran T X, Pompili D. Joint Task Offloading and Resource Allocation for Multi-Server Mobile-edge Computing Networks [J]. IEEE Transactions on Vehicular Technology, 2019, 68(1): 856–868.

[21] Liu Z, Liang C, Yuan Y, et al. Resource Allocation Based on User Pairing and Subcarrier Matching for Downlink Non-Orthogonal Multiple Access Networks [J]. IEEE/CAA Journal of Automatica Sinica, 2021, 8(3): 679–689.

[22] Xiao H, Zhu D, Chronopoulos A T. Power Allocation with Energy Efficiency Optimization in Cellular D2D-Based V2X Communication Network [J]. IEEE Transactions on Intelligent Transportation Systems, 2020, 21(12): 4947–4957.

[23] Chen Y, Wang Y, Jiao L. Robust Transmission for Reconfigurable Intelligent Surface Aided Millimeter Wave Vehicular Communications with Statistical CSI [J]. IEEE Transactions on Wireless Communications, 2022, 21(2): 928–944.

[24] Liu Z, Xie Y, Chan K Y, et al. Chance-Constrained Optimization in D2D-Based Vehicular Communication Network [J]. IEEE Transactions on Vehicular Technology, 2019, 68(5): 5045–5058.

[25] Li X, Ma L, Xu Y, et al. Resource Allocation for D2D-Based V2X Communication With Imperfect CSI [J]. IEEE Internet of Things Journal, 2020, 7(4): 3545–3558.

[26] Xie Y a, Liu Z, Chan K Y, et al. Energy-Spectral Efficiency Optimization in Vehicular Communications: Joint Clustering and Pricing-Based Robust Power Control Approach [J]. IEEE Transactions on Vehicular Technology, 2020, 69(11): 13673–13685.

[27] Wu H, Lyu F, Zhou C, et al. Optimal UAV Caching and Trajectory in Aerial-Assisted Vehicular Networks: A Learning-based Approach [J]. IEEE Journal on Selected Areas in Communications, 2020, 38(12): 2783–2797.

[28] Lyu F, Yang P, Wu H, et al. Service-Oriented Dynamic Resource Slicing and Optimization for Space-Air-Ground Integrated Vehicular Networks [J]. IEEE Transactions on Intelligent Transportation Systems, 2022, 23(7): 7469–7483.

[29] Wu Q, Xu J, Zeng Y, et al. A Comprehensive Overview on 5G-and-Beyond Networks With UAVs: From Communications to Sensing and Intelligence [J]. IEEE Journal on Selected Areas in Communications, 2021, 39(10): 2912–2945.

[30] Kato N, Fadlullah Z M, Tang F, et al. Optimizing Space-Air-Ground Integrated Networks by Artificial Intelligence [J]. IEEE Wireless Communications, 2019, 26(4): 140–147.

[31] Liu M, Yang J, Gui G. DSF-NOMA: UAV-Assisted Emergency Communication Technology in a Heterogeneous Internet of Things [J]. IEEE Internet of Things Journal, 2019, 6(3): 5508–5519.

[32] Yang G, Dai R, Liang Y C. Energy-Efficient UAV Backscatter Communication with Joint Trajectory Design and Resource Optimization [J]. IEEE Transactions on Wireless Communications, 2021, 20(2): 926–941.

[33] Lim W Y B, Huang J, Xiong Z, et al. Towards Federated Learning in UAV-Enabled Internet of Vehicles: A Multi-dimensional Contract-matching Approach [J]. IEEE Transactions on Intelligent Transportation Systems, 2021, 22(8): 5140–5154.

[34] 胡益恺, 王春香. 智能车辆决策方法研究综述 [J]. 上海交通大学学报, 2021, 55(8): 1035.

[35] Liu Z, Su J, Xie Y a, et al. Resource Allocation in D2D Enabled Vehicular Communications: A Robust Stackelberg Game Approach Based on Price-Penalty Mechanism [J]. IEEE Transactions on Vehicular Technology, 2021, 70(8): 8186–8200.

[36] Back Matter [J]. Econometrica, 1968, 36(3/4).

[37] Ren Y, Liu F, Liu Z, et al. Power Control in D2D-Based Vehicular Communication Networks [J]. IEEE Transactions on Vehicular Technology, 2015, 64(12): 5547–5562.

[38] Zhou Z, Guo Y, He Y, et al. Access Control and Resource Allocation for M2M Communications in Industrial Automation [J]. IEEE Transactions on Industrial Informatics, 2019, 15(5): 3093–3103.

[39] 王小进. 基于车辆边缘计算的任务卸载策略研究 [D]. 南京邮电大学, 2023.

[40] Mao Y, You C, Zhang J, et al. A Survey on Mobile Edge Computing: The Communication Perspective [J]. IEEE Communications Surveys & Tutorials, 2017, 19(4): 2322–2358.

[41] Abbas N, Zhang Y, Taherkordi A, et al. Mobile Edge Computing: A Survey [J]. IEEE Internet of Things Journal, 2018, 5(1): 450–465.

[42] Li Z, Zhang H, Li X, et al. Distributed Task Scheduling for MEC-Assisted Virtual Reality: A Fully-Cooperative Multi-Agent Perspective [J]. IEEE Transactions on Vehicular Technology, 2024: 1–15.

[43] Liu Q, Gong J, Liu Q. Blockchain-Assisted Reputation Management Scheme for Internet of Vehicles [J]. Sensors, 2023, 23(10).

[44] 曹宇慧. 车载边缘计算环境下任务协同卸载方法研究 [D]. 重庆交通大学, 2023.

[45] Zhang Y, Xiong L, Li F, et al. Blockchain-Based Privacy-Preserving Authentication with Hierarchical Access Control Using Polynomial Commitment for Mobile Cloud Computing [J]. IEEE Internet of Things Journal, 2024: 1–1.

[46] Kim T, Love D J, Clerckx B. Does Frequent Low Resolution Feedback Outperform Infrequent High Resolution Feedback for Multiple Antenna Beamforming Systems? [J]. IEEE Transactions on Signal Processing, 2011, 59(4): 1654–1669.

[47] Sakr A, Hossain E. Cognitive and Energy Harvesting-based D2D Communication in Cellular Networks: Stochastic Geometry Modeling and Analysis [J]. IEEE Transactions on Communications, 2014, 63: 1867–1880.

[48] Guo C, Liang L, Li G Y. Resource Allocation for High-reliability Low-latency Vehicular Communications with Packet Retransmission [J]. IEEE Transactions on Vehicular Technology, 2019, 68(7): 6219–6230.

[49] Zhang K, Mao Y, Leng S, et al. Mobile-Edge Computing for Vehicular Networks: A Promising Network Paradigm with Predictive Off-Loading [J]. IEEE Vehicular Technology Magazine, 2017, 12(2): 36–44.

[50] Saleem U, Liu Y, Jangsher S, et al. Mobility-Aware Joint Task Scheduling and Resource Allocation for Cooperative Mobile Edge Computing [J]. IEEE Transactions on Wireless Communications, 2021, 20(1): 360–374.

[51] Liu Z, Su J, Xie Y a, et al. Resource Allocation in D2D-Enabled Vehicular Communications: A Robust Stackelberg Game Approach Based on Price-Penalty Mechanism [J]. IEEE Transactions on Vehicular Technology, 2021, 70(8): 8186–8200.

[52] Chen X, Jiao L, Li W, et al. Efficient Multi-User Computation Offloading for Mobile-Edge Cloud Computing [J]. IEEE/ACM Transactions on Networking, 2016, 24(5): 2795–2808.

[53] Khuwaja A A, Chen Y, Zheng G. Effect of User Mobility and Channel Fading on the Outage Performance of UAV Communications [J]. IEEE Wireless Communications Letters, 2020, 9(3): 367–370.

[54] Zhao Z, Xu G, Zhang N, et al. Performance Analysis of the Hybrid Satellite-terrestrial Relay Network with Opportunistic Scheduling Over Generalized Fading Channels [J]. IEEE Transactions on Vehicular Technology, 2022, 71(3): 2914–2924.

[55] Zhan P, Yu K, Swindlehurst A L. Wireless Relay Communications with Unmanned Aerial Vehicles: Performance and Optimization [J]. IEEE Transactions on Aerospace and Electronic Systems, 2011, 47(3): 2068–2085.

[56] 方宇杰, 李萌, 司鹏搏, et al. 无人机技术辅助的车联网: 发展与展望 [J]. 高技术通讯, 32(1262).

[57] 王智煊. 无人机辅助下的车联边缘计算卸载机制研究 [D]. 电子科技大学, 2023.

[58] Do-Duy T, Nguyen L D, Duong T Q, et al. Joint Optimisation of Real-Time Deployment and Resource Allocation for UAV-Aided Disaster Emergency Communications [J]. IEEE Journal on Selected Areas in Communications, 2021, 39(11): 3411–3424.

[59] Zhang R, Lu R, Cheng X, et al. A UAV-Enabled Data Dissemination Protocol with Proactive Caching and File Sharing in V2X Networks [J]. IEEE Transactions on Communications, 2021, 69(6): 3930–3942.

[60] Liu F, Chen Z, Xia B. Data Dissemination with Network Coding in Two-Way Vehicle-to-Vehicle Networks [J]. IEEE Transactions on Vehicular Technology, 2016, 65(4): 2445–2456.

[61] Zhang Z, Mao G, Anderson B D O. On the Information Propagation Process in Mobile Vehicular Ad Hoc Networks [J]. IEEE Transactions on Vehicular Technology, 2011, 60(5): 2314–2325.

[62] Baccelli E, Jacquet P, Mans B, et al. Highway Vehicular Delay Tolerant Networks: Information Propagation Speed Properties [J]. IEEE Transactions on Information Theory, 2012, 58(3): 1743–1756.

[63] Wu H, Fujimoto R M, Riley G F, et al. Spatial Propagation of Information in Vehicular Networks [J]. IEEE Transactions on Vehicular Technology, 2009, 58(1): 420–431.

[64] Zhang Z, Mao G, Anderson B D O. Stochastic Characterization of Information Propagation Process in Vehicular Ad Hoc Networks [J]. IEEE Transactions on Intelligent Transportation Systems, 2014, 15(1): 122–135.

[65] A Real-time Computer Vision System for Vehicle Tracking and Traffic Surveillance [J]. Transportation Research Part C: Emerging Technologies, 1998, 6(4): 271–288.

[66] Liang Y, Xiao L, Yang D, et al. Joint Trajectory and Resource Optimization for UAV-Aided Two-Way Relay Networks [J]. IEEE Transactions on Vehicular Technology, 2022, 71(1): 639–652.

攻读硕士学位期间取得的成果

1. 发表的学术论文

[1]

致 谢