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论文题目　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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RESEARCH ON TASK OFFLOADING AND RESOURCE ALLOCATION FOR UAV-ASSISTED VEHICULAR NETWORKS

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By

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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。

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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》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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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 (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有了可能，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，并制定了合理的功率控制及轨迹优化等联合优化方案以全方位的提高车联网的系统性能。

首先，针对空地一体化的大规模通信异构车载网络，提出了一种基于博弈的鲁棒资源分配算法，该方案以用户间的博弈关系为核心，制定了实时功率分配和定价策略，在新颖的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，所提算法具有复杂多用户干扰和信道不确定性的空地一体化异构车载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。由于信道存在不确定性，优化问题受到传输速率、计算通信延迟和同信道干扰概率形式的限制。最初的优化问题被表述为鲁棒性功率控制和任务卸载调度问题，应用了 SCA 技术，将变量耦合的 NP 难问题转化为可处理的凸问题。仿真结果表明，我们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，考虑了更加实际的物理场景，将无人机辅助通信与任务卸载相结合，提出了一种高效的天地一体化的无人机辅助双向车道的车辆通信方案。构建了车辆通信时的吞吐量与通信及无人机飞行能耗的基本平衡方案。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

Abstract

In recent years, with the increasing density of road traffic vehicles, the problems of road traffic safety and vehicle communication congestion have become increasingly prominent. With the continuous development of intelligence and networking, Intelligent Traffic Systems (ITS) are being widely developed and deployed around the world. In particular, vehicle-to-vehicle (Vehicle-to-Vehicle, V2V) communication. Throughout the first four generations of mobile communication technology, it has only realized the information interaction between people, and has not really transformed to the interconnection between people and things, and between things. The emergence of 5G makes the interconnection of everything no longer stay in the conceptual stage. 5G has large capacity, high speed, low latency, and low cost. , high speed, low latency, high bandwidth and high mobility. With device-to-device (D2D) communication and mobile/multi-access edge computing (MEC), end-to-end latency is reduced to 1 millisecond. Therefore, as an important means to realize smart cities and intelligent transportation, Telematics is highly expected. The proposal of the Internet of Everything This paper focuses on the UAV as an airborne base station to assist the communication and task offloading between vehicles and roadside units, and formulates a reasonable power control and trajectory optimization and other joint optimization schemes to improve the system performance of Vehicular Networking in an all-round way.

First, a robust game-based resource allocation algorithm is proposed for air-ground integrated large-scale communication heterogeneous vehicular networks, which is centered on the game relationship between users, and formulates real-time power allocation and pricing strategies to maximize user benefits in a novel optimization scheme. Probabilistic constraints are introduced to ensure the reliability and stability of user services. Simulation results show that the proposed algorithm is effective in air-ground integrated heterogeneous vehicular communication scenarios with complex multi-user interference and channel uncertainty.

Second, 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. Due to the uncertainty in the channel, the optimization problem is limited by the form of transmission rate, computational communication delay and co-channel interference probability. The initial optimization problem is formulated as a robust power control and task offload scheduling problem, and the SCA technique is applied to transform the variable-coupled NP-hard problem into a tractable convex problem. Simulation results show that our proposed algorithm yields a near-optimal solution. Compared with the existing methods, the average system offloading utility is significantly improved.

Finally, a more realistic physical scenario is considered, combining the aforementioned UAV-assisted communication with task offloading to propose an efficient heaven and earth integrated UAV-assisted vehicular communication scheme for two-way lanes. A basic throughput and communication and UAV flight energy consumption during vehicular communication is constructed as a basic balancing scheme. By optimizing the vehicle's transmit power and the UAV's flight trajectory, as well as the allocation of time slots, the energy efficiency of the system can be maximized. Numerical simulations show that the performance of this scheme in terms of energy efficiency is significantly higher than that of other comparative schemes, and it can significantly improve the efficiency of vehicular network communication.

Keywords: Photonic crystal fiber; dispersion; birefringence; genetic algorithm; finite element method; terahertz UAV relay; Throughput; Outage probability; Relay selection; Power control; Trajectory optimization

目　录

结 论

本文以移动无人机辅助的云边计算的车联网为背景，充分体现了车辆用户的移动性，分别研究了空地一体化的大规模通信异构车载网络、云辅助 MEC 的车辆任务卸载网络、天地一体化的无人机辅助的车辆任务卸载通信网络三个场景，在考虑了功率约束、无人机移动性约束、车辆用户服务质量约束等条件下，以吞吐量、能量效率为指标，对中继选择、无人机轨迹、功率控制进行联合优化，通过博弈论、拉格朗日法、SCA 法、交替优化法、贝恩斯坦近似法、积分变换法等方法提升车联网的高效性与可靠性。本文的研究工作可以总结为：

首先，针对空地一体化的大规模通信异构车载网络，提出了一种基于博弈的鲁棒资源分配算法，该方案以用户间的博弈关系为核心，制定了实时功率分配和定价策略，在新颖的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，所提算法具有复杂多用户干扰和信道不确定性的空地一体化异构车载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。由于信道存在不确定性，优化问题受到传输速率、计算通信延迟和同信道干扰概率形式的限制。最初的优化问题被表述为鲁棒性功率控制和任务卸载调度问题，应用了 SCA 技术，将变量耦合的 NP 难问题转化为可处理的凸问题。仿真结果表明，我们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，考虑了更加实际的物理场景，将无人机辅助通信与任务卸载相结合，提出了一种高效的天地一体化的无人机辅助双向车道的车辆通信方案。构建了车辆通信时的吞吐量与通信及无人机飞行能耗的基本平衡方案。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。

但是现有工作需要进一步完善，主要包括以下几点：

(1) 现阶段所研究的场景中，构建的问题是高动态的车联网，但是优化过程很难获取到全局的信息，导致没有站在长期的视角进行优化。

(2) 只对上行链路通信研究了车辆用户的吞吐量以及能效的优化问题，并且认为节点以单工模式工作，并未考虑双工模式下的双向通信以及未来车辆通信过程中可能会遇到的窃听者窃听的问题。当用户的信息在传输过程中面临被窃听的风险时，其信息安全便无法得到保障。因此，对车联网中的通信安全性能进行深入分析显得

尤为重要，这也是该领域值得研究的关键所在。

(3) 此外，本文已经对车联网中的鲁棒功率控制以及车对与信道复用的资源优化问题进行了初步的探索。然而，目前的研究主要停留在理论层面，未来的研究重点将转向构建实验平台，实现理论与实践的有机结合，以期将最新的科研成果应用于实际，为相关领域的进步做出贡献。

参考文献

[1] 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.

[2] 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.

[3] 陈进. 浅析中国城市智能交通系统产业化发展趋势 [J]. 人民交通, 2020, 000(009): P.84–84,86.

[4] 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.

[5] Asghar R, Sulaiman M H, Mustaffa Z, et al. Integration of Electric Vehicles in Smart Grids: A Review of the Advantages and Challenges of Vehicle-to-grid Technology [C]//2022 International Conference on IT and Industrial Technologies (ICIT). .[S.l.]: [s.n.] , 2022: 1–7.

[6] 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.

[7] 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.

[8] 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.

[9] 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.

[10] 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.

[11] 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.

[12] 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.

[13] 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.

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

[15] 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.

[16] 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.

[17] 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.

[18] 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.

[19] 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.

[20] 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.

[21] 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.

[22] 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.

[23] 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.

[24] 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.

[25] 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.

[26] 田秋来. 无人机辅助车联网中继管理与功率控制 [D]. 燕山大学, 2023.

[27] 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.

[28] 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.

[29] 谭国平, 易文雄, 周思源, et al. 无人机辅助 MEC 车辆任务卸载与功率控制近端策略优化算法 [J]. 电子与信息学报, 2024: 1–11.

[30] 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.

[31] 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.

[32] 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.

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

[34] 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.

[35] 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.

[36] 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.

[37] Mondal M K, Banerjee S, Das D, et al. Towards Energy-Efficient and Cost-Effective Task Offloading in Mobile Edge Computing for Intelligent Surveillance Systems [J]. IEEE Transactions on Consumer Electronics, 2024: 1–1.

[38] 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.

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

[40] 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.

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

[42] 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.

[43] 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.

[44] 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.

[45] 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.

[46] 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.

[47] 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.

[48] 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.

[49] 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.

[50] 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.

[51] 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.

[52] 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.

[53] 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.

[54] 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).

[55] 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.

[] 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.

[] 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.

[] 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.

[] 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.

[] 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.

[] 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.

[] 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.

[] Fiore M, Härri J. The Networking Shape of Vehicular Mobility [C]//. New York, NY, USA: Association for Computing Machinery, 2008.

[] 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.

攻读硕士学位期间承担的科研任务与主要成果

(一) 参与的科研项目

[1] 参与，国家自然科学基金项目.

[2] 参与，河北省自然科学基金重点项目.

[3] 参与，5G 无线蜂窝网络资源优化管理与安全传输, 河北省自然科学基金重点资助项目. 课题编号：F2019203095.

[4] 参与，高动态环境下车联网络信息可靠传输与资源优化管理, 国家自然科学基金资助项目. 课题编号：61873223.

[5] 参与，5G 工业物联网无线资源协同优化与安全传输, 国家自然科学基金资助项目. 课题编号：62273298.

[6] 参与，分布式工业网络中适配业务传输需求的多域资源协同优化研究, 国家自然科学基金资助项目. 课题编号：62273295.

(二) 发表的学术论文

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