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Mobile Edge Caching in Heterogeneous Vehicular Networks

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Preface

The advanced technology of connected and automated vehicle (CAV) is expected to revolutionize the future transportation systems, which can enable vehicular information exchange and content delivery in real time. By utilizing cutting-edge technologies (e.g., advanced sensors, wireless communications and networking, and on-board processing), CAVs can be responsive to on-road emergencies rapidly and the road safety can be enhanced significantly. Furthermore, CAVs are also expected to support multifarious vehicular infotainment applications to improve the experience of both drivers and passengers. In particular, empowered by vehicle-to-everything (V2X) communications, safety-related and infotainment contents (such as road conditions, weather and traffic reports, news, video, music, and webpage) can be exchanged among vehicles or delivered to the vehicles from the infrastructure (such as roadside unit [RSU] and LTE base station [BS]) to provide comfortable driving experiences and content-rich multimedia services.

To facilitate smart vehicular services especially in the future driverless era, high-bandwidth content delivery and reliable accessibility of various applications are expected. However, current cellular networks cannot cope with the explosively growing mobile traffic demand to satisfy diversified content delivery services. To support tremendous vehicular content delivery, heterogeneous vehicular networks (HetVNets), which integrate the terrestrial networks with aerial networks formed by unmanned aerial vehicles (UAVs) and space networks constituting of low-Earth-orbit (LEO) satellites, can be utilized to provide seamless, robust, and reliable vehicular service provisioning. In addition, edge caching is an efficient solution to facilitate content delivery by caching popular files in HetVNet access points (APs) with one-hop content delivery from the caching-enabled APs to vehicles, which can mitigate the backhaul traffic and reduce the content delivery delay. However, it is challenging to achieve satisfying edge caching performance in HetVNets as various technical issues remain to be fully addressed. First, edge caching in HetVNet APs should jointly consider the differentiated file profiles and network characteristics (e.g., network coverage, network capacity, AP distribution) to fully unleash the potential of HetVNets for caching performance enhancement. Second, when UAVs are involved, the UAV trajectory should be jointly optimized with content

placement and content delivery, which has not been well-addressed due to their complicated intercoupling relationships. Third, for caching-based HetVNet content delivery, different network segments should cooperatively serve vehicular content requests by leveraging heterogeneous network resources ingeniously, rendering the problem intractable. The scheme design of the cooperative content delivery and the corresponding resource allocation are crucial to content delivery performance yet challenging to be addressed. Fourth, as the vehicular network topology and service requests vary significantly with uncertainties, the decision-making system should be able to keep pace with the dynamic vehicular environments, posing real-time requirements to the optimization solutions.

In this monograph, we investigate mobile edge content caching and delivery in HetVNets to provide better service quality for vehicular users with resource utilization efficiency enhancement. In Chap. 1, we provide an overview of HetVNets, including how it can support high-bandwidth content applications, technical challenges, and the research objective of this monograph. In Chap. 2, we review the state-of-the-art techniques for content delivery performance enhancement and organize a comprehensive survey related to the HetVNet-based content delivery and mobile edge caching-based techniques. In Chap. 3, a coding-based content caching scheme is designed for the terrestrial HetVNet with intermittent network connections, and a matching-based algorithm is proposed to optimize the content placement to minimize the average content delivery delay. In Chap. 4, UAVs with caching capabilities are leveraged to cache content files and serve the vehicular users. A joint caching and trajectory optimization problem is investigated to make decisions on content placement, content delivery, and UAVs' trajectories simultaneously. A deep learning-based algorithm is then proposed to enable real-time decision-making in the highly dynamic vehicular networks. In Chap. 5, a space–air–ground integrated vehicular network (SAGVN) is studied where LEO satellites, UAVs, and terrestrial networks cooperate to serve the vehicular users in content delivery. Considering the characteristics of different network segments, a cooperative content delivery scheme is designed to jointly optimize the user association, bandwidth allocation, and content delivery ratio. At last, we conclude this monograph and provide potential future research directions in Chap. 6. The systematic principle in this monograph provides valuable insights on the mobile edge caching scheme design and efficient exploitation of the heterogeneous network resources to fully unleash their differential merits in vehicular networks.

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Contents

Acronyms

CAV	Connected and automated vehicle
HetVNet	Heterogeneous vehicular network
RSU	Roadside unit
BS	Base station
UAV	Unmanned aerial vehicle
V2X	Vehicle-to-everything
V2V	Vehicle-to-vehicle
V2I	Vehicle-to-infrastructure
VN	Vehicular network
SAG	Space–air–ground
DSRC	Dedicated short-range communication
QoS	Quality of service
SAGVN	Space–air–ground integrated vehicular network
RAT	Radio access technology
TVWS	TV white space
HAP	High altitude platform
LAP	Low altitude platform
LoS	Line-of-sight
GEO	Geostationary Earth orbit
MEO	Medium Earth orbit
LEO	Low Earth orbit
AP	Access point
CBS	Cellular base station
ILP	Integer linear programming
AGVN	Aerial–ground vehicular network
JCTO	Joint caching and trajectory optimization
DSL	Deep supervised learning
CBTL	Clustering-based two-layered
CNN	Convolutional neural network
ABC	User association, bandwidth allocation, and content delivery ratio
LMA-ABC	Load- and mobility-aware ABC

DRL	Deep reinforcement learning
3GPP	3rd generation partnership project
CR	Cognitive radio
SDN	Software-defined networking
NFV	Network function virtualization
AI	Artificial intelligence
CDN	Content delivery network
QoE	Quality of experience
SE	Spectral efficiency
PRAI	Partial repeat after interruption
SA	Student admission
GS	Gale–Shapley
PSO	Particle swarm optimization
IoV	Internet of vehicle
U2V	UAV-to-vehicle
RCSP	Resource constrained shortest path
SNR	Signal-to-noise ratio
S2V	Satellite-to-vehicle
B2V	BS-to-vehicle