Zhaolong Ning, Xiaojie Wang,
and Jun Huang

To meet the requirements of real-time and mission-critical applications in vehicular networks, mobile edge computing (MEC) has become an emerging ecosystem that extends the centralized cloud computing capability to the edge close to terminal devices. Although MEC can bring various benefits, such as high-efficiency use of mobile backhaul networks, coping with the ever-increasing demands of ubiquitous connectivity, energy-efficient computation, and ultralow latency is still challenging. Nonorthogonal multiple access (NOMA) technology is acknowledged as a promising solution to provide massive connectivity and ubiquitous communications in 5G.

Currently, more than 60% of the population in the world has mobile subscriptions, whereas this number was 20% 10 years ago. The ever-increasing mobile services are supported by the huge number of smart devices equipped with sensors in the Internet of Things (IoT), where the generated mobile data are expected to grow by 53% annually from now through 2020 [1]. As an important branch of the IoT, the Internet of Vehicles is playing a key role for traffic management and road safety. By 2020, more than 1.5 billion vehicles will be connected. Each vehicle will generate around 30 TB of data within a day, challenging the ever-saturating spectrum bandwidth. On one hand, although the cellular network can

MOBILE EDGE COMPUTING-ENABLED 5G VEHICULAR NETWORKS

Toward the Integration of Communication and Computing

Digital Object Identifier 10.1109/MVT.2018.2882873
Date of publication: 19 December 2018

provide citywide network access, it is difficult to cope with the unprecedented growth of mobile data traffic. On the other hand, the huge volume of data has not only become an albatross for the current cloud-based infrastructure but also caused unbearable transmission delay and low quality of user experience.

Mobile cloud computing (MCC) is powerful enough to offload network traffic and guarantee network security in a centralized manner. Although MCC-based infrastructures are designed to manage network resources in wireless networks, they are not high efficiency and scalable enough, especially in the coming big data era of vehicular networks. The reasons are 1) they impose significant costs (such as time, bandwidth, and energy) on data transmission from clouds to vehicles, 2) satisfying user quality of service (QoS) and extracting real-time and valuable information from vehicles is difficult for central clouds, and 3) it is challenging to update the mobility and geo-distribution information of vehicles in a timely manner.

It is estimated that around 45% of the generated data in 2020 will be processed by edge devices instead of centralized clouds. To fully explore the benefits of future networks, MEC is a promising alternative that transfers the computing capability from clouds to edge devices. MEC is favorable to satisfy delay-sensitive network scenarios, optimize mobile resources at network edges via hosting computing-intensive applications, preprocess the generated data before delivering to the cloud, and offer the context-aware applications assisted by information from radio access networks [2]. Feature comparison between MCC and MEC is illustrated in Table 1.

Current vehicular networks contain heterogeneous physical resources and support various network access components, such as access points, end devices, and edge routers with distinct memories and storage capacities. Figure 1 illustrates an MEC-enabled vehicular network, where a computing server is equipped with a macrocell to execute computing-intensive tasks. Roadside units (RSUs) and Wi-Fi hotspots can be connected to the macrocell and support multiple kinds of network access patterns. It should be noted that the current cellular infrastructure is mainly based on orthogonal multiple access, resulting in the access rate of vehicles being difficult to guarantee in dense vehicular networks due to the limited bandwidth. RSUs and Wi-Fi hotspots are generally deployed by the mobile network operator [3].

To provide massive connectivity and reduce access collision in bandwidth-limited networks (such as vehicular and cellular networks), NOMA is advocated in 5G, enabling nonorthogonal channel access by multiplexing either power domain or code domain. NOMA-based communications between macrocell and vehicular users (VUs) are illustrated in Figure 2, where the macrocell transmits signals to multiple VUs and separates the bandwidth to multiple subchannels. VUs can reuse multiple subchannels for communication and transmission. Generally speaking, the macrocell in 5G can act as 1) a global communication router, 2) an MEC server, and 3) a software-defined networking-based local controller [4].

SAFETY-CRITICAL AND TRAFFIC-EFFICIENT APPLICATIONS ARE VIEWED AS TWO KINDS OF PROMISING SERVICES IN VEHICULAR NETWORKS.

By taking advantage of NOMA and MEC technologies, this article intends to maximize the achievable transmission rate by integrating both cellular and RSU access to offload network traffic dynamically. A vehicle-to-vehicle (V2V)-enabled predictive offloading scheme is designed first. After that, subchannel and power allocations are specified.

Overview of NOMA for MEC-Enabled Vehicular Networks

Because the study of NOMA technology for MEC-enabled vehicular networks is in its beginning stages, this section discusses the corresponding studies from the aspects of NOMA-based vehicular communications and MEC-enabled vehicular networks.

NOMA-Based Vehicular Communications

Safety-critical and traffic-efficient applications are viewed as two kinds of promising services in vehicular networks. The former has strict latency requirements, whereas the latter concentrates on guaranteeing

TABLE 1 A comparison of MEC and MCC.

Items	MEC	MCC
Architecture	Distributed, mobile operators	Centralized, cloud providers
Objective user	Mobile devices	Internet users
Hierarchy	Three tiers	Two tiers
Number of server nodes	Large	Small
Sharing population	Medium	Large
Data storage duration	Short	Long
Bandwidth requirement	Direct proportion to the data sent to clouds	Direct proportion to the data generated by clients
Communication overhead	Medium	High
Location awareness	Yes	No
Hardware	Limited computing power and storage space	Ample computing power and storage space
Service type	Localized information to specific deployment location	Worldwide global information
Deployment manner	Sophisticated or ad hoc manner	Sophisticated
Work environment	Outdoor or indoor	Indoor with large space and ventilation
Delay toleration	Tens of milliseconds or fewer	A few seconds or longer
Connectivity	Uninterrupted or intermitted	Uninterrupted
Major service provider	Cisco IOx	Amazon, Microsoft, IBM
Applications	Cyberdomain and cyberphysical applications	Cyberdomain applications

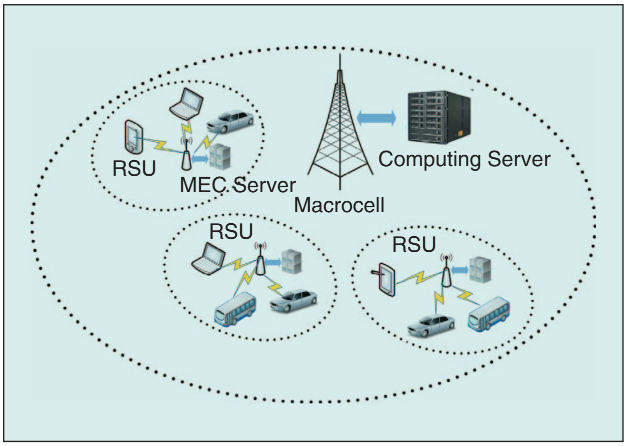

FIGURE 1 An illustration of MEC-enabled vehicular networks.

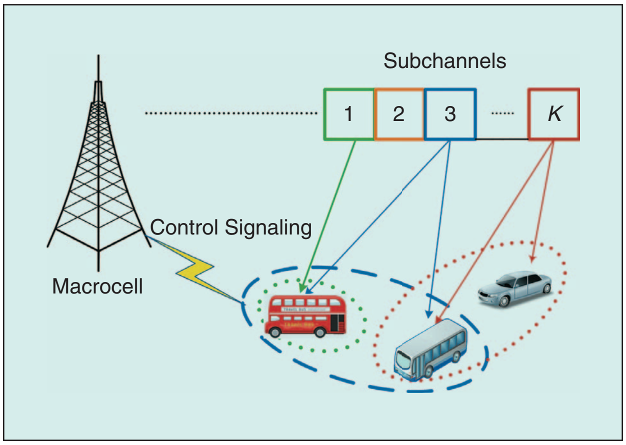

FIGURE 2 The NOMA for MEC-enabled vehicular networks.

continuous communications in a high-dynamic environment. Vehicle-to-everything communications, containing V2V and vehicle-to-infrastructure (V2I) communication patterns, require updated radio access technology to provide ubiquitous network converge and efficient spectrum utilization. The bandwidth of V2V communications is rather limited and unstable. However, V2I communications suffer from serious cochannel interference and unbalanced network traffic, especially in urban vehicular networks with dense network traffic demands. Although multiple-input, multiple-output technology can be leveraged to improve spectrum efficiency and link reliability, the achievable multiple-antenna gain is seriously degraded by channel correlation.

As an emerging technology in 5G networks, NOMA enables multiple users to reuse frequency resources in a nonorthogonal manner with the main advantages of spectrum, connectivity, and energy-efficiency improvements. To cope with high-speed moving vehicles and time-varying communication circumstances in vehicular networks, power allocation is investigated in NOMA-enabled vehicle-to-small-cell networks [5]. Because safety applications require low latency and high reliability, reducing access latency and improving the packet reception probability is rather challenging in urban vehicular networks with dense communications.

MEC-Enabled Vehicular Networks

One of the core requirements in 5G-enabled vehicular communications is low latency. By moving some core functionalities near to the edge devices, MEC will become a fundamental technology in 5G networks [6]. Collaborative MEC is promising to shed light on real-time context-aware applications. The idea of vehicular fog computing is proposed in [7], which employs underused vehicles (such as those in parking spaces) as the infrastructures for task computing and communications. By stimulating the collaboration of edge devices to offload computational and communicational tasks, the link connectivity and QoS index in MEC networks can be promoted. By leveraging both parked and moving vehicles as edge nodes, a feasible solution for real-time traffic management in MEC-enabled vehicular networks is to minimize the average response time of the reported events by vehicles [8]. By jointly considering the heterogeneous requirements of both vehicle mobility and computation tasks, an MEC offloading method is designed in [9] for vehicular networks to optimally select MEC servers and manage transmission tasks. According to the predicted transmission time, tasks are offloaded to MEC servers via either direct uploading or predictive relay forwarding. With the objective of relieving urban traffic congestion, an urban traffic management architecture is constructed by comprehensively leveraging the technologies of software-defined networking, MEC, and 5G [10]. A successful accident rescue application demonstrates the high-efficiency road accident response of the constructed architecture.

NOMA ENABLES MULTIPLE USERS TO REUSE FREQUENCY RESOURCES IN A NONORTHOGONAL MANNER WITH THE MAIN ADVANTAGES OF SPECTRUM, CONNECTIVITY, AND ENERGY-EFFICIENCY IMPROVEMENTS.

Although some efforts have been dedicated toward NOMA-based vehicular communications and MEC-enabled vehicular networks, the study of NOMA for MEC-enabled vehicular networks is almost nonexistent. Correspondingly, subchannel and power allocations for MEC-enabled vehicular networks with NOMA deserve to be well investigated. Motivated by these observations, this article integrates MEC-enhanced vehicular networks with NOMA technology to fully utilize the wireless spectrum for traffic offloading.

A NOMA-Based Offloading Scheme for Vehicular Networks Enabled by MEC

This section illustrates the system model before formulating the studied problem by network optimization.

System Model

The main components in the investigated system model contain macrocells, RSUs, and vehicles. The occurred events, e.g., traffic jams or traffic accidents, can be recorded by the drivers or passengers in the form of texts, pictures, or short videos. After that, the recorded information is packaged by vehicles before offloading. Vehicles are clustered, where a cluster head collects messages to reduce the communication cost. Then, a message is generated to illustrate the occurred event through feature extraction.

If the generated message is uploaded by the macrocell, the delay can be ignored. However, an additional fee is charged by the mobile operator. If the message is uploaded by an RSU, it is free but causes additional transmission delay. The bandwidth of the macrocell is divided into distinct subchannels. For an edge device within the coverage of a macrocell, its computing task includes three parts, i.e., task size, the required amount of CPU cycled for task computation, and the maximum tolerable latency.

We first demonstrate how to obtain the achievable transmission rate of VUs covered by the macrocell. In NOMA-based vehicular networks, one subchannel can be accessed by various VUs, and one VU can receive packets from the macrocell via multiple subchannels. Successive interference cancellation (SIC) can be leveraged to demodulate the target message after the

Messages are more likely to be offloaded by different vehicles or RSUs as the traffic arrival interval increases.

reception of superposed signals. Transmit power of each VU is allocated dynamically, where the VUs with better (worse) link states are assigned with low (high) transmit power levels. Signals with better link state can be recovered by SIC decoding, whereas the counterparts with worse link state are viewed as noise. We denote $h_{k,j}$ and $n_{k,j}$ as the channel gain and noise of user j over subchannel k, respectively. If $h_{k,j}/n_{k,j} > h_{k,j'}/n_{k,j'}$, user j can successfully decode the signals from VU j'. Due to the network complexity brought by SIC, we set the largest number of VUs sharing one subchannel simultaneously as d_f.

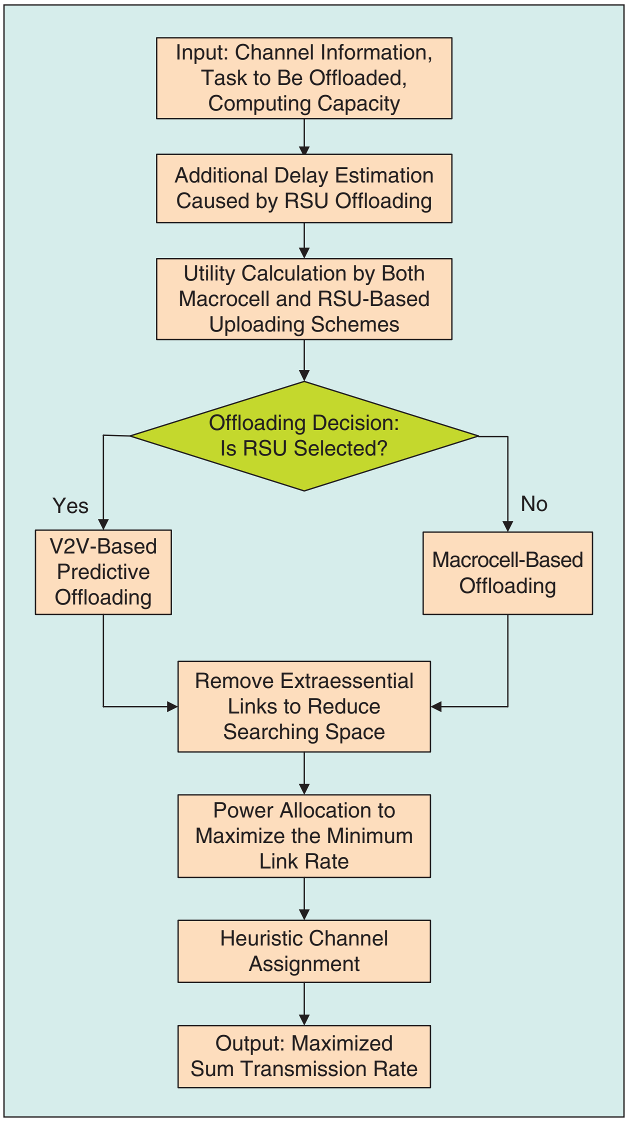

FIGURE 3 The flowchart of our heuristic scheme.

If VU j uploads messages to the macrocell directly, the achievable transmission rate is

$$r_{k,j}^{M} = \sum_{k \in K} W_{k,j} b_{k,j} \log_2\left(1 + \frac{P_{k,j} h_{k,j}}{n_{k,j} + I_{k,j}}\right), \tag{1}$$

where $W_{k,j}$ and $P_{k,j}$ are the bandwidth and transmit power of user j over subchannel k, respectively. Set K is the collection of subchannels. The binary variable $b_{k,j}$ denotes whether subchannel k is allocated to user j for offloading. The interference from other concurrent transmitted VUs to device i over subchannel k is denoted by $I_{i,k}$.

If the task from VU j is offloaded to edge device i, its achievable rate is

$$r_{i,j}^{E} = W_{i,j} \log_2\left(1 + \frac{P_{i,j} h_{i,j}}{n_{i,j} + I_{i,j}}\right), \tag{2}$$

where $W_{i,j}$ and $n_{i,j}$ represent the corresponding bandwidth and noise between edge device i and user j, respectively. $P_{i,j}$ and $h_{i,j}$ are the allocated transmit power and channel gain between device i and user j, respectively. $I_{i,j}$ can be defined similarly with $I_{i,k}$.

If network traffic is uploaded by the edge device, extra delay is caused, including the transmission delay, processing delay, and task execution time. The first part can be obtained by the ratio between the task size and the total transmission rate. The second part is the summation of the computation time for task processing. The third part is the ratio between the required number of CPU cycles to accomplish the computation task and the CPU-cycle frequency of the MEC server.

Problem Formulation

To support high-efficiency communications for MEC-enabled vehicular networks, this section intends to maximize the total transmission rate by considering both cellular and RSU-based offloading schemes, i.e., max $s_i r_{i,j}^{E} + (1 - s_i) r_{k,j}^{M}$. Herein, offloading decision is defined by s_i to denote whether network traffic is offloaded by RSU or not. The optimization problem becomes how to regulate the transmit power of VUs and allocate subchannels to maximize the overall transmission rate, which should satisfy the following constraints.

1) Each subchannel can be allocated to, at most, d_f VUs, and each VU can occupy at most d_v subchannels for the consideration of user fairness.
2) The summation of allocated transmit power to VUs over different subchannels cannot exceed the total transmit power of the macrocell.
3) The tolerated offloading delay should not exceed the maximum tolerable latency of the edge device.
4) Offloading decision and subchannel allocation variables are integer, and the allocated transmit power is a real variable.

The joint subchannel assignment and power allocation for NOMA in [11] has been formulated and demonstrated to be NP-hard. In this article, we take task offloading and user selection between macrocells and edge devices into consideration. Therefore, the investigated problem of our work is also NP-hard. In the next section, we put forward a heuristic algorithm to solve it by separating the formulated problem into offloading decision as well as power and subchannel assignment. The flowchart of our presented heuristic scheme is illustrated in Figure 3.

Offloading Decision

Vehicles can offload their computation tasks via either macrocells or RSUs. Offloading decision depends on the utility function, which has associations with the server reward for message uploading, message size, offloading cost, and delay.

The utility of macrocell offloading can be calculated by the access price of macrocell multiples of the required offloading traffic. Message offloading by RSU is free, but it causes additional delay compared with that by the macrocell. The delay mainly comes from the message forwarding time from the cluster head to the nearest RSU and the offloading time from RSUs to the traffic management server. It should be noticed that the accuracy of delay estimation affects offloading decision.

For the expected delay from the cluster head to the nearest RSU, the estimated delay for one road segment can be first worked by jointly considering the vehicle arrival rate, the average travel time of vehicles, and the probability density function of the message waiting time along road segments. If the estimated value is larger than the threshold, a macrocell is chosen for offloading; otherwise, an RSU is preferred for offloading.

Power Allocation and Subchannel Assignment

For the sake of fully considering the mobility characteristics and latency requirements of VUs, a hybrid scheduling solution is leveraged, where the macrocell performs semipersistent scheduling in a centralized manner, and VUs dynamically adjust their transmit power in a distributed way. The reasons are twofold. On one hand, centralized scheduling by macrocells will largely delay communications among VUs, and the acquirement of accurate channel state information (CSI) is challenging in dynamic vehicular networks. On the other hand, although CSI can be updated by distributed scheduling, it is not profitable for VUs to communicate in a contention-based manner, especially when they are within the coverage of macrocells.

With the observations mentioned, we put forward a two-step solution to cope with the joint power allocation and subchannel assignment problem. In the first step, the frequency resource is allocated to VUs by macrocells with global position information. Then, VUs regulate transmit power in a distributed way to enable real-time V2V communications.

BOTH NOMA AND MEC ARE VIEWED AS PROMISING TECHNOLOGIES TO PROVIDE MASSIVE CONNECTIVITY AND SUPPORT DELAY-SENSITIVE APPLICATIONS FOR NEXT-GENERATION NETWORKS.

According to the updated position information of VUs at the beginning of each scheduling period, a macrocell allocates frequency resources correspondingly. It should be noted that cochannel interference exists in NOMA-based vehicular communications. Define $x_{i,k}$ as an integer variable to denote whether VU i can access subchannel k. To maximize the transmission rate of the whole network, we intend to maximize the total number of $x_{i,k}$, i.e., connecting as many VUs as possible to subchannels. The following two constraints should be satisfied.

1) The value of link signal-to-interference-plus-noise ratio (SINR) should be above the threshold for decoding.
2) The maximum number of allocated subchannels for each VU and VUs within one subchannel should not exceed d_v and d_f, respectively.

Due to the complexity of the formulated problem, we present a heuristic solution to fully use the available numbers of subchannels and accessed VUs while satisfying network constraints. Define the maximum and minimum numbers of VUs accessed into the subchannel as $\varphi/\min(d_v, d_f)$ and $\varphi/\max(d_v, d_f)$, respectively, where φ is the total number of VUs to be accessed into the channel. We set the initial value of $x_{i,k}$ equal to $\varphi/\max(d_v, d_f)$. If a feasible access solution can be found (i.e., the constraints of SINR, subchannel allocation, and transmit power of accessed VUs can be satisfied), the initial value of $x_{i,k}$ increases by 1. Otherwise, the iteration process terminates, and the output is the corresponding number of the accessed VUs into subchannels. Power control is regulated in each iteration, which includes various transmitter–receiver blocks. In a transmitter block, the transmit power of each user is controlled so that the SINR requirement of transmission links can be satisfied while minimizing interference to other concurrent users. After that, the potential cochannel interference caused by transmitter users is computed in the receiver block before feeding back for analysis in the next transmitter block. An iterative power control method can be performed, such as the scheme in [12].

Performance Evaluation

This section demonstrates the effectiveness of our method. A real-world trajectory of taxies in Shanghai (China) in April 2015 is leveraged for evaluation, containing GPS locations, speed, and record time. According to the

PERFORMANCE EVALUATIONS DEMONSTRATE THAT OUR SCHEME CAN INCREASE TRANSMISSION RATE GAIN AND TRAFFIC OFFLOADING EFFICIENCY UNDER VARIOUS NETWORK CIRCUMSTANCES.

administrative division in Shanghai [13], we select Hongkou and Jingan Districts as examples for performance evaluation, where RSUs are deployed randomly. The number of RSUs is set to 15. The communication ranges of vehicles and RSUs are 50 and 300 m, respectively. The message size ranges between 40 and 500 MB [14]. The price charged by leveraging macrocell networks is US$0.007/Mb according to AT&T's prepaid plan. By considering fairness of VUs, we set d_v and d_f as 2 and 2, respectively.

To demonstrate the superiority of our method, we take both NOMA-based fog radio access networks (F-RANs) [15] and random offloading into consideration. The former comprehensively takes transmission rate and interference into account. However, the interaction between edge devices and the macrocell has not been fully considered. For random offloading, the offloading decision of macrocell and edge devices is chosen in a random manner.

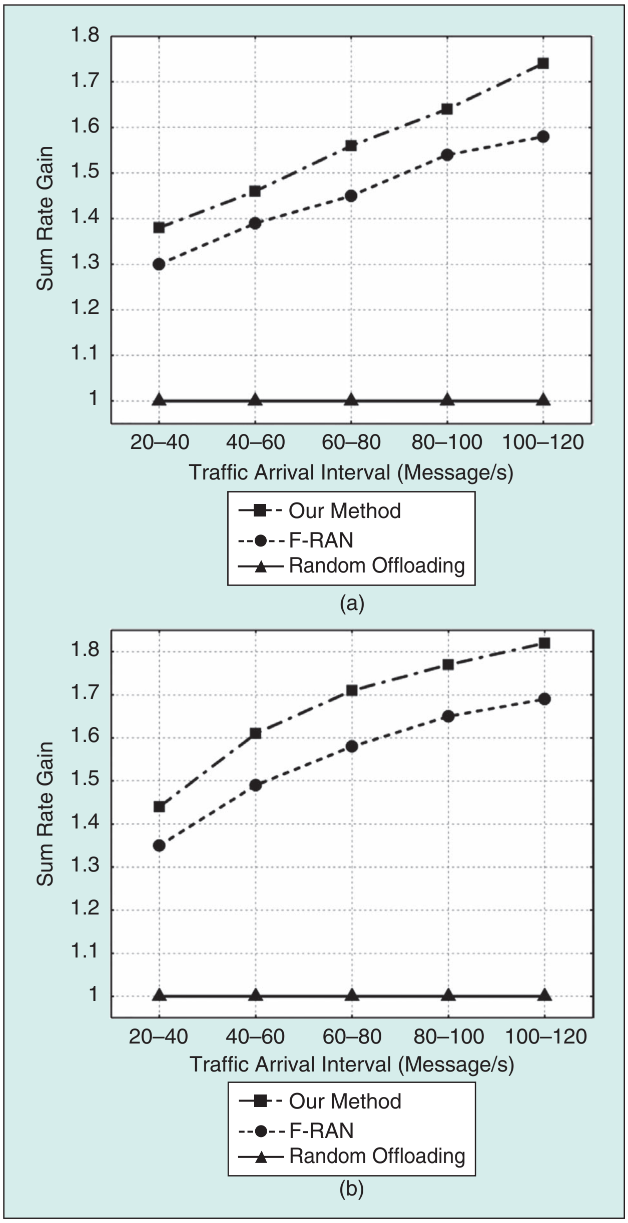

FIGURE 4 The sum rate gain in terms of traffic arrival intervals: (a) Hongkou District and (b) Jingan District.

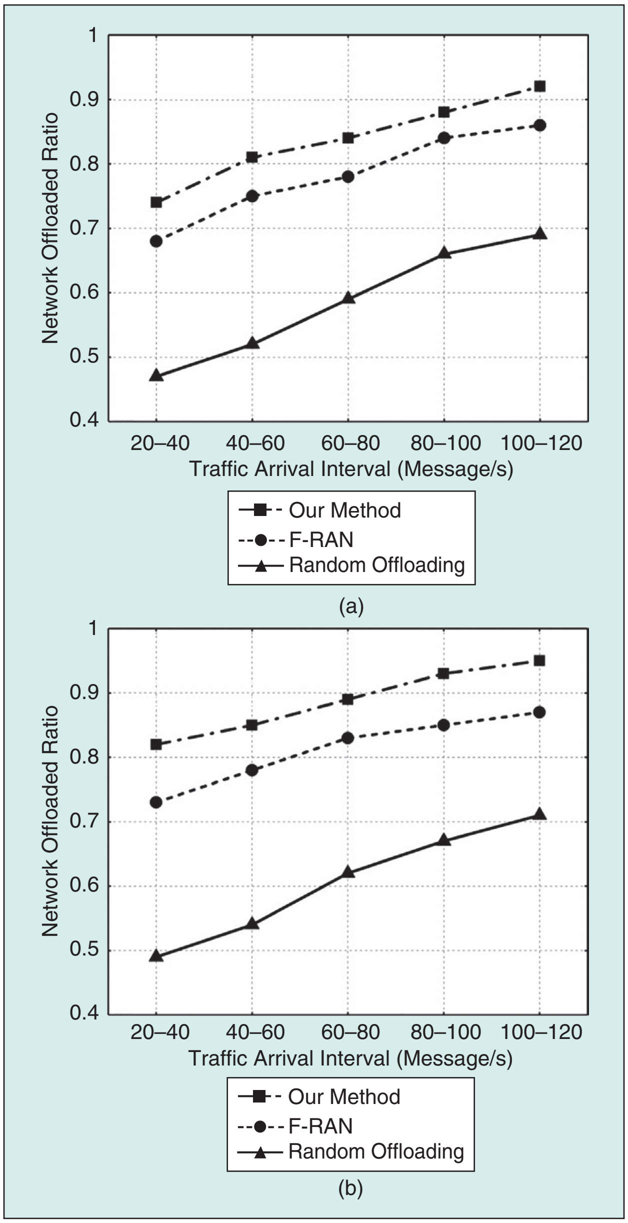

FIGURE 5 The network offloaded ratio in terms of traffic arrival rate: (a) Hongkou District and (b) Jingan District.

We first analyze the sum rate gain of different schemes in Figure 4, which is the ratio between the summation of the obtained transmission rate and that achieved by the random offloading solution. Obviously, our scheme performs better than the F-RAN scheme. For example, the sum rate gain obtained by our method is 1.74, whereas that in F-RAN is 1.58, when the traffic arrival rate is 100–120 messages/s in Figure 4(a). This is because our method considers the clustering-based traffic management, whereas the cooperative offloading is ignored by the F-RAN scheme. Similar trends can be found in Figure 4(b).

The network offloaded ratio achieved by these three methods is demonstrated in Figure 5, which is defined as the percentage of traffic that can be offloaded by either macrocells or RSUs. We can observe that the offloaded ratios of these three methods enhance as the speed of a vehicle increases. The main reason is that messages are more likely to be offloaded by different vehicles or RSUs as the traffic arrival interval increases. We also notice that the gained performances in Jingan District are better than those in Hongkou District. The main reason for this is the statistics regarding vehicles and traffic flows in different areas.

Conclusions

Both NOMA and MEC are viewed as promising technologies to provide massive connectivity and support delay-sensitive applications for next-generation networks. This article presents a NOMA-based scheme for vehicular networks enabled by MEC, which is an early attempt to offload network traffic by comprehensively leveraging the technologies of spectrum reuse and high-efficiency computing. Due to the high computational complexity of the formulated problem, a heuristic method is designed from the aspects of offloading decision, channel assignment, and power control. Performance evaluations demonstrate that our scheme can increase transmission rate gain and traffic offloading efficiency under various network circumstances.

Acknowledgments

This work was supported by the National Natural Science Foundation of China under grant 61502075, China Postdoctoral Science Foundation under grant 2018T110210, Fundamental Research Funds for the Central University under grant DUT17RC(4)49, and State Key Laboratory for Novel Software Technology, Nanjing University (KFKT2018B04).

Author Information

Zhaolong Ning (zhaolongning@dlut.edu.cn) is with the Key Laboratory for Ubiquitous Network and Service Software of Liaoning Province, School of Software, Dalian University of Technology, China; the School of Communication and Information Engineering, Chongqing University of Posts and Telecommunications, China; and the State Key Laboratory for Novel Software Technology, Nanjing University, China. His research interests include vehicular networks, edge computing, and network optimization. He is a Senior Member of the IEEE.

Xiaojie Wang (wangxj1988@mail.dlut.edu.cn) is with the School of Software, Dalian University of Technology, China. Her research interests are vehicular social networks and network security.

Jun Huang (jhuang@cqupt.edu.cn) is a professor with the School of Communication and Information Engineering, Chongqing University of Posts and Telecommunications, China. His current research interests include network optimization and control and quality of service. He is a Senior Member of the IEEE.

References

[1] Cisco, “Cisco visual networking index: Global mobile data traffic forecast update, 2015–2020,” Cisco, San Jose, CA, White Paper, 2016.

[2] S. Maharjan, Q. Zhu, Y. Zhang, S. Gjessing, and T. Basar, “Dependable demand response management in the smart grid: A Stackelberg game approach,” *IEEE Trans. Smart Grid*, vol. 4, no. 1, pp. 120–132, 2013.

[3] Y. Zhang, R. Yu, S. Xie, W. Yao, Y. Xiao, and M. Guizani, “Home M2M networks: Architectures, standards, and QoS improvement,” *IEEE Commun. Mag.*, vol. 49, no. 4, pp. 44–52, 2011.

[4] Y. Zhang, R. Yu, M. Nekovee, Y. Liu, S. Xie, and S. Gjessing, “Cognitive machine-to-machine communications: Visions and potentials for the smart grid,” *IEEE Netw.*, vol. 26, no. 3, pp. 6–13, 2012.

[5] L. P. Qian, Y. Wu, H. Zhou, and X. Shen, “Dynamic cell association for non-orthogonal multiple-access V2S networks,” *IEEE J. Sel. Areas Commun.*, vol. 35, no. 10, pp. 2342–2356, 2017.

[6] S. A. A. Shah, E. Ahmed, M. Imran, and S. Zeadally, “5G for vehicular communications,” *IEEE Commun. Mag.*, vol. 56, no. 1, pp. 111–117, 2018.

[7] X. Hou, Y. Li, M. Chen, D. Wu, D. Jin, and S. Chen, “Vehicular fog computing: A viewpoint of vehicles as the infrastructures,” *IEEE Trans. Veh. Technol.*, vol. 65, no. 6, pp. 3860–3873, 2016.

[8] X. Wang, Z. Ning, and L. Wang, “Offloading in Internet of Vehicles: A fog-enabled real-time traffic management system,” *IEEE Trans. Ind. Informat.*, vol. 14, no. 10, pp. 4568–4578, 2018.

[9] K. Zhang, Y. Mao, S. Leng, Y. He, and Y. Zhang, “Mobile-edge computing for vehicular networks: A promising network paradigm with predictive off-loading,” *IEEE Veh. Technol. Mag.*, vol. 12, no. 2, pp. 36–44, 2017.

[10] J. Liu et al., “High-efficiency urban traffic management in context-aware computing and 5G communication,” *IEEE Commun. Mag.*, vol. 55, no. 1, pp. 34–40, 2017.

[11] B. Di, L. Song, and Y. Li, “Sub-channel assignment, power allocation, and user scheduling for non-orthogonal multiple access networks,” *IEEE Trans. Wireless Commun.*, vol. 15, no. 11, pp. 7686–7698, 2016.

[12] Z. Ning, X. Wang, X. Kong, and W. Hou, “A social-aware group formation framework for information diffusion in narrowband Internet of Things,” *IEEE Internet Things J.*, vol. 5, no. 3, pp. 1527–1538, 2018.

[13] Wikipedia, “Administrative divisions of Shanghai,” 2018. [Online]. Available: Https://en.wikipedia.org/wiki/List_of_administrative_divisions_of_Shanghai

[14] Z. Ning et al., “A cooperative quality aware service access system for social Internet of Vehicles,” *IEEE Internet Things J.*, vol. 5, no. 4, pp. 2506–2517, 2018.

[15] H. Zhang, Y. Qiu, K. Long, G. K. Karagiannidis, X. Wang, and A. Nallanathan, “Resource allocation in NOMA-based fog radio access networks,” *IEEE Wireless Commun.*, vol. 25, no. 3, pp. 110–115, 2018.

VT