**Joint Task Offloading and Resource Allocation for Mobile-Edge Computing Enable Vehicular Networks**

**Power Control and Task Offloading for Cloud Assisted MEC in Vehicular Networks**

**Abstract—**

原来的In order to support delay-sensitive applications of vehicle equipment (V-UE) in the Internet-of-Vehicles (IoV) systems, it is necessary to allow V-UEs to offload their computationally intensive applications to a cloud or edge computing server. Where the uplink channel is reused by multiple vehicles. For the current Mobile-Edge computing enable vehicular networks, interference in the dense vehicle arena often leads to acutely poor communication quality. In addition, a vehicle’s mobility leads to an uncertain channel state and further affects the stability of communication. The resulting optimization problem corresponds to nonconvex fractional programming, and the block coordinate descent (BCD) algorithm and the successive convex approximation (SCA) technique is proposed to solve it. Furthermore, we decompose the problem into two subproblems for distributed and parallel problem-solving. Numerical simulations are performed to evaluate the algorithm performances, and the results indicate that the proposed algorithm is effective in high mobility under uncertain channel MEC-enable vehicular network environments.

自己改的Mobile-edge computing (MEC) has been witnessed as a promising solution for vehicular networks under massive data processing in the future. In this paper, a novel scheme for maximizing network utility has been proposed to solve this problem. MEC has limited computing resources, and the cloud which has huge computing resources needs to be allocated to the MEC to support large-scale data processing. However, the channel reuse technology is adopted to deal with the poor spectrum resources of the Internet of Vehicles, but it can bring co-channel interference, and the vehicle’s mobility leads to an uncertain channel state and affects communication stability. The first-order Markov process and a convex approximation method namely Bernstein approximations are raised to solve problems respectively. Furthermore, the resulting optimization problem corresponds to nonconvex fractional programming, finding the optimal result to ensure the best performance is a difficult task, then the block coordinate descent (BCD) algorithm and the successive convex approximation (SCA) technique is proposed to solve it. Numerical simulations are performed to evaluate the algorithm performances, and the results indicate that the proposed algorithm is effective in high mobility under uncertain channel MEC-enable vehicular network environments.

后来的Cloud-assisted mobile-edge computing (C-MEC) has been witnessed as a novel solution for task offloading in vehicular networks, which is able to provide rich computing resources. In this paper, a robust power control scheme is proposed to offload the computation task and maximize the utility of C-MEC networks. However,

an uncertain channel state seriously affects the stable transmission of the offloading signal. The first-order Markov process is adopted to simulate channel uncertainty, where vehicular mobility is highly considered. Moreover, channel reusing is assumed due to the limited spectrum resources, which leads to complex co-channel interference and communication delay. To depress the above challenges, probability constraints of signal links are constructed to ensure communication quality. Furthermore, the Bernstein approximations method is adopted to transform the original constraints into solvable ones. Scrupulously, the block coordinate descent (BCD) method and the successive convex approximation (SCA) technique are further adopted to solve the nonconvex robust optimization framework. Furthermore, a robust power control algorithm is proposed to approach the optimal solutions. Numerical simulations are performed to evaluate the system performances, and the results indicate that the proposed algorithm is effective and outperform the benchmarks, especially in communication environments with channel uncertainty.

**Ⅰ INTRODUCTION**

原来的Urban traffic congestion is becoming more and more serious, traffic accidents are becoming more frequent, and many environmental and energy problems are also caused. Vehicular networks are envisioned to deliver data transmission services ubiquitously, especially in the upcoming autonomous driving era. Accordingly, the high data traffic load poses a heavy burden to the terrestrial network infrastructure. The vehicle speed is fast and the network topology constantly changes under the Vehicle-To-Infrastructure (V2I) environment. The transmission of low delay is also required in intelligent driving tasks, then the data can be transmitted through V2I to complete the intelligent driving task, the vehicle can communicate with the base station (BS) directly or the relay vehicle can help to forward the data.

Considering the rich computing resources provided by the Internet, cloud-based vehicular networks have been proposed to address the explosive growth of computing task requirements of vehicles. Traditional cloud computing can no longer meet the stringent low latency requirement of smart driving. Emerging computing mode represented by MEC is rising rapidly \cite{Pang2021}. Roadside units (RSUs), which have strong computing capability and are close to vehicle nodes, have been widely used to process delay and computation-intensive tasks of vehicle nodes. Edge computing, which is an information hinge for vehicles and roadside units, can enhance the level of vehicle intelligence in the scene of vehicle-road synergy sensing \cite{Cai2014}. Therefore, multiaccess edge computing (MEC) or formerly mobile-edge computing, as new architecture and key technology for the emerging 5G networks, has been proposed to address the V2I problem \cite{sym2019}. Different from traditional mobile cloud computing (MCC), MEC migrates remote cloud computing resources to the edge of the network to curtail the end-to-end transmission delay of data and to free the computing and storage pressure of vehicles or roadside units \cite{Wang2020}. Our objective is to design a comprehensive solution for joint task offloading and resource allocation in a multi-server MEC-enable vehicular network. Specifically, we consider a multi-cell ultra-dense network where each base station (BS) is equipped with a MEC server to provide computation offloading services to the mobile vehicles.

遇到问题

提出问题

解决问题

车联网中由于车辆本身计算能力有限，因此面临着越来越多的任务卸载的需求，云计算与边缘计算被越来越多的人提出来解决此问题。越来越多的研究使用边缘计算来辅助进行任务的卸载，边缘计算的优点是处于网络的边缘，距离较近所以时延更小，但是边缘计算的计算能力仍然有限。然后文献支撑，有人用云计算来进行更大数据量的卸载，云计算有着更加富足的计算能力，更能胜任未来大数据卸载的需求，但是云计算往往距离网络比较远，在高动态的车联网中，有些数据对时间是敏感的，于是跟云计算与边缘计算相结合有望解决这个问题。

在网络模型构建介绍之后，我们希望这样的网络结构可以解决车联网中的任务卸载的问题。但是这样的网络结构中仍然存在着共信道的干扰并且影响着系统的可靠性，系统对通信与卸载时延的容忍度也提出了新的要求。所以功率控制与计算资源的联合分配是个解决这两个问题的好方法

总结:面对任务卸载的需求，云和边缘计算相结合的方式致力于解决这个问题。最后这部分做一个总结，网络结构+资源优化提出了一个有希望能解决这篇文章想要解决的大问题

**but the Doppler effect in the high mobility of vehicles poses a challenge to V2I communication.**

SINR level of V2V links in order to satisfy the communication conditions. High reliable communication quality

硕士论文中参考

MEC 支持新型应用程序和资源管理，并且在云中心和终端用户之间建立了协同管理体系从而进行高效通信。

自己改的The high data traffic load poses a heavy burden to the Vehicular Networks because of the limited of the computing resources. Mobile-edge computing (MEC) or mobile cloud computing (MCC), as new architecture and a key technology for the emerging 5G networks, has been proposed to address the V2I problem \cite{sym2019}. MEC migrates remote cloud computing resources to the edge of the network to curtail the end-to-end transmission delay of data and to free the computing and storage pressure of vehicles or roadside units \cite{Wang2020}. But the computing resources of MEC is still limited. Considering the rich computing resources provided by the Internet, cloud-based vehicular networks have been proposed to address the explosive growth of computing task requirements of vehicles. However, cloud computing centers tend to be far from the network. In the highly dynamic Internet of Vehicles, the amount of data will be produced by vehicles, which must be processed in a short period of time. Therefore, the (C-MEC) is expected to solve this problem.

Our objective is to design a (C-MEC) vehicular network. Specifically, we consider a multi-cell network where each Base Station (BS) is equipped with a MEC server to provide computation offloading services to the mobile vehicles. For MEC layer, which has moderate computation capacity and deploys close to networks, can be used to assist the vehicles. Cloud computing layer, can be used to process the large-scale, delay-insensitive data that MEC layer can not process. We hope that such a network structure can solve the problem of task offloading in the Internet of Vehicles. However, for the current Mobile-Edge computing enable vehicular networks, interference in the dense vehicle scenario often leads to acutely poor communication Quality of Service (QoS). In addition, a vehicle’s mobility leads to an uncertain channel state and further affects the stability of communication. So joint power control and computing resource allocation in multi-vehicles, the multi-MEC system will resolve the task offloading problem in a C-MEC vehicular network.

**A. Related Works**

这里是解决的方法，也可以是对云计算与边缘计算的解释

总分总

总

首先是移动性带来的多普勒效应

信道的复用带来了干扰，尤其在高速移动情况下更难处理

车辆设备对时延与传输的可靠性提出了容忍度降低因此提出了更高的要求

所以有了边缘计算和云计算可以更好的提高稳定性，

面对任务卸载会遇到的这些情况，大家针对这些问题研究了什么，通过云边结合之后有什么好处，有什么优势

分

具体的挑战，展开这些挑战，文献的扩充

信道不确定性怎么带来的，稀缺的频谱资源导致了使用信道复用可以提高效率，然后是高动态环境下干扰与信干噪比问题更难以处理，因此使用了贝恩斯坦近似的方法求解，时延的问题也是一个关键性的指标，使用了概率约束的方式，结合积分变换进行了求解

总结 通过建立这样的网络结构，然后使用这样的资源分配与功率控制方案，有希望解决车联网中面临的这样的问题

重点应该是融合MEC和MCC，列举文献来突出两种结合的优势

原来的Recently, some works have been devoted to solving problems of computation offloading of mobile devices in MEC or MCC-enable vehicle network architectures. Several works have focused on exploiting the benefits of computation offloading in MEC network. Note that similar problems have been investigated in \cite{Dai2022}, the horizontal and vertical cooperations between MEC cloud servers are utilized for balancing the workload distribution in dynamic vehicular environment.

Some papers investigated the computation offloading of mobile terminals in single-user scenarios. Aliyu et al. \cite{Ahmed2016} proposed a systematic review of MCC energy-aware issues and grouped some research works on battery energy in MCC into dynamic and nondynamic energy-aware task offloading \cite{Dai2022}. Investigate the service scenario of cooperative computation offloading in MEC-assisted service architecture, where multiple MEC servers and remote cloud offload computation-intensive tasks in a collaborative way \cite{Pang2021}, propose a hybrid transmission and reputation management strategy to accommodate the fast-changing IoV topology and to meet the low latency requirements of intelligent driving tasks. In the V2I networks, the authorized vehicular users with spectrum resources can directly communicate to the RSU. However, the scarce spectrum resources appear inadequate in high-density vehicular networks \cite{Xie2020}. To realize more V2X communication under the limited spectrum resources, Chen et al. \cite{Chen2017} proposed a Device-to-Device (D2D) crowd framework where a massive crowd of devices at the network edge leverage network-assisted D2D collaboration for computation and communication resource sharing. D2D connects two geographically close devices to achieve low latency communication. D2D can improve spectrum efficiency, reduce cellular network pressure and optimize network performance \cite{Liu2015}. Zhou et al. \cite{Zhou2017} investigated dynamic sharing of the 5G spectrum and proposed a sharing architecture of DSRC and the 5G spectrum for immersive experience-driven vehicular communications. Tran et al. \cite{Tran2019} design a holistic solution for joint task offloading and resource allocation in a multi-server MEC-assisted network. As the vehicles transmitting to the same BS use different sub-bands, the up-link intra-cell interference is well mitigated. It can be see effective channel reusing is crucial \cite{Liang2021}, \cite{Liang2017} studies resource allocation problems under the one-to-one reusing mode, but the spectrum efficiency of the whole system is low. In order to address the defects of one to one reusing mode, the authors introduce a many-to-one reusing mode where the spectrum utilization is well improved \cite{Ren2015}.

The moving vehicles, can communicate with different MEC servers in different time slots, and each MEC can only connect with vehicles within its coverage. For the high-speed V2I communication, the generated Doppler effect has a significant influence on the small-scale fading of CSI and thereby causes the fast channel variations. So the temporal correlation coefficient $$ is a function of the speed $$ and decreases as $$ increases, the average sum-rate degenerates as $$ grows larger, which means that a larger speed probably endows the acquisition of real-time CSI with more difficulty \cite{Chen2022}. In other words, the CSIs used are outdated. Therein, the Bernstein approximation method has commonly been used to deal with this difficult handling non-convex problem \cite{Wang2015}. To deal with the interference constraint, the probability constraint is constructed to depress the uncertain co-channel interference. And the Bernstein approximation method is used to transform it into a solvable closed form. To deal with the outage probability constraint, we assume the CSIs are obtained through channel estimation \cite{Xiao2020}. Therefore, the outage constraint is transformed according to the Bernstein-type inequality to make it a deterministic optimization problem. Based on the characteristics of our constraints, Bernstein method is also used in this paper.

Some papers focused on the problem of computation offloading in the multiple users’ scenario. Tan and Hu \cite{Tan2018} designed a joint communication, caching and computing problem for achieving the operational excellence and the cost efficiency of the vehicular networks. \cite{Wang2020} formulated the problem as a generalized NE problem and presented a game theory algorithm to analysis the equilibrium problem. It is assumed in \cite{Wang2020} that the vehicles use a constant transmit power while our approach optimizes vehicles’ transmit power. However, it seems like a new problem because the objective function is difficult to handle. Nemirovski and Shapiro have proposed a convex approximation approach in \cite{Nemirovski2007} that can solve it. In summary, most of the existing works did not consider a holistic approach that jointly power control and the computing resource allocation in a multi-vehicles, multi-MEC system as considered in this paper.

自己改的Related Works Recently, some works have been devoted to an IoV edge computing network, consisting of a cloud computing layer and MEC layer vehicle network architectures. But the Doppler effect in the high mobility of vehicles poses a challenge to V2I communication. interference caused by channel reuse in the vehicle scenario often leads to acutely poor communication quality. Vehicle equipment has a reduced tolerance for delay and transmission reliability, so higher requirements are put forward. Aliyu et al. \cite{Ahmed2016} proposed a systematic review of MCC energy-aware issues and grouped some research works on battery energy in MCC into dynamic and nondynamic energy-aware task offloading \cite{Dai2022}. \cite{Zhou2019} Proposed a hierarchical computing framework for vehicular networks which is composed of the control layer, the VEC server layer, and the vehicular network layer. Investigate the service scenario of cooperative computation offloading in MEC-assisted service architecture, where multiple MEC servers and remote cloud offload computation-intensive tasks in a collaborative way \cite{Pang2021}, propose a hybrid transmission and reputation management strategy to accommodate the fast-changing IoV topology and to meet the low latency requirements of intelligent driving tasks.

In the V2I networks, the authorized vehicles with spectrum resources can directly communicate to the RSU. However, the scarce spectrum resources appear inadequate in high-density vehicular networks \cite{Xie2020}. Zhou et al. \cite{Zhou2017} investigated dynamic sharing of the 5G spectrum and proposed a sharing architecture of DSRC and the 5G spectrum for immersive experience-driven vehicular communications. Tran et al. \cite{Tran2019} design a holistic solution for joint task offloading and resource allocation in a multi-server MEC-assisted network. As the vehicles transmitting to the same BS use different sub-bands, the up-link intra-cell interference is well mitigated. It can be see effective channel reusing is crucial \cite{Liang2021}.

When the fast-moving vehicles communicate with different MEC servers in different time slots, and each MEC can only connect with vehicles within its coverage, the generated Doppler effect has a significant influence on the small-scale fading of CSI and thereby causing fast channel variations. In other words, the CSIs used are outdated. First-order Gauss-Markov process is adopted to describe the impacts of the Doppler frequency shift on the channel in \cite{Liu2019}. So the temporal correlation coefficient is a function of the speed $$ and decreases as $$ increases, the average sum-rate degenerates as $$ grows larger, which means that a larger speed probably endows the acquisition of real-time CSI with more difficulty \cite{Chen2022}. Therein, the Bernstein approximation method has commonly been used to deal with this difficult handling non-convex problem \cite{Wang2015}. To deal with the interference constraint, the probability constraint is constructed to depress the uncertain co-channel interference. And the Bernstein approximation method is used to transform it into a solvable closed form. To deal with the outage probability constraint, we assume the CSIs are obtained through channel estimation \cite{Xiao2020}. Therefore, the outage constraint is transformed according to the Bernstein-type inequality to make it a deterministic optimization problem. Based on the characteristics of our constraints, Bernstein method is also used in this paper.

Moreover, due to the outstanding performance in low communication delay and computing delay, Li et al. introduce the outage probability constraint to guarantee the reliability of vehicular links \cite{Li2020}. Considering that the exact expression contains the exponential integral function, to make it tractable, consider an approximate closed-form expression such that the computational complexity can be reduced.

Some papers focused on the problem of computation offloading in the vehicle computing scenario. Tan and Hu \cite{Tan2018} designed a joint communication, caching and computing problem for achieving the operational excellence and the cost efficiency of the vehicular networks. \cite{Wang2020} formulated the problem as a generalized NE problem and presented a game theory algorithm to analysis the equilibrium problem. In summary, most of the existing works did not consider a holistic approach that jointly power control and the computing resource allocation in a multi-vehicles, multi-MEC system as considered in this paper.

It is assumed in \cite{Wang2020} that the vehicles use a constant transmit power while our approach optimizes vehicle’s transmit power. However, it seems like a new problem because the objective function is difficult to handle. Nemirovski and Shapiro have proposed a convex approximation approach in \cite{Nemirovski2007} that can solve it. Aiming at the non-convex of the problem with two variables, Some research decouples the original problem into two subproblems and deploys the block coordinate descent (BCD).

**B. Challenges and Contributions**

**Generally, for the low-speed V2I communication case, the Doppler effect is not noticeable, thereby being ignored, but the high mobility of vehicles poses a challenge to V2I communication. it is analyzed that the original stochastic optimization problem with two variables can be transformed into a deterministic non-convex optimization problem. It is likely to bring a new difficulty.**

**In this paper, The main contributions are summarized as follows:**

* The Doppler effect in the process of high-speed movement of vehicles will affect the communication quality between vehicles and roadside units, different from previous studies, this paper considers the mobility of vehicles in the research of the edge computing system of the Internet of Vehicles, and verifies the adverse effects of vehicle mobility through comparative simulation
* We propose an efficient hybrid transmission task scheduling strategy. The transmission mode is predicted, and the task is scheduled according to the vehicle context. V2V transmission is adopted to minimize the delay when the task-initiating vehicle cannot complete the task independently
* Considering the channel uncertainty caused by the high-speed movement of vehicles in the scenario of the Internet of Vehicles, the first-order Markov process is introduced. A reasonable and feasible IoV network scenario is constructed to more realistically describe the dynamic characteristics of the Internet of Vehicles. The Bernstein approximation method previously used in interference constraints is improved and generalized, and it is applied to the matrix form of interruption probability to deal with non-convex outage constraint in large-scale dynamic vehicle network environments to ensure the quality of network communication services
* 贡献点
* 不同于以往的研究新意是什么，什么被提出，考虑解决了什么，建立了什么样的模型
* 云边协同的好处是什么
* 不同于以往的研究，本文研究了云计算与边缘计算协同情况下的车联网，提出了鲁棒的功率控制算法与计算资源分配方案，考虑了低时延与高可靠性的网络结构，建立了(C-MEC)模型辅助车辆完成任务卸载并保证通信的质量。

The remainder of this article is organized as follows: the model of computation offloading in MEC-assisted vehicular networks is established defines in Section II. In Section III, the probability constraints and the objective function of the primal problem are formulated, and the optimization is proposed. In Section IV, simulation results and performance analysis are presented. Finally, we draw a conclusion in Section V.

自己改的贡献点 **In this paper, a robust power control and task offloading algorithm is proposed for the cloud assisted MEC in vehicular networks with highly dynamic vehicles. The communication delay and computing delay are guaranteed by probabilistic constraints, and vehicle QoS is also guaranteed in the framework. The main contributions of this paper include the following aspects:**

**We present a C-MEC vehicular networks for computation offloading architecture. For MEC layer, which has moderate computation capacity and deploys close to networks, can be used to assist the vehicles. Cloud computing layer, can be used to process the large-scale, delay-insensitive data that MEC layer can not process.**

**Considering the channel uncertainty caused by the high-speed movement of vehicles in the scenario of the Internet of Vehicles, the first-order Markov process is introduced. A reasonable and feasible IoV network environment is constructed to more realistically describe the dynamic characteristics of the Internet of Vehicles. The Bernstein approximation method previously used in interference constraints is improved and generalized, and it is applied to the matrix form of interruption probability to deal with non-convex outage constraint in large-scale dynamic vehicle network environments to ensure the quality of network communication services.**

**Our proposed algorithm considers cross-layer computation and communication resources to guarantee the vehicle QoS and various task requirements under C-MEC vehicular networks.**

The remainder of this article is organized as follows: the model of power control and task offloading for cloud assisted MEC in vehicular networks is established deﬁnes in Section II. In Section III, the probability constraints and the objective function of the primal problem are formulated, and the optimization is proposed. In Section IV, simulation results and performance analysis are presented. Finally, we draw a conclusion in Section V.

**Ⅱ SYSTEM MODEL**

系统模型就不要再解释了，直接说我建立了什么样的模型

原来的In this paper, we consider a IoV edge computing network, consisting of a cloud computing layer, MEC layer, as shown in Fig. 1. For MEC layer, which has moderate computation capacity and deploys close to networks, can be used to assist the vehicles. Cloud computing layer, can be used to process the large-scale, delay-insensitive data that MEC layer can not process. \cite{Cui2021} Numerous vehicle-to-RSU (V2I) cells underlay a cell. In which each RSU is equipped with a MEC server to provide computation offloading services to the vehicles. To avoid inter-cell interference, the time division multiple access (TDMA) communication technology is adopted. Time resource is divided into multi-frames, and each frame is divided into several time slots. Different vehicles access its time slots when they communicate with the RSU, and signal transmission in different time slots will produce no interference [10]. We denote the set of vehicles and MEC servers in the mobile system as $$ and $$, respectively. Some notations are given in Table I.

自己改的In this work, the road network is divided into multiple geographic zones within the RSU’s coverage in Fig. 1, which is composed of the MEC layer, and the cloud computing layer hierarchical architecture of computation offloading, numerous vehicle-to-RSU (V2I) cells underlay a macro cell. In which each RSU is equipped with a MEC server to provide computation offloading services to the vehicles. The detailed offloading process is described as follows. Firstly, the vehicles offload request messages by the wireless interface, which includes required communication resources, the task ID and submission time, and the expected service delay of the task to the cloud. Secondly, the MEC server makes scheduling according to the received request messages, including the task upload server and task computation server. Finally, after task upload, the task waits in the computation queue until one of the processors is available. We denote the set of vehicles and MEC servers in the mobile system as $$ and $$, respectively. Some notations are given in Table I.

Remark1

**In this paper, we only consider the simplified single-segment case in order to derive a tractable solution. The more complicated multi-segment case is beyond the scope of this paper and will be investigated in future works. Nevertheless, the proposed solution can be easily extended to the multi-segment scenario by adopting a** time division multiple access communication technology**. That is, the number of vehicles in each segment remains constant within a slot and varies across different slots. Hence,** time resource is divided into multi-frames, and each frame is divided into several time slots. Different vehicles access its time slots when they communicate with the RSU**.**

**A. Communication Model**

Different from the traditional cellular communication, Due to the fast mobility of vehicles, their CSIs are hard to be estimated precisely. In particular, RSU can only achieve the accurate knowledge of large-scale fading $$ of vehicular to RSU links while the small-scale fading $h$ is greatly influenced by the fast channel variations caused by the Doppler effect. We assume the CSIs are obtained through channel estimation \cite{Xiao2020}, Therefore, we model the small-scale fading channel estimation of $$ by using the first-order Gauss-Markov process \cite{Kim2011} in each transmission time interval (TTI) as follows.

We assume that the estimated channel gain $$ denotes the estimate of $$ and $$ is exponentially distributed with unit mean \cite{Sakr2014}. Furthermore, $$ represents the correlation coefficient over $$ link, and $$ stands for the channel gain and follows a complex Gaussian distribution $$ and independent and uncorrelated of $$. The coefficient $$ quantifies the channel correlation between the two consecutive time slots and we assume that time correlation coefficient $$ is same for all VUEs. According to the Jakes statistical model for the fading channel \cite{Kim2011}, $$ is given as $$ , where $$ is the zero-order Bessel function of the first kind. $= $ is the maximum Doppler frequency, where $$ indicates the vehicle speed, $$ indicates the carrier frequency at 5.9 Ghz, and $$, $$ is a period feedback latency. erally, both transmitter vehicles and RSU can know the accurate $$.

Based on the aforementioned discussion, the mobile V2I channel power gain of the effective links and interference links in $$ time slot from $$ transmitter to $$ receiver can be expressed as a shared expression:

Where $ $, $ $, and $ $ denotes the kth time slot large-scale fading effects including shadow-fading and path loss from $$ transmitter to $$ receiver on the road section. Moreover, $$ is an observed value. $$ denotes an exponential random variable with parameter,

$$

To improve the spectrum utilization and realize multi-vehicles joint communication, V2I communications reuse the same uplink channel. In this case, the Signal-to-Interference-plus-Noise Ratio (SINR) from vehicle $$ to RSU can be formulated as,

$$

Where $$ denotes the transmit power of the $$ vehicles, where $$ is the background noise. Therefore, the deterministic equivalent transmission rate of VUEs calculated by Shannon’s theorem is,

$ $

Hence, the transmission time of vehicle $$ when sending its task input $$ in the uplink can be calculated as,

$ $

Where $$ is the bandwidth of the reused channel. Therefore, the upload time of each V2I link can be formulated as,

$ $

And $$ is the amount of input data including system settings, program codes, and input parameters, which is necessary to transfer the program execution.

Communication delay is another significant index that affects the performance of wireless networks. The packets to V2I receivers must be in the queue before they transmit at the speed of $$. It is assumed that the process of a packet arriving at the $$ V2I receiver is a Poisson process with parameter $$, and the length of the data packet obeys the exponential distribution of parameter $$. We develop the M/M/1 model instructions the relationship between the expected delay and transmission rate of the $$ V2I links can be expressed as,

$$

**B. Vehicle Computation Mode** l