A Multi-Hop VANETs-Assisted Offloading Strategy in Vehicular Mobile Edge Computing

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ABSTRACT Mobile edge computing (MEC) is a suitable solution to improve computational capabilities in vehicular environments, and the computation offloading plays a critical role in MEC. After the computation task generates, in traditional offloading strategies, vehicles offload data only when they have entered the communication range of the MEC server, which greatly increases the time cost and cannot satisfy the delay requirement of certain applications in many cases. To deploy a large number of MEC servers for full coverage of roads is not a realistic solution due to its high construction cost. In this paper, we make full use of the multi-hop vehicular ad hoc networks (VANETs) to assist in computation offloading of vehicles. In the real-time traffic environment, based on the link correlation theory in VANETs, the reliability model of multi-hop routing path is built. Meeting the delay constraints, the optimal offloading strategy with the lowest relaying and computing cost is executed by the binary search algorithm. The simulation results show that the proposed multi-hop VANETs-assisted offloading strategy (MHVA) shows better performance in offloading delay and cost than existing typical strategies under various environments.

INDEX TERMS Mobile edge computing, computation offloading, VANETs, link correlation, cost optimization.

I. INTRODUCTION

Advances in the Internet of Things (IoT) and wireless communication technology contribute to the developments of vehicle intelligence and support to various applications such as autonomous driving and cloud computing. With consistent progress and emergence of new applications, the computing resource for vehicles has played increasingly a prominent role [1]–[4]. Although new mobile devices are becoming more powerful in terms of data-processing capability, they cannot retrieve and process large volume data in a short time, which are not satisfactory for the constraint of delay time in some certain applications [5], [6]. In addition, high battery consumption is still a serious obstacle which limits users’ full access to demanding applications on their devices.

Cloud computing has the feature of centralized computation and storage in the cloud server, which can provide the remote storage capacity and computational facilities for mobile nodes. However, for a large number of running vehicles with high mobility, how to ensure the delay requirement and an active end-to-end connection are the questions we have to face.

Mobile edge computing (MEC) is a promising solution [5]–[7]. By distributing intensive computational work to the MEC servers around vehicles, the computational delays can be reduced, the energy consumption can be saved and the computational quality can be greatly improved [8]–[10]. Due to the proximity of user equipment, MEC sever provides a fast interactive response and a relatively stable wireless network condition for computation offloading, and enhances the user experience in many delay-sensitive applications. However, MEC servers always have limited computing resource, which sometimes makes it impossible to fully meet all the vehicles’ offload requirements within specified delay constraints, especially in a busy traffic environment.

The computation offloading strategy plays a crucial role in MEC, especially in the vehicular environment. Some studies add the consideration of the utilization of vehicular
networks [11]–[16] to the mobile edge computing. However, with the high-speed mobile vehicles and the rapidly changing network topology, two important factors in computation offloading, i.e., delay and cost can hardly be well treated. Furthermore, in the multi-hop environment of vehicular ad hoc networks (VANETs), having the aid of other vehicles to offload data to the MEC server, task vehicle (i.e., the vehicle demands to offload its computation task currently) charge a fee for their data relaying service is reasonable and practicable in the visible future. However, as far as we know, in most of existing computation offloading strategies, only the calculation cost on the MEC Sever is considered. In addition, a large computation task may form a calculating pressure on only one receiving MEC server and higher delay in the multi-hop delivering. How to handle the divided different data parts of the task separately presents a very challenging problem for strategy design.

Aiming at the reducing transmission delay, saving the offloading cost of vehicles and increasing the work efficiency of MEC servers, in this paper, we apply the consideration of VANETs multi-hop routing to the mobile edge computation offloading, which enables the data to be transmitted in advance; the link correlation theory [17], [18] is adopted to analyze the most suitable forwarding path for each computation task; and the optimization mechanism for both relaying and calculation cost is executed under the delay constraint.

The main contributions of this paper are as follows:
1) Multi-hop connection in VANETs is used to transmit the offloading data, which can save the waiting time for the vehicle which is not in the transmission range of MEC Sever and then satisfy the delay requirement of more applications.
2) For each data block in one offloading task, based on the characteristics of VANETs environment, we utilize the link correlation theory to evaluate the quality of each multi-hop path separately which can make the delay estimation more reasonable and accurate.
3) Besides calculation cost on the MEC server, the concept of relaying cost on vehicle-nodes which help to relay packets during the computation offloading is proposed for the first time. The optimization problem of offloading cost under the delay constraint is studied as well. The model which is built to describe the offloading delay and cost is applicable to most vehicular network environments.

The rest of the paper is organized as follows: Section II discusses the related work. Section III presents the offloading path quality model in VANETs. Section IV presents the proposed minimum cost offloading strategy under the delay constraint. Section V analyzes the simulation results. Finally, we conclude this paper in Section VI.

II. RELATED WORK
In this section, we summarize the existing work related to offloading strategy in mobile edge computing.

In [19], by analyzing the average delay of each task and the average power consumption of mobile devices, a power-limited delay minimization problem is established, and an effective one-dimensional search algorithm is proposed to find the best task scheduling strategy. In [20], a common optimization of the transmission power under the application-defined average delay constraint is proposed to minimize the power consumption requirements of the mobile terminal. Leveraging the idea of software defined network, authors in [21] investigate the task offloading problem in ultra-dense network aiming to minimize the delay while saving the battery life of user’s equipment. A MIMO multi-cell system [22] is considered in which several mobile users (MUs) require offloading computing tasks to the public cloud server through their nano access points. The computational shunt problem is expressed as a joint optimization of broadcast and computing resources. A green MEC system with EH equipment is studied in [23], and execution costs that solve the execution delay and task failure are used as performance indicators. In [24], with the objective of minimizing the long-term average weighted sum power consumption of the mobile devices, the authors develop an online joint radio and computational resource management algorithm for multi-user MEC systems. However, without consideration of specific environment, above optimizations in computation offloading have limited effect for the vehicular network with high mobility.

In [25], a collaborative approach based on MEC and cloud computing that offloads services to automobiles in vehicular networks is proposed. The cloud-MEC computation offloading problem is formulated through jointly optimizing decision and resource allocation. In [26], a method for effectively utilizing the potential resources of Internet vehicles is proposed to alleviate the congestion problem in other data networks. To further reduce the latency and the transmission cost in the computation offloading, an efficient cloud-based mobile edge computing vehicular network offloading framework is designed through a contract theoretic approach in [27] and [28]. In [29], a three-layer fog calculation (VFC) model was proposed to support distributed traffic management to minimize vehicle collection and reporting time. Although fog calculation has the advantages of position sensing and low latency, the requirements for ubiquitous connectivity and ultra-low latency are becoming more and more powerless. In [30], an adaptive resource allocation approach is investigated to enhance the user experience in vehicular edge computing networks. Specifically, leveraging the idea of task scalability, a model for balancing computing quality and resource consumption is introduced to exploit the computational resources fully. In [31], the authors propose integrating load balancing with offloading, and study resource allocation for a multiuser multiserver VEC system in vehicular edge computing and networks. Although above research works take into consideration the specifics of vehicular networks in computation offloading, the multi-hop delivery in VANETs is not well studied and utilized to offload the computation data, and then the offloading delay can be not reduced further. Moreover, the relaying cost on the vehicle-nodes which help to relay packets during the computation offloading is not considered in them.
III. ROUTING PATH QUALITY MODEL IN VANETS

So far, most of strategies start to offload computation task until the vehicle enters the MEC Sever communication range as shown in Fig. 1 (a). For some applications with high real-time requirements, the waiting time is too long to meet the delay constraint. The proposed offloading scheme in this paper is based on the support of VANETs. As illustrated in Fig. 1 (b), once the vehicle needs to offload computation data to the MEC sever, it can immediately execute offloading through the multi-hop connection if the current network condition allows, which greatly reduces the offloading delay. Furthermore, with the assistance of VANETs, the number of MEC severs needing to be deployed can be reduced significantly, and it can support more application scenarios of the vehicular mobile edge computing.

During the offloading process, the whole task volume is divided into multiple data blocks. Each data block needs to be forwarded through multi-hops relaying to reach its MEC sever selected. In VANETs environment, the key problem in seeking and selecting a stable and low-latency multi-hop path to offload computation task is how to estimate the quality and the delay of each link (i.e., the link availability). In the proposed model, we evaluate the distance after a certain time between each pair of successive vehicles, and then calculate the connectivity probability and the required number of retransmissions, finally determine the quality of the whole path which can support the selection of optimal offloading path in section IV.

A. LINK AVAILABILITY

The link we called in this paper is the one-hop connection between two successive vehicles in VANETs. We assume that each vehicle is equipped with the global position system (GPS) and the digital map. And then it can easily acquire the information about its own position, velocity, moving direction, etc. For selecting the optimal next relay node, every vehicle maintains an information table of its neighbors by the periodical exchanging beacon message. However, due to the high mobility of vehicles, these information may be outdated, which results in the irrationality and unavailability in relay node selection as shown in Fig. 2. The multi-hop connection is active at time $t_1$, but if there is a vehicle which has left the communication range of the last one at time $t_2$ and the source vehicle continues to use the outdated neighbors’ information to forward the packet, packet dropping occurs. In this paper, according to the link correlation theory, the estimation of the connectivity probability (i.e., link availability) between two successive vehicle nodes after a certain time is calculated by means of the prediction of vehicles’ positions. To achieve that, we build the model using current neighboring vehicles’ information such as positions, velocities, accelerations and timestamps of them.

We assume that the sequence of vehicles on the road (i.e., one-dimensional queuing) is $\{C_1, C_2, C_3, \ldots, C_n\}$. According to the results of [32], [33], vehicle’s mean velocity under the ideal motion is stable, and the velocity variation $\Delta v$ follows the standard normal distribution. In real environment, the vehicle does not run at a uniform velocity consistently, and it is in an unstable state. Therefore, a Brown motion model can be introduced to describe the velocity changing. With the velocity variation $\Delta v$, the Brown motion model is described as follows:

$$\Delta v_{i,t_1,t_2} = v_{i,t_2} - v_{i,t_1} = \mu_i (t_2 - t_1) + \sigma_i \sqrt{t_2 - t_1}$$

where $\Delta v_{i,t_1,t_2}$ is the changing amount in velocity during $[t_1,t_2]$ of vehicle $C_i$, $v_{i,t_1}$, $v_{i,t_2}$ are the velocities of $C_i$ at
$t_1, t_2$ respectively, $\Delta v_{i,t_1,t_2}$ follows the Gaussian distribution with the parameter $\mu_i$ and the Brown motion model with the parameters $\sigma_i$. Note that, due to different traffic density, the vehicle may be in different motion state, i.e., accelerating, decelerating and uniform motions. Then $\mu_i$ may mean the acceleration or deceleration of the vehicle in current motion process and does not always equal to 0 in the uniform motion. According to this equation, the actual motion state of a moving vehicle can be described.

In this case, the distance $\text{dis}(C_i, C_j, n\Delta t)$ between any two successive vehicles after $n\Delta t$ is:

$$\text{dis}(C_i, C_j, n\Delta t) = \sum_{k=1}^{n} (v_{i,t_k} - v_{j,t_k} + \Delta v_{i,t_k} - \Delta v_{j,t_k}) \cdot \Delta t,$$

(2)

where $v_{i,t_k}$ and $v_{j,t_k}$ denote the velocities of vehicle $C_i$ and $C_j$ at the time $t_k$. As $\Delta v_{i,t_k}, \Delta v_{j,t_k}$ follow the Gaussian distribution with parameters $\mu_i, \mu_j$ respectively and the Brown motion model with the parameters $\sigma_i, \sigma_j$ respectively. Then $\Delta v_{i,t_k} - \Delta v_{j,t_k}$ also follows the Gaussian distribution subject to the parameter $\mu_i - \mu_j$:

$$\Delta v_{i,t_k} - \Delta v_{j,t_k} \sim N\left(\mu_i - \mu_j, \sigma_i^2 \Delta t + \sigma_j^2 \Delta t\right),$$

(3)

$$\Delta v_{i,t_k} \sim N\left(\mu_i, \sigma_i^2 \Delta t\right),$$

(4)

$$\Delta v_{j,t_k} \sim N\left(\mu_j, \sigma_j^2 \Delta t\right).$$

(5)

By utilizing equivalent transformation, the changed amount in distance between any two successive vehicles after $n\Delta t$ can be calculated as:

$$\text{dis}(C_i, C_j, n\Delta t) = (\bar{v}_i - \bar{v}_j + \Delta v_{i,t_k} - \Delta v_{j,t_k}) \cdot n\Delta t,$$

(6)

where $\bar{v}_i, \bar{v}_j$ denote the mean velocities of $C_i, C_j$ and then the connectivity probability of any two vehicles after time $T$ is:

$$P_{i,j}(T) = P(D_{des} + \text{dis} \leq R),$$

(7)

where $D_{des}$ denotes the distance between two vehicles at current time, $R$ denotes the transmission range of vehicle.

**B. PATH RELIABILITY MODEL**

To evaluate the reliability of the whole path, not only do we need to consider the expected number of retransmissions of each single link, but also the location of the link which has a critical impact on the quality of the whole routing path. As shown in Fig. 3, there are two paths between the source vehicle (S) and destination vehicle (D): S-A-B-D and S-C-E-D, and both of them have three single links with the same connectivity probability values (i.e., $1/2, 1/3, 1/4$) but different locations. Although they have the same path connectivity probability: $1/2 \times 1/3 \times 1/4$, they generate different retransmission numbers due to the retransmission mechanism of end-to-end connection in the transport layer. Once packet dropping occurs on one link, this packet should be resent from the source to the destination. In other words, the loss of packet and its retransmission not only waste the network resources on the current link, but also waste resources on previous links in the multi-hop connection. Furthermore, the expected total numbers of transmissions for a packet in different routing paths are different.

For instance, as shown in Fig. 4, there are $n$ links in the middle routing path with $n$ connectivity probabilities ($p_i$) for each link. The failure probability of transmission on the $i$th link is $1 - p_i$. Let us discuss the retransmissions on the first and second links. When the transmission fails on the first link, the retransmission probability of is $1 - p_1$. When the transmission fails on the second link, which means the packet needs to be retransmitted on both links, the retransmission probability is $2 \cdot p_1 (1 - p_2)$. And then the total retransmission probability including that caused by the packet droppings on both of the first and second links is $(1 - p_1) + 2 \cdot p_1 (1 - p_2)$. Therefore, when the packet dropping occurs on the first $i$ links, the expected cost of failure transmissions $Fc(i)$ on the $i$th and previous links [24] is:

$$Fc(i) = (1 - p_1) + 2 \cdot p_1 (1 - p_2) + \ldots + i \cdot p_1 p_2 \ldots (1 - p_i).$$

(8)

The probability of the successful delivery from the source to the destination for one packet is $\prod_{k=1}^{n} p_k$. And then the expected number of transmissions required $Fs(n)$ along the $n$-links path for one successful arrived packet is:

$$Fs(n) = Fc(n) + n \cdot \prod_{k=1}^{n} p_k / \prod_{k=1}^{n} p_k.$$  

(9)

According to (9), in Fig. 3, the expected transmission numbers of path S-A-B-D and S-C-E-D are 40 and 34.67 respectively. Obviously they have different network reliabilities for the end-to-end connection from vehicle node S to D.

**IV. MULTI-HOP VANETS-ASSISTED OFFLOADING STRATEGY**

Based on link availability and path reliability models described in the previous section, we present the complete decision-making process for computation offloading in this section, including the representation of the offloading delay.
and offloading cost, and the binary search algorithm which is suitable for most of pricing policy.

In our scheme, the task vehicle can maximize the utilization of VANETs to offload computation data through the multi-hop connection even it has not entered the communication range of the MEC Sever. Without loss of facticity, we consider the environment with multiple MEC severs on the road side for receiving computation task from running vehicles as shown in Fig. 5. The computation offloading task can be divided into n offloadable and parallelizable data blocks to be processed individually. For each block, there are two main factors to be considered in offloading: delay and cost. In terms of delay, we evaluate the expected time of one successful end-to-end delivery including transmissions on each link in the whole path, and then select the appropriate MEC sever and optimal multi-hop path which can meet the delay requirement. In terms of cost, considering not only the computing price of each MEC server but also the data relaying price of each vehicle, the multi-hop routing path and MEC sever with the lowest cost are chosen under the real-time environment. As mentioned above, the delivery delay of data block \( i \) on an n-hops end-to-end connection can be presented as:

\[
    t_{tra}^i = F_s(n) \cdot d_i, t_{unit},
\]

where \( t_{unit} \) is the required transmission time for unit data volume in VANETs. As more details about the transmission process including the propagation in the air, the waiting in the transmission buffer and etc., are not the focus of this paper, we assume that they are counted in \( t_{unit} \) and do not give too much description.

MEC severs on the side of the road that can provide the service of edge computing can be represented as the sequence \( \{ M_1, M_2, M_3, \ldots, M_e \} \). The calculation delay on the MEC sever for the data block \( U_i : \{ d_i, b_i, t_{Task} \} \) is calculated as:

\[
    t_{cal}^i = \frac{r_k + b_i}{f_k},
\]

where \( r_k \) is the remaining amount which needs to be calculated before \( U_i \) on the \( k \)th MEC Sever, \( f_k \) denotes the computation speed (i.e., processing capacity) of the \( k \)th MEC sever. And then the total delay including the time in the delivery and computing processes for the given data block is:

\[
    t_{sum}^i = t_{tra}^i + t_{cal}^i.
\]

Since an offloading task consists of multiple data blocks, the last offloaded block determines the delay of the whole task \( t_{sum}^k \):

\[
    t_{sum}^k = \max\{ t_{sum}^1, t_{sum}^2, \ldots, t_{sum}^n \}.
\]

### A. EVALUATION OF DELIVERY & COMPUTING DELAY

Generally, in order to fully exploit the computing resource and save the time, the volume of computation offloading task on each vehicle can be divided into \( n \) data blocks to process individually which can be expressed as:

\[
    Task = \{ U_1, U_2, U_3, \ldots, U_n \}.
\]

And each data block \( U_i \) can be described as:

\[
    U_i = \{ d_i, b_i, t_{Task} \},
\]

where \( d_i \) is the amount of data block \( i \), \( b_i \) is the required computation amount for the data block and \( t_{Task}^i \) denotes the value of delay constraint of the whole offloading task which is determined by concrete application. Note that \( d_i \) and \( b_i \) are not the same meaning: the former is the data size to the transmission; the latter is the amount to the computation on MEC server. For each data block, the decision-making system evaluates and selects the appropriate MEC sever and the optimal routing path according to the real-time environment. However, combining the estimation of computing time on the MEC server, the end-to-end delivery time of all data blocks needs to meet the delay constraint of the task as a precondition.

As mentioned above, the delivery delay of data block \( U_i \).
We assume that each vehicle has its respective price for relaying offloading data. Corresponding to the vehicles \(\{Cr_1, Cr_2, Cr_3, \ldots, Cr_m\}\) (except the source vehicle) in the routing path for data block \(U_i\), the relaying price (per unit data volume) sequence is \(\{Pr_1, Pr_2, \ldots, Pr_m\}\) and the total cost to relay the block can be calculated as:

\[
Pr_{sum}^i = \sum_{j=1}^{m} Pr_j \cdot d_j. \tag{16}
\]

Thus the relaying cost for the whole computation task with \(n\) data blocks is:

\[
Pr_{Task} = \sum_{i=1}^{n} Pr_{sum}^i. \tag{17}
\]

For the calculation cost on the MEC server, according to MEC servers \(\{M_1, M_2, M_3, \ldots, M_k\}\) on the road side, the computing prices of them are \(\{Pc_1, Pc_2, Pc_3, \ldots, Pc_k\}\). The calculation cost of data block \(U_i\) on the given MEC server \(M_k\) is:

\[
Pc^i = Pc_k \cdot b_i. \tag{18}
\]

And the calculation cost of the whole task is:

\[
Pc_{Task} = \sum_{i=1}^{n} Pc^i. \tag{19}
\]

Finally, we can obtain the offloading cost (i.e., the relaying cost plus the calculation cost) of the computation task:

\[
\text{cost} = Pr_{Task} + Pc_{Task}. \tag{20}
\]

### C. BINARY SEARCH ALGORITHM

Based on above representation, in order to make the optimal offloading decision meeting the delay constraint and with lowest cost, a binary search algorithm is proposed in this section. For each data block, utilizing the real-time information of vehicles (i.e., position, velocity, acceleration, etc.) from the exchanged beacon messages periodically, we can obtain the connectivity probability according to the model in section III. Based on the binary search principle, the algorithm traverses the candidate vehicle routing sequences (with its MEC sever) and calculates the offloading cost for them of which the delay can meet the constraint. And then the optimal sequence with the lowest cost is selected to deliver the data block. The complexity of our algorithm is \(O(\log N)\) and the pseudo code is as follows:

### V. PERFORMANCE EVALUATION

#### A. SIMULATION ENVIRONMENT

In order to evaluate the proposed multi-hop VANETs-assisted offloading strategy (MHVA), the open-source microscopic traffic simulation software SUMO [34] is utilized to simulate the road environment and the mobility of vehicles in this section. Without loss of generality, a 3-km road with bi-direction and four lanes is generated. The vehicles with random velocities following a normal distribution \(N(70, 10^2)\) are inserted with random departure time and driven through the road. The average traffic flow is set to various values (i.e., 100/200/300/400/500 veh/lane/h) in different tests to measure the performance separately.

For network simulation, the mobility trace files generated in SUMO are injected into OMNeT++ tools [35] to simulate mobile wireless nodes in vehicular ad hoc networks. The MAC layer protocol is DCF of IEEE 802.11 at a channel data rate of 2Mb/s and the transmission range of each vehicle-node is set to 250m. For exchanging information between vehicles, the periodic beacon message with 1s interval is adopted. The uniform standard wireless interface with the same transmission range is set for the MEC server. And the number of MEC servers which are deployed evenly on the road is set to different values (1/2/3/4/5 i.e., the coverage ratio of 16.7%/33.3%/50%/66.7%/83.3%) to evaluate the offloading performance respectively. The computation offloading task which has the size of 10Mb is generated on one random vehicle every 10s and then divided into 10 data blocks (packets) to transmit. The delay constraint of offloading task is set to 10s.

The simulation is arranged as four parts to evaluate the validity, offloading delay, offloading cost and the impact of concurrent data amount in MHVA strategy comparing to other strategies respectively. The duration of each test in the simulation is 3000s identically and similar tests with different random seeds are executed for enough times to calculate the average value of result. Table 1 summarizes the key parameters in the simulation.

#### B. VALIDITY OF MHVA OFFLOADING STRATEGY

In this group of experiments, the offloading effectiveness (i.e., successful offloading ratio and offloading delay) of MHVA is validated under different environments of MEC server coverage ratio. For comparison, the traditional

| Parameter                  | Value     |
|----------------------------|-----------|
| Streets Length             | 3km       |
| Traffic Flow               | 100/200/300/400/500 veh/lane/h |
| MEC Server Coverage Ratio  | 16.7%/33.3%/50%/66.7%/83.3% |
| Vehicle Velocity           | N(70, 10^2) KPH |
| MAC Layer                  | DCF of IEEE 802.11 |
| Channel Data Rate          | 2Mb/s    |
| Beacon Interval            | 1s       |
| Transmission Range         | 250m     |
| Size of Offloading Task     | 10Mb     |
| delay Constraint of Task    | 10s      |
| Simulation Time            | 3000s    |

#### Algorithm 1 Decision on the Lowest-Cost Path Meeting the Delay Constraint \(t_{\text{task}}^\text{thr}\)

1: Initialization: cost = 0; divide the offloading task into \(n\) data blocks \([U_1, U_2, U_3, \ldots, U_n]\)
2: For each data block \(U_j\):
3: Optimal relaying sequence \(Cr = \{\emptyset\}\)
4: \(T = t_c + \sum_{k=1}^{n} t_{\text{tra}} (t_c \text{ is the current time})\):
5: Calculate the connectivity probability \(P_{ij}\) of any two vehicles between the source vehicle and MEC server
6: Calculate \(t_{\text{sum}}^k, Pr_{\text{sum}}^k, Pc^k\)
7: while \((t_{\text{sum}}^k > t_{\text{thr}})\);
8: for minimum \(P_{ij}\), add the vehicle \(C_{(i+j)/2}\) into \(Cr\)
9: Calculate \(t_{\text{sum}}^k, Pr_{\text{sum}}^k, Pc^k\)
10: end for
11: cost = \(\sum_{k=1}^{n} (Pr_{\text{sum}}^k + Pc^k)\)
offloading strategy in which vehicles send the computation data only when they are in the communication range of the MEC server is executed as well. The average traffic flow is set uniformly to 300 veh/ lane/h to evaluate their performance. As shown in Fig. 7 (a), both the successful offloading ratios (i.e., achieved within the delay constraint 10s) of MHVA and traditional strategy increase with the increasing coverage ratio. The performance in MHVA is obviously better than that in the traditional strategy, especially under the environment of low coverage ratio of MEC server, e.g., 16.7%, the offloading ratios are 78.2% and 33.4% respectively. It is because that MHVA effectively utilized the multi-hop connection in vehicular ad hoc networks to offload data and did not have to wait for entering the communication range of MEC server. Due to the same reason, as shown in Fig. 7 (b), the average delay of all successful offloading tasks in MHVA is generally shorter than that in the traditional strategy, especially under 16.7% coverage ratio, the difference is 2.4s.

C. DELAY EVALUATION

In this section, for comparison under the multi-hop connection environment, we introduced AODV-proximate strategy in which the proximate MEC server is selected to receive the computation offloading data, and based on the classical wireless ad hoc routing protocol: AODV [36], [37], packets can be relayed by the vehicle-nodes between the task vehicle and the selected MEC. Under the environment of MEC sever coverage ratio of 33.3%, as shown in Fig. 8 (a), with the increasing of traffic flow, the delays in both MHVA and AODV-proximate strategies gradually decrease. More vehicles in the street, less times the breaking occurred in the multi-hop connection. In the condition of traffic flow of 300 veh/lane/h, as shown in Fig. 8 (b), with the increasing of MEC sever coverage ratio, MHVA and AODV-proximate strategies have similar curve trends. Wider coverage of MEC serves in the street, less times the multi-hop connection is utilized and lower delay is acquired correspondingly. Whether under different traffic flows or different MEC server coverage ratios, the proposed MHVA strategy shows better performance than AODV-proximate strategy which also uses the multi-hop connection to deliver data. It is due to that, in MHVA, the short-term movement of vehicle is well estimated. And assisted by the link correlation theory, the routing path with lowest delay is selected accurately for each data block. Furthermore, by real-time information collection, the freest MEC server (i.e., with the maximum computing capacity and idle time at current moment) not the nearest MEC sever is selected to compute the data.
D. COST EVALUATION

In computation offloading strategy, offloading cost is the vital factor to be considered. In order to evaluate the cost in our proposed MHVA strategy, we first need to set the computing prices for different MEC servers and the relaying prices for different vehicles respectively. In this simulation group, the traffic flow is set to 300 veh/lane/h and the relaying price (per Mb) of each vehicle is generated randomly following a normal distribution $N(10, 2^2)$. Two MEC servers are deployed on the road side, i.e., 33.3% coverage ratio, and we set three price (per Mb) combinations for them (100&110, 100&130 and 100&150) to evaluate the performance. Note that these prices are not the actual expenses in the real world, but the simulative values which are used to compare the offloading cost between different strategies. For comparison, we added another strategy in the simulation: AODV-cost, in which differing from AODV-proximate, the MEC server with lower computing price is selected to receive the computation offloading data.

As shown in Fig. 9, AODV-proximate strategy has the worst performance, which is due to the lack of consideration for offloading cost but only considering offloading delay. In contrast, the lowest cost is achieved in MHVA strategy which considers not only the computing prices of MEC servers but also the optimization combination of relaying nodes with different relaying prices. In either computing price combination, AODV-cost strategy displays roughly the same performance which is because that the task vehicle only selects the MEC server with the lowest computing...
price to offload data. Thus no matter which price combination (100&110, 100&130 or 100&150 /Mb) there is, the MEC server with the price of 100/Mb is selected and then their offloading cost is roughly same under the same environment (i.e., traffic flow, MEC server coverage ratio and etc.). In addition, as the weight influence of relaying cost (i.e., cost in routing path) on the MEC server selection which is considered in MHVA strategy but not in AODV-cost strategy decreases, with the widening between computing prices of two MEC servers, the offloading cost gap between AODV-cost and MHVA strategies is narrowing gradually, e.g., 45.54 with the combination 100&110 and 12.39 with the combination 100&150.

Fig. 10 shows the offloading cost in MHVA strategy under different delay constraints (8/9/10/11/12 s). The computing prices of two MEC servers are set to 100&130/Mb. We can see that larger delay constraint means more choices on multi-hop paths and MEC servers, and then the lower offloading cost can be achieved by the estimation mechanism in MHVA strategy.

E. IMPACT OF CONCURRENT OFFLOADING DATA AMOUNT
In order to evaluate the impact of computation data amount on offloading performance, in this group of experiments, we change the number of concurrent offloading tasks from 1 to 5 (i.e., from 10 to 50 Mb, as the size of one task is 10Mb) to observe the results of successful offloading ratio, delay and cost. The traffic flow is set to 300 veh/lane/h, the MEC server coverage ratio is set to 33.3% (i.e., 2 MEC servers) and the computing price combination of MEC servers is 100&130.

As shown in Fig. 11, with the increasing of offloading data amount, the offloading ratio decreases, the offloading delay increases and the offloading cost increases no matter in AODV-proximate, AODV-cost or MHVA strategy. With different considerations, AODV-proximate strategy has a higher successful offloading ratio (by 0.61s on average) and a lower offloading delay (by 8.2% on average) than AODV-cost strategy; on the other side, AODV-cost outperforms AODV-proximate strategy (by 117.45 on average) in the aspect of offloading cost. Due to the real-time information collection and the reliability analysis of multi-hop routing path, our proposed MHVA strategy which provides consideration to both delay and cost displays the best performance in three strategies.

VI. CONCLUSION AND FUTURE WORK
In this paper, aiming at the reducing offloading delay and saving the offloading cost, we proposed the multi-hop VANETs-assisted offloading strategy (MHVA). Based on the link correlation theory in VANETs, the reliability model of multi-hop routing path is built; and meeting the delay constraints, the optimal offloading strategy with the lowest relaying and computing cost is executed by the binary search algorithm for each data block in the offloading task. The simulation results show that the proposed MHVA strategy has the better performance in offloading ratio, offloading delay and offloading cost than the traditional vehicular computation offloading strategies under various environments. As future work, how to take into account the centralized cloud computing server and even the spare computation resource on the road vehicles (i.e., fog computing) with the MEC servers, and then utilize these resources collaboratively and balance the communication and computation load effectively are the meaningful and interesting issues for us.
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