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Research Article

PASS: Parking-Lot-Assisted Carpool over Vehicular Ad Hoc Networks

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Information interaction is a crucial part of modern transportation activities. In this paper, we propose the idea of PASS: a parking-lot-assisted carpool method over vehicular ad hoc networks (VANETs). PASS aims at optimizing transport utilization by the carpooling among car drivers who cover a part of the same traveling route. With wireless device enabled in the vehicle, a user can easily get matched vehicles information and then express his travel demands via radio queries over VANETs to the corresponding driver. The driver can decide whether to provide carpooling services or not. We investigate the main challenges in PASS design, via the parking lot to collect vehicle trajectories, via accelerator sensor to sense vehicle's movement, establish a routing tree to delivery vehicle trajectory information to nearby parking lots, and design a suitable matching scheme to match the target vehicle in VANETs. Finally, simulation results prove that PASS is effective and efficient in carpooling among vehicle drivers.

1. Introduction

Vehicular ad hoc networks (VANETs) are network of vehicles which communicate with each other via wireless communications. They are emerging as a new technology, integrating the capabilities of new generation peer-to-peer (P2P) wireless networks with vehicles. In VANETs, vehicles can exchange messages with each other as vehicle-to-vehicle communication (V2V) or exchange messages with roadside infrastructures as vehicle-to-infrastructure (V2I) as well. Nowadays, with the technology development, various intelligent sensor nodes are equipped in vehicles. These sensor devices can sense various physical quantities with very low cost and high accuracy. VANETs have many appealing applications such as driving safety [1], Internet access [2], and intelligent transport and infrastructure monitoring [3]. However, such applications are all aimed at providing services for drivers in moving cars, while transport utilization of vehicles is ignored. In other words, the traditional V2V and V2I communication mode cannot offer any additional advantages to the waste of transportation abilities.

In recent years, although government and more and more researchers have paid more attention to improve transportation efficiency, the waste of transportation abilities is still general in current vehicle transportation. For example, according to NHTS [4] from the US Department of Transportation, the mean occupancy rate of personal vehicle trips is 1.6 persons per vehicle mile. Since a regular vehicle carries 5 persons in full occupancy, 68% of transportation abilities are wasted as a result. In USA alone, more than 87% of people travel in private vehicles every day [5], which result in a great deal of loss. On the other side, the large travel demand for personal car with low occupancies also leads to traffic congestion problem which has become an increasingly important issue in many countries. In 2007, congestion caused urban Americans to travel 4.2 billion hours more and to purchase an extra 2.8 billion gallons of fuel [6]. As more and more private vehicles are purchased and the degree of expensive transportation fuel cost in nowadays, the traffic congestion problem will be worsen. Moreover, personal cars also cause environment pollution inevitably. Thus, wise usage of personal automobiles to reduce the consumption of energy and the emission of harmful gases is gaining more and more attraction.

Many transportation enterprises, carpool associations, and other institutions try to provide effective ride sharing for drivers, but the centralized methods they introduced are not scalable enough for real-time, dynamic, convenient, and rapid-changing carpooling service. Several carpooling methods have been proposed to increase the occupancy of vehicles, but these unfortunately, interaction methods are all made between moving vehicles and roadside passengers, while ride sharing among vehicle drivers is not considered. Some administrations have introduced high occupancy vehicle (HOV) lanes to encourage ride sharing. Casual carpools, as impromptu carpools formed among strangers, can team up in public areas near HOV lanes [7], but it is severely limited in deployed roads.

In this paper, we propose that a parking-lot-assisted carpooling method (PASS) over VANETs, which enable direct, instant, and flexible communication between car drivers. By taking the parking lot as a central database, the PASS method aims at optimizing transport utilization by ride sharing among car drivers who cover a part of the same traveling route. With wireless device enabled in the vehicle, a user can easily get matched vehicles information and then expresses his travel demands via radio queries over VANETs to the corresponding matched vehicle driver. The driver can decide whether to provide carpooling services or not. We investigate the main challenges in PASS design, via the parking lot to collect vehicle trajectories knowledge, via the accelerator sensor to sense vehicle movement, establish a routing tree to delivery vehicle trajectory information to nearby parking lots, and design a suitable matching scheme to match the target vehicle in VANETs. Since office worker and staff made up 68% user of current carpool service [8] people who work together usually prefer to live near each other in China. For example, most of teachers of our university live in the *bali* residential. We believe that PASS will be very useful for people who live neighboring and share common or adjacent destinations. Based on a realistic simulation, we prove that the PASS method is effective and efficient in ride sharing.

Our major contributions in this paper are summarized as follows.

(1) To the best of our knowledge, we are the first to consider the using of parking lot to assist ride sharing. Compared to previous carpooling researches, by encouraging car drivers to share their personal cars, PASS succeeds in improving transportation efficiency, reducing the price of travel cost and improving the traffic congestion problem.

(2) After clustering parked vehicles in a parking lot, we properly select a cluster head for vehicular trajectory knowledge gathering and matching. The key insight is to guarantee the effective and accuracy in trip matching.

(3) We design a suitable vehicle-matching scheme to match the target vehicles. As a result, a target user can inquiry matched vehicles according to his wishes.

The remainder of this paper is structured as follows: Section 2 discusses related works. Section 3 discusses PASS and its implementation. Section 4 evaluates PASS via extensive simulation and Section 5 summarizes the paper.

2. Related Works

In recent years, carpool system became a hot point for the VANETs researchers, and many studies on carpool have been proposed for VANETs. Traditional carpools usually take place among neighbors or coworkers who have similar routes, and they can easily contact with each other for possible ride sharing. Nowadays, with the development of the Internet, many carpool associations appear [9]. Thus, people are allowed to match their trips over the Internet, even though they are strangers. However, such carpooling systems have their own problems. Firstly, whether we can find a matched driver or not by using these systems entirely depends on the number of registered users. Since people are not widely encouraged to practice carpooling, for example, by governments or employers, the number of registered users is usually limited and the process of trip matching is usually failed as a result. Secondly, the centralized framework which relies on a central server to collect the information on all trip demands online is not scalable enough and flexible enough.

Alternatively, other endeavors aim to implement dynamic ride sharing have been considered in recent years. Paper [10] investigates the challenges in casual carpooling and suggests a travel matching system by extending current cell phone services. In paper [11], the authors undertake a review of technology-assisted carpooling in order to understand the challenge of designing participation and consider how mobile social software and interface design can be brought to bear. But this study mainly focuses on examining the possibility of designing participation, while a practical ride sharing system is not considered. In paper [12], Ghoseiri et al. present a dynamic rideshare matching Optimization model (DRMO) to match between the passenger and car drivers. DRMO receives passengers and drivers information and preferences continuously over time and assigns passengers to drivers with respect to proximity in time and space. The ride sharing preferences such as age, gender, and smoke are considered in the model. In [13], the authors define dynamic ride sharing and outline the optimization challenges that arise when developing technology to support ride sharing. However, not only the vehicle trip information collection process in this paper is obstacle to the system but also available ride sharing relies on the numbers of the drivers who are willing to input their trips. Moreover, the use of smartphones while driving is illegal in many countries and is also a major cause of accidents. Thus, this method is not so appropriate to support dynamic ride sharing. Plan et al. [14] explore the feasibility and challenges of WiFi-based ride sharing systems in metropolitan locations and indicate that WiFi connectivity works well while vehicles are traveling at slow speed. In [15], Liu et al. propose the idea of vehicle-to-passenger communication (V2P), which allows direct communication between moving vehicles and roadside passengers. However, since passengers have to call moving vehicles via extra wireless devices, this method is inconvenient for passenger. Furthermore, the method or systems mentioned above all concentrate on ride sharing between passengers and car drivers but have not taken ride sharing among vehicle drivers into consideration. Compared with the initial ride sharing work, PASS aims at developing a flexible vehicle calling and travel-matching solution among car drivers.

Besides, http://www.carpoolworld.com/ [16] uses the commuter's precise latitude and longitude coordinates to find the best matches among the other commuters in the database; based on exactly how close together they live and exactly how close together they work. In [17–19], dynamic ride sharing approaches based on distributed framework have also been proposed, but these work lack the concrete realization of implementation of travel matching, which are far from a practical ride sharing system.

3. PASS and Its Implementation

In this section, we present the PASS method for dynamic ride sharing. We first describe the vehicle-matching idea and then focus on the implementation of PASS.

3.1. The Vehicle Matching Idea. For the idea of PASS, we first discuss how to get a user to communicate with a matched vehicle driver through a vehicular communication. As shown in Figure 1, a typical vehicle carpool process among car drivers has the following steps

(1) information acquisition: once a user activates the vehicle carpool application, he starts an onboard device such as the trip computer equipped in his car in order to acquire all the matched vehicles information. Since GPS, electric map, trip computer as well as wireless devices are widely deployed in today's vehicles, we believe that drivers are allowed to get useful information and communicate with each other through these devices.

(2) Send query message: the user chooses a matched vehicle according to his/her requirements and then sends a special query message over VANETs to the selected vehicle.

(3) Echo: when getting the query message via the trip computer, the matched vehicle driver can then decide to accept or ignore the message calling. Once the driver accepts the query message, an ACK message is sent to the user. They can further communicate with each other via QQ application or smartphones.

(4) Send query message again: if the query message is reject by the vehicle driver in step 3, the user will continue to send query messages until a right car driver is found.

In the implementation stage of PASS, some social and economic problem should be considered, which will be discussed later. Moreover, we assume query message can be received successfully by its receiver.

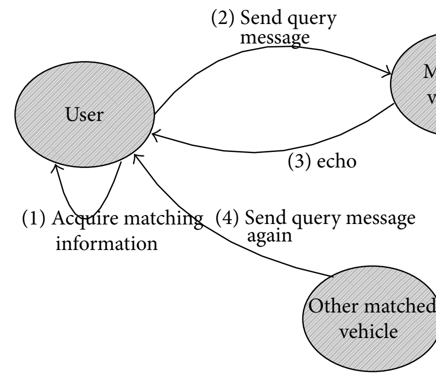


Figure 1: A typical vehicle carpool process.

3.2. Vehicle Trajectory Collection Assisted by Parking Lot. This section concentrates on parking-lot-assisted vehicle trajectory information collection and realization. Generally, from the viewpoint of vehicle drivers, the relationship of vehicles in driven on the urban street can be divided into four categories: vehicles with the same origin and the same destination, vehicles which have the same origin but different destinations, vehicles with different origins but the same destination and vehicles whose origins and destinations are distinct with each other. Since vehicles in the first three categories enter the same parking lot when parked, we explain the idea of parking-lot-assisted vehicle trajectory collection process from two cases consequently.

3.2.1. Vehicles Parked in the Same Parking Lot. For the vehicles have the same origins or the same destinations, they enter the same parking lot when parked. Thus, we try to collect vehicle trips assisted by the parking lot. Here we assume that some vehicle drivers would like to share their devices during parking. In other words, vehicle users can leave their wireless devices alive in parking, for downloading requested contents or continuing unfinished transmission.

As shown in Figure 2, at first all parked vehicles in the same parking lot are grouped into a cluster. Since the radio range of a vehicle can achieve to 250 m, the parked vehicles in the cluster can coordinate with each other from one hop or multihop communication. Besides, we assume each vehicle in the parking lot has a unique ID number (can be identified by vehiclelicense plate). Secondly, a vehicle located in the parking lot is randomly elected main cluster head, as H1 in Figure 2. Other vehicles are taken as cluster members. Thirdly, since the cluster head may fail in the complex environment of parking lot, we appoint a spare head as H2. A spare head is a cluster member nearest to the cluster head, which always keep a copy of recent cluster status and a copy of gathered vehicle trajectories knowledge from the main cluster head. Thus, a spare head becomes a special cluster member, working as the "warm backup" for the management of the parking lot cluster. The introduced spare head enhances the robustness of the parking lot cluster. In our study, the main cluster head needs to handle the following tasks: (a) cluster management, including membership management

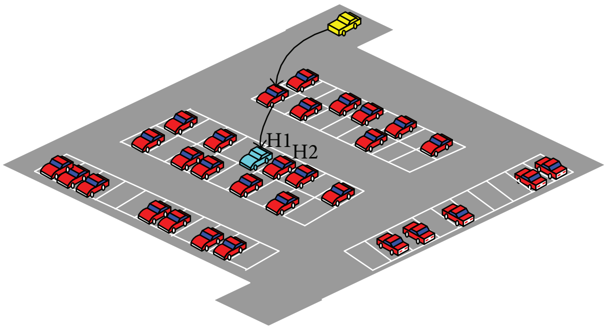


FIGURE 2: A typical parking lot cluster.

FIGURE 3: Trips for two drivers.

and vehicle trajectories knowledge management; (b) trip matching, that is, to find the matched trips from various vehicle trajectories. (c) Send matched vehicle information to demanders. Finally, once the vehicle acts as cluster head stops parking and drives away, the information it owes should be transmitted at once to another vehicle, which confirms the absence of the old cluster head and then becomes the new cluster head instead.

Each parked vehicle operates the following operations.

(1) Parking: once parked, a vehicle periodically senses its parked status and sends beacon messages to the main cluster head to report its existence.

(2) Joining a cluster: a vehicle receives the echo from the cluster head and then becomes a parking lot cluster member.

(3) Sending message: after operation 2, a vehicle begins to route its history vehicle trajectory records to the cluster head, whose main task is to maintain the trajectory records of all parked vehicles. As a kind of human activity, driving is controlled by individual drivers. As depicted in paper [20], human trajectories show a high degree of temporal and spatial regularity: each individual can be characterized by a time-independent characteristic length scale, and a significant probability to return to a few highly frequented locations. Paper [20] also discovers that two-to-four main locations (including home) cover more than 70% of the overall trips of a vehicle. Consequently, we can predict a vehicle's movement via its trip history for transparent travel matching.

(4) Send query message: once a vehicle driver enters his/her car and actives the vehicle carpool application through the on-board device, he chooses a promising driver on demand and sends a query message to the matched vehicle over VANETs.

(5) Leaving: once a vehicle senses its moving tendency through the accelerator sensor, it sends a message to inform the cluster head that it will stop parking and drive away from the parking lot.

3.2.2. Vehicles with Different Origins and Destinations. In regards to vehicles with different origins and destinations, dynamic carpool can be realized among car drivers contenting the following two cases: (a) for two drivers such as i and j, when both their origins and destinations near each other and (b) when their origins are adjacent to each other and the point of destination of driver i is within the acceptable walking distance, from the vehicle route of driver j. Since the average human walking speed is 3 m/s, if a person tolerates a walking time of ten minutes; for instance, the acceptable walking distance for a person is 1800 meters as a result.

Here we explain our idea by giving a simple example. In Figure 3, trips taken by driver i and j are concisely presented.

(1) Driver i: trip is from home (the origin is A) to work place (denote as B) at 8:40.

(2) Driver j: trip is from home (the origin is C) to work place (denoted as D) at 8:30.

We can see from Figure 3 that though the two trips differ in sources and destinations, since their sources and destinations are all not so far away from each other, the two divers can make a ride sharing once needed.

For vehicle drivers such as i and j mentioned above, since their vehicle trajectories are maintained by different cluster head, in order to find matched vehicles, we need a proper strategy to spread their history trip trajectories out to neighboring parking lot clusters over VANETs. To achieve this aim, when a vehicle stops parking and starts moving out, it gets the exact location of its local parking lot exit by GPS. This location will be taken as the location of the local parking lot in geography in our study. Later, this location information is passed to other vehicles and broadcasted on urban streets within a certain scope limit. Whenever a vehicle keeps this location information access a destined nearby parking lot, the location information message will be delivered to the destined cluster head via VANETs communication. In addition, in order to pass location information to all nearby parking lots as quickly and efficiently as possible, we consider vehicles parked at roadside near the underground parking lot. Figure 4 describes when a vehicle drives on a road, it delivers parking lot location messages it maintains to a roadside-parked vehicle, which keeps these messages and transmits them to a vehicle ready to enter the underground parking lot. These messages are finally passed to that underground parking lot cluster head. After a certain time of message

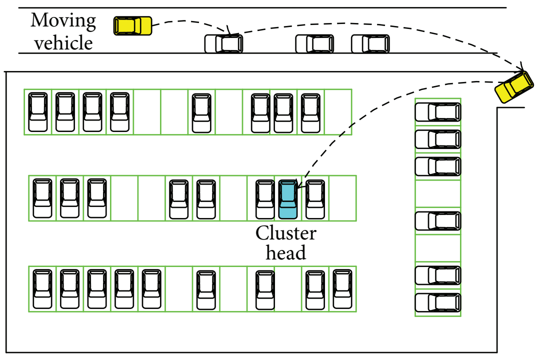


Figure 4: Position information dissemination.

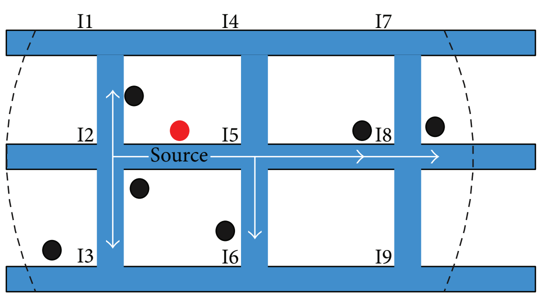


Figure 5: A routing tree for message transmission.

broadcasting, every parking lot cluster head masters the exact location information of all nearby parking lots.

In order to deliver vehicle trajectories mastered by a parking lot cluster head to all its nearby parking lots with low overhead, here a shortest path routing tree is constructed, as depicted in Figure 5. Messages are then routed along the routing tree to all its nearby parking lot.

Vehicle trajectories information forwarding process is described as follows. This process will be executed if and only if the vehicle trajectories knowledge mastered by the cluster head updated.

(1) At first, vehicle trajectory messages maintained by the underground parking lot cluster head (denoted as H1) are sent to a car which ready to drive away from this parking lot. These messages are then replicated to neighboring roadside-parked vehicles, which keep these messages and send them to moving vehicles in the local street directly, as shown in Figure 6.

(2) Secondly, in the city scenario shown in Figure 5, vehicle trajectory messages should be transmitted by moving vehicles along the routing tree to all parking lots within an acceptable detour scope (the size of this scope is determined by a special user). To achieve this aim, the messages from source parking lot are attached to a scope limit and destined for neighbor intersections as I2 and I8. We assume all intersection positions from I1 to I11 are marked in the electric map. Whenever a message carried and forwarded by vehicles in driven reaches the destined intersection, the message is discarded definitely. More specifically, we assume each data message has a field to record its survival time, whenever the message is timeout, it is discarded.

(3) Finally, we let vehicle trajectory messages transmit to roadside parked vehicles near the destined parking lot. These messages are passed to a vehicle ready to enter the parking lot and finally delivered to the underground parking lot cluster head accordingly.

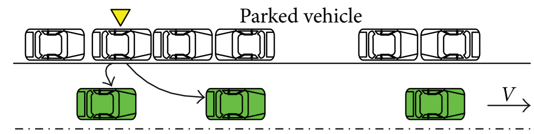


Figure 6: Data transmission from parked vehicle to moving vehicle.

3.3. Vehicle Matching Scheme. Another task for the main cluster head of a parking lot is to match target vehicles for a user. For each driver i, a trip trajectory consisting of successive points, $v_1^i, v_2^i, v_3^i \cdots v_n^i$ with v_1^i as source point and v_n^i as destination point, is specified at the time that he/she starts this trip.

Here we take two vehicles A and B, for example. The start time and trajectories of A and B are described as T^A, v_1^A, $v_2^A, v_3^A \cdots v_n^A$ and T^B, v_1^B, $v_2^B, v_3^B \cdots v_n^B$, respectively. A matches B if and only if

$$\left|v_1^A - v_1^B\right| < d, \qquad \left|v_n^A - v_n^B\right| < d\ , \qquad \left|T^A - T^B\right| < \tau \tag{1}$$

or

$$\begin{gathered} \left|v_1^A - v_1^B\right| < d, \quad \text{distance}\left(v_n^A, v_1^B, v_2^B, v_3^B \cdots v_n^B\right) < d, \\ \left|T^A - T^B\right| < \tau, \end{gathered} \tag{2}$$

where d is the acceptable walking distance assigned by a user, τ is the acceptable waiting time the user spends to wait a matched car, and distance $(v_n^A,\ v_1^B,\ v_2^B, v_3^B \cdots v_n^B)$ denotes the expected shortest distance from the destination of vehicle A to trip trajectory of vehicle B.

In our study, we let matching degree indicate the likelihood that two vehicles match each other. The higher the matching degree, the more possible two vehicle matched. Here function $f(x)$ is defined to calculate the matching degree value. For two matched vehicle A and B, if they satisfy formula (1), we have

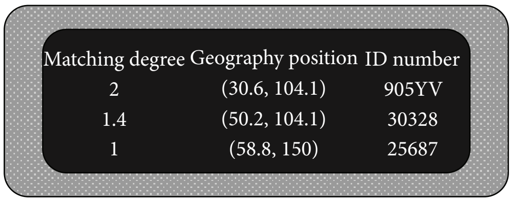
$$f(x) = \alpha\left|v_1^A - v_1^B\right| + \beta\left|v_n^A - v_n^B\right| + \gamma\left|T^A - T^B\right|. \tag{3}$$

Otherwise, when formula (2) is content, we set

$$\begin{aligned} f(x) = {} & \alpha\left|v_1^A - v_1^B\right| + \beta \text{ distance}\left(v_n^A, v_1^B, v_2^B, v_3^B \cdots v_n^B\right) \\ & + \gamma\left|T^A - T^B\right| \end{aligned} \tag{4}$$

here

$$\alpha + \beta + \gamma = 1. \tag{5}$$



Matching degree	Geography position	ID number
2	(30.6, 104.1)	905YV
1.4	(50.2, 104.1)	30328
1	(58.8, 150)	25687

Figure 7: Matched vehicles on on-board device.

In the above formulas, $0 \leq \alpha \leq 1$, $0 \leq \beta \leq 1$, $0 \leq \gamma \leq 1$ are constants decided on users demand. We can see from (8) and (9) that the definition of $f(x)$ is simple yet flexible, and it is entirely based on the user's will.

After trip matching, if one or more matched vehicles are founded, the local main cluster head sends matched vehicles information, including matching degrees, geography positions these matched vehicles parked and, their ID numbers to the target user once the user activates the vehicle carpool application. For user convenient, we believe that the vehicle with higher matching degree is more important and should appear with a higher priority on the target user's on-board device. This is done by arranging the matched vehicle on the target user's on-board device with a decreasing order of their matching degree. That is to say, vehicle with the largest matching degree value should appear at the most front, as seen in Figure 7. If no vehicle matches, a null message will be sent to the target user instead. The target user can then select a matched vehicle on demand and send query message via VANETs to that matched vehicle for carpooling service.

3.4. Implementation Discussion. Even though vehicle matching between car drivers is feasible in technique, the implementation still confronts lots of social and economic problems. We list them as follows.

Privacy is a matter that causes a lot of worry. Some drivers may have a problem with exposing their travel destinations. In this case, accurate travel destinations can be replaced by some common transit points, such as intersection or street name. For further anonymity, some encryption and decryption mechanisms should be considered. Furthermore, security and comfort are other important factors that deeply concern users. Strangers in the same vehicle need to have a basic level of trust for comfortable carpooling. We think that a reputation system is helpful in regulating individual actions in a trustworthy manner. Once a matched driver and the user make a deal and start a ride sharing, two sides can, respectively, send the deal note to the reputation system via VANETs. After finishing a carry, they can send feedback to one another, similarly.

Moreover, since people going to the same or adjacent working places usually prefer to live close to each other in China, the matched vehicle drivers found by using our method may know each other with a high probability. Thus, people using PASS are easier to trust each other and make a comfortable ride sharing than using other ride sharing methods mentioned before. Although involving many problems, the PASS method not only represents an

Figure 8: Road topology in simulation.

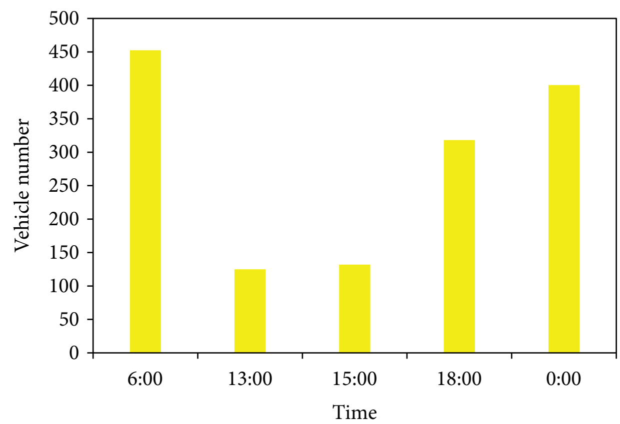


Figure 9: Parked vehicle number at different time.

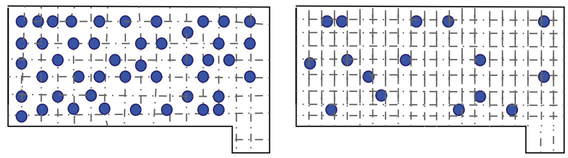
opportunity to decrease the cost and undesirable impacts of traffic congestion, fuel consumption, and pollution, but also brings convenient to vehicle drivers.

4. Simulation

In this section, in order to evaluate PASS accurately, we examine the performance of PASS in vehicle carpooling.

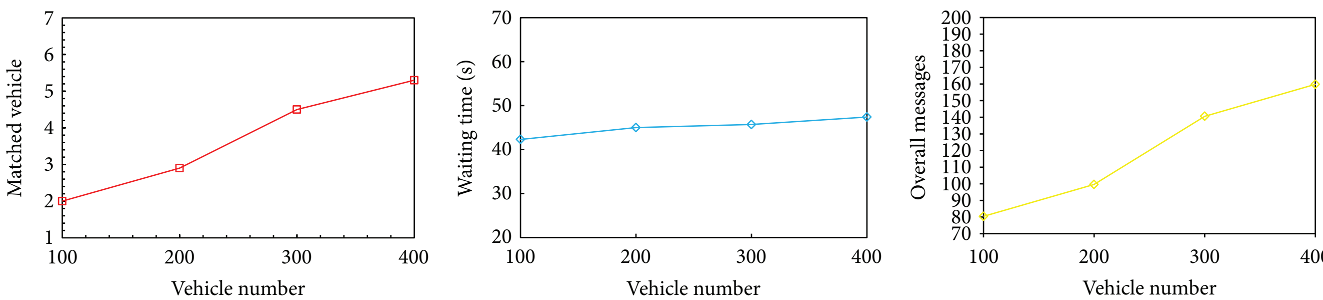
4.1. Simulation Environment. As shown in Figure 8, we extract a regional urban area with the range of 2400 m × 1600 m from a real street map of Chengdu, which is a city in China and contains 12 intersections and 20 bidirectional roads. Each intersection is marked by a number from 0 to 11.

To evaluate the vehicle carpooling in different traffic density environments, we deploy different vehicle numbers, that is, 100, 200, 300, and 400, to the map, with the average speed ranges of from 40 to 80 kilometers per hour. The radio range is set at 250 m, and the MAC protocol is 2 Mbps 802.11. The beacon interval is 1s, and all messages have a uniform size of 1 kb. In the simulation, we assume that each vehicle has enough buffer space to prevent message elimination from occurring. Besides, we find 14 parking lots are deployed in the



(a) 6 AM (b) 13 PM

Figure 10: Vehicle distribution at 6 AM and 13 PM.



(a) Matched vehicle (b) Waiting time (c) Overhead

Figure 11: Vehicle matching in carpooling.

urban region. Since accurately modeling vehicles' movement is very important for performance evaluation, we use the open source software, VanetMobiSim-1.1 [21], to generate the sources and destinations for all vehicles. That is, we let all vehicles drive from one randomly chosen parking lot to another parking lot in our simulation area. The movement of vehicles from source to destination on the road is also generated by VanetMobiSim-1.1 and can be directly utilized by NS-2.33. Since vehicles are more likely to enter or drive out of their local parking lot on the morning or from work due to human moving characteristics, inspired from long-term observation, we define 65% of the total vehicles moving out or driving in a parking lot at time periods 7:00–8:30 and 18:00–19:30. In other time periods, the overall vehicles moving in or out of a parking lot are provided to follow uniform distribution with a mean value of 10%. The average parking time is 41.40 minutes with a standard deviation of 27.17, which is provided in [22]. Moreover, in the simulation, we assume vehicles that moving on the road enter a randomly chosen parking lot with a probability of 10%. Some parked vehicle nodes are located on random positions of each street. Other simulation parameters and their default values are summarized in Table 1.

4.2. The Number of Vehicles in a Parking Lot. We investigate parked vehicle statistics in a residential parking lot at 6:00, 13:00 15:00, 18:00, and 24:00 of every Monday, Wednesday, and Friday, respectively. We counted the vehicle numbers parked in the parking lot and find that, generally, the total amount vehicles at 6:00 and 24:00 are much larger than vehicles numbers at 13:00 and 15:00 as shown in Figure 9. Besides, we also find that the parked vehicle numbers are stable in working hours of a day.

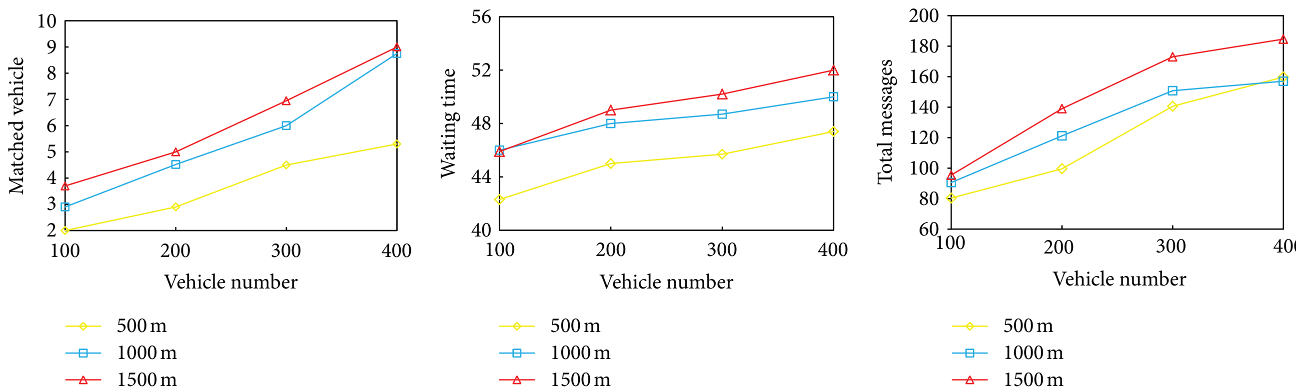
Table 1: Simulation parameters.

Parameter	Default value
Network size	3200 × 2200
Transmission radii R (m)	250 m
d	500 m
τ	30 minutes
α	0.4
β	0.4
γ	0.2

Figure 10 shows the number of vehicles at 6 AM and 13 PM in a parking lot, respectively, in our simulation. We can see that the number of parked vehicles changes, with the amount of vehicles parked at 6 AM is much larger than the vehicle number at 13 PM. This is consisted with our investigation since a large number of vehicles drive out at day time, which fits vehicle distribution in the parking lot.

4.3. Performance Analysis. In parking-lot-assisted carpool, we assume a vehicle driver who needs ride sharing has randomly chosen source parking lot and destination parking lot in the whole simulation area. Other vehicles are personal vehicles having randomly predefined movement sources and destinations. These vehicles record their history trajectories and deliver them to their local parking lot once parked. We assume that parking lot clusters are established at the beginning of simulation and are maintained at a cycle of 60 seconds.

Figure 11(a) demonstrates that the target vehicle can find an average number of 3–7 matched vehicles when the total vehicle number changes from 100 to 400. This is



(a) Matched vehicle (b) Waiting time (c) Overhead

Figure 12: d to vehicle.

reasonable because the number of vehicles parked in nearby parking lot increases then, and thus more matched vehicles would be found as a result. This result also means that our method is effective in matched vehicle finding. The impact of vehicle density to the effect of target users waiting time is presented in Figure 11(b). As we can see, the target user waiting time which is the time a user spends to wait for the matched vehicles information varies slightly with the increment of vehicle numbers, which denote that vehicle density does not have significant impact on the waiting time. Since PASS introduces roadside parked vehicles to speed up the dissemination of message, it also shortens the waiting time of users. Figure 11(c) illustrates the overhead in PASS in order to find matched vehicles. The overhead is defined as the total number of messages distributed in the simulation area in order to find matched vehicles. As we can see, the amount of messages is no more than 30. The main reason is that, by establishing a routing tree to forward messages, unnecessary message transfers are greatly reduced. With higher vehicle density, the overhead in PASS increases. This mainly stems from the vehicle trajectories collected by main cluster updated more quickly, and thus more messages are delivered.

In our study, the target user can gradually expand the acceptable walking scope to match nearby target vehicles. We exam the performance of PASS with different acceptable walking distance d, including 500 m, 1000 m, and 1500 m, in target vehicle matching, with results described in Figure 12. Figure 12(a) describes that the number of matched vehicles increases rapidly with the increase of acceptable walking distance. This is because more vehicles are provided in vehicle matching, and thus the target user can find target vehicle in a large area more easily. In Figure 12(b), users waiting time increase slightly with acceptable walking distance, while, in Figure 12(c), acceptable walking distance is positive to the network overhead, mainly because more nearby parking lots are founded with larger matching scope. Generally, simulation results show that the proposed PASS method for ride sharing is a simple and efficient vehicle-to-vehicle interaction. Although the carpooling response is not real-time, the average waiting time spent to get matched vehicles information is tolerable for users.

5. Conclusion

We presented a dynamic rideshare matching method assisted by parking lot (PASS) in this paper. PASS aims at identifying suitable matches between vehicle drivers requesting ride sharing services. The basic idea of PASS is simple since every vehicle in driven will be parked at a parking lot, why not we group these parked vehicles into a connective cluster and select a parked vehicle to support vehicle trajectories knowledge collection and trip matching? In VANETs, through the accelerator sensor equipped in a vehicle, the vehicle could sense the movement of itself. The cluster head then delivers all vehicle trajectories knowledge messages it mastered to this vehicle. These messages are transferred along urban streets to all nearby vehicles for trip matching. At last, the simulation results show the effectiveness of PASS. PASS contributes revolutionary vehicle ride sharing and promotes the vehicle carpool research in depth.

In the future, ride sharing preferences and characteristics such as age, gender, smoke, and pet restrictions as well as the maximum number of people sharing a ride should be considered in carpool matching algorithm design. Furthermore, how to use sensors equipped in today's vehicles to sense urban surroundings, such as traffic congestion, in order to reduce environmental effect on message delivery and trip matching will be considered.

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