# Distributed Location-Assisted Multiple Access Scheme for Vehicular Ad Hoc Networks

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***Abstract*—This paper proposes a location-assisted random medium access control (MAC) scheme for distributed vehicular ad hoc networks (VANETs). Consider a vehicular network with a wireless bandwidth of $M$ orthogonal channels that shared by multiple vehicles. Efficient distributed channel access mechanism should be used to improve the bandwidth utilization. We observe that each vehicle has a unique location, which could be exploited as a key information to identify its access channel. Motivated by this observation, we design a location-to-channel (L2C) randomized mapping approach. In the approach, each vehicle will access to the channels with optimal location-dependent probabilities. The simulation results are presented to demonstrate the performance of this MAC scheme by comparing it to the general random MAC scheme. It is shown that the average collision probability of channel access is clearly reduced and the average throughput of the channel is significantly enhanced.**

***Index Terms*—location-assisted, medium access control(MAC), vehicular ad hoc networks**

## I. Introduction

Mobile ad hoc network (MANET) is a type of self-organized wireless network which is formed by a group of cooperative mobile nodes. Vehicular ad hoc network (VANET) is an important branch of MANET that consists of moving vehicles [1]. The main objective of VANETs is to allow a group of communication vehicles to set up and maintain a connectivity among themselves without the support of a base station or a centralized node and to provide reliable and efficient vehicle to vehicle (V2V) and vehicle to Roadside unit (V2R) communications. Based on the two kinds of communications, VANETs can support many kinds of applications in safety, entertainment, and vehicle traffic scheduling and optimization [1-4].

Diverse medium access control (MAC) protocols have been proposed for VANETs, such as Carrier Sense Multiple Access (CSMA) and Time Division Multiple Access (TDMA). IEEE 802.11p is a recently proposed MAC standard for VANET, which is based on CSMA. This protocol has some inherent disadvantages because it cannot avoid collisions effectively and the channel switching scheme defined in IEEE 1609.4 might result in inefficient use of wireless resources[5]. Therein, ADHOC MAC is proposed for inter-vehicle communication networks using TDMA-based access strategy. Distinguishing from IEEE 802.11p, ADHOC MAC can support reliable broadcast service and avoid the hidden terminal problem. The protocols in [6-8] are also the TDMA-based mechanisms, in which TDMA slots are selected by the nodes themselves in a distributed manner. However, the process of TDMA slot allocation is based on completely random contention. This leads to bandwidth inefficiency due to frequent collisions among stations. Therefore, it is not suitable for safety application which requires fast reconfiguration and low message delivery latency[9].

In VANETs, the network topology will change dynamically. The design of an efficient MAC protocol faces a considerable challenge. This unique challenge posed by VANETs necessitate new protocol design, as well as advanced optimization and planning approaches[10, 11]. To design a MAC protocol for VANETs, we have the following observation. Each vehicle has an individual geographical location. We can exploit this unique feature and construct a discretized mapping table which connects the vehicle location with its accessing channel, called location-to-channel (L2C) table. However, the number of potential vehicle locations are far more than the number of time slots. As a consequence, the collision of channel access is inevitable. In this paper, we are motivated to devise a sub-optimal L2C table to decrease the collision probability and improve the throughput.

The rest of this paper is organized as follows. Section II describes the proposed location-assisted random access scheme. The performance analysis is given in Section III. The formulation of optimization problem and the solution of this research are presented in Section IV. Section V presents the simulation results and the outstanding performance of the novel location-assisted channel access scheme. Finally, Section VI concludes this research and suggests some future works.

## II. Location-Assisted Random Access Scheme

### A. System Model

A VANET generally consists of some vehicles distributed randomly on the road and a set of RSUs deployed along the roadside. The connectivity of communication is dynamically changing due to the vehicle mobility. Taking the distance of wireless communication into account, the road is divided into several areas. The distance of the area $d$ is determined by the maximum distance which can guarantee the vehicles in this area to communicate with each other and RSUs (if it exists in the area) normally. The scenario of VANET is shown as Fig. 1.

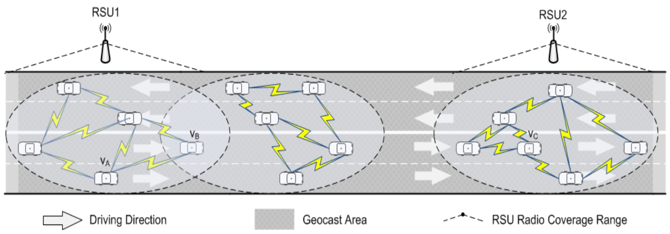


Fig. 1. The scenario of Location-Assisted Multiple Access Scheme.

We assume that the wireless bandwidth is divided into $M$ orthogonal channels. Each channel can only be accessed by a vehicle user exclusively at a time. Multiple users on a same channel will cause interference and none of the users could successfully use the channel to transmit. When a vehicle accesses a channel successfully, it can use the wireless bandwidth in a period of time, called a time slot. All the vehicles are aware of their location information by using the GPS receiver. Generally, vehicles travel on the road independently. The locations of vehicles are not overlap. Due to the uniqueness of the vehicles location, the vehicle users can access the channels according to their location information. A location-to-channel (L2C) mapping approach should be designed to facilitate a vehicle to select a channel. The geographic area of a road is divided into several locations. As shown in Fig. 2, we number the location by two-dimensional coordinate. The driving direction is taken as the horizontal direction $x$, and the other direction is taken as the vertical direction $y$. In the $y$ direction, the maximum $K$ is decided by the number of lanes of the road. In the horizontal direction $x$, the area is divided into $N$ locations. In general, the area can be formed by three steps as follows:

1) The vehicle (called as the central node) which wants to transmit information will broadcast the requirement information in the range of its communication;
2) Vehicles (slave nodes) which have received the information will reply their location information to the central node. The location information of a vehicle can be acquired by the GPS receiver equipped with it;
3) The central node numbers the other nodes in its area based on their relative locations which are acquired by comparison with central node. Then the serial number (from 1 to $N$) of each node will be transmitted to them by the central node.

In Fig. 2, each vehicle has an individual index number in this area, i.e., $L(i,j)$.Generally, the number of the orthogonal channel $M$ is less than the location number $K*N$. This means that, there may exist collision when multiple vehicles access to a same channel. We are motivated to design an optimal L2C mapping with minimal collision probability and high throughput.

### B. Location-Assisted Random Access Scheme

The location-assisted random access scheme uses the vehicular location information sufficiently to help the vehicle users access the channel in an efficient way. In this scheme, a vehicle accesses each orthogonal channel with different probabilities according to its location information. There are some rules of this scheme is described as follows:

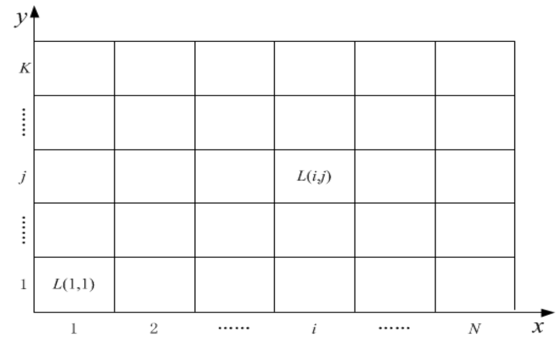


Fig. 2. The location partition of the studied area.

1) An exclusive function is employed to make the vehicular location information $L(i,j)$ map to a random variable $Y$ which is about the sequence number of the orthogonal channel. The function can be expressed by:

$$Y^k(e) = f^k[L(i,j)]; \qquad k = 1,2,\ldots,K*N$$

where, $Y_k$ denotes the random variable mapped by the $k$-th location, $f^k$ denotes the function of the $n$-th location, $L(i,j)$ denotes the location of a vehicle, $K$ denotes the number of the lanes, $N$ denotes the number of the locations in the studied area.

2) Each random variable $Y$ has a particular probability distribution which is expressed as follows

$$\begin{aligned} P\{Y^k = m\} &= p_m^k, \qquad m = 1,2,\ldots,M \\ \sum_{m=1}^{M} p_m^k &= 1; \end{aligned}$$

where, $M$ represents the number of the orthogonal channels, $p_m$ represents the probability that a vehicle access the $m$-th channel.

3) To satisfy the requirement of the distributed channel access, the mapping between the location information and the probability distribution should have the following properties:
   a) For any area, the mapping is identical. In other words, when the area is formed, the location has been divided. As well, the mapping of any location has been determined too;
   b) The mapping only depends on the probability distribution and the relative location of vehicle. But has nothing to do with the absolute location which is obtained by the GPS receiver;
   c) The mapping only exists in two neighboring geographic areas which have no interference with each other.
4) If vehicles in different locations access to the same channel at the same time (i.e. the values of two random variables are equal), the collision emerges. Under this situation, none of the vehicles could successfully use the channel to transmit. The expression of this situation can

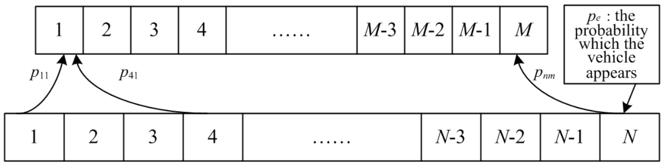


Fig. 3. Illustration of Location-Assisted Multiple Access Scheme.

be expressed by:

$$y^i = y^j; \qquad i \neq j$$

where, $y^i$ and $y^j$ are the value of the random variable $Y^i$ and $Y^j$ respectively.

## III. Collision Probability and Throughput Analysis

### A. Analysis of Average Collision Probability

In this section, the model of the average collision probability is derived. Without loss of generality,we assume that the scenario of VANET taken into account is an area on the one-way traffic road. The length of the area $L$ depends on the effective distance which can guarantee vehicles in this area to communicate with each other normally. We assume that every location in the area has a unique index number such as $1, 2, \ldots, N$. Meanwhile, the probability which any vehicles exist in each location is equivalent and denoted by $p_e$. The probability which the vehicle in the $N$-th location accesses the $M$-th time slot is denoted by $p_{nm}$. Such as the probability of the vehicle in the fourth location accessing the first channel is denoted by $p_{41}$ as shown in Fig. 3.

Based on the above assumption, $N * M$ unknown parameters can be obtained, such as $p_{ij}(i = 1, 2, \ldots, N; j = 1, 2, \ldots, M)$. In this paper, we employ the genetic algorithm (GA) to optimize the $N * M$ unknown parameters. The objective of the optimization is to decrease the *average collision probability* (ACP) among the vehicles in the studied area. The optimal values of the probability will be regarded as the basis for the vehicles to access the channel. In other words, when the vehicle wants to choose a channel to transmit information, it will occupy the corresponding channel according to the probability $p_{ij}$. We consider the general random access scheme for comparison. In order to compare these two schemes, some index should be used to evaluate the performance of them. We can calculate the average collision probability and the throughput of them respectively. The detailed calculation process of the average collision probability and the throughput using these two schemes is shown as follows:

*1) Average Collision Probability in Location-Assisted Random Access Scheme:* As mentioned above, a vehicle appears in any location with equal probability. In location-assisted random access scheme, the vehicle in every location accesses channels with different probabilities. The vehicle will suffer from the collision caused by the vehicles in other locations, when it accesses the channel. First, we calculate the collision probability of the vehicle appears in every location accessing the channel. Then add up all the collision probabilities to get the total collision probability. Finally, let the total collision probability be divided by the location number $N$, the average collision probability will be obtained. To obtain the expression of average collision probability, we first compute the collision probability of a vehicle in a certain location. In this location, a vehicle may randomly access the orthogonal channels. If the vehicle access the channel that is also accessed by other vehicles, the collision takes place. The collision probability model of the vehicle in a certain location can be founded as:

$$P_{c1} = 1 - P_{nc1}, \tag{1}$$

$$P_{nc1} = \sum_{i=1}^{M} p_{1i} \prod_{j=2}^{N} (1 - p_e p_{ji}); \tag{2}$$

where, $P_{c1}$ denotes the collision probability of the vehicle in a certain location accessing channels, $P_{nc1}$ denotes the non-collision probability of the vehicle in the first location accessing channels, $N$ denotes the location number in the studied area, $M$ denotes the channel number of the wireless bandwidth divided, $p_e$ denotes the probability of a vehicle appears in a location.

Based on the above derivation, the expression of total collision probability of the vehicle in all locations can be given by:

$$P_{tc} = 1 - P_{tnc}, \tag{3}$$

$$P_{tnc} = \sum_{k=1}^{N} P_{nck} = \sum_{k=1}^{N} \sum_{i=1}^{M} p_{ki} \prod_{\substack{j=1 \\ j \neq i}} (1 - p_e p_{ji}), \tag{4}$$

$$P_{aver-c} = \frac{1}{N} P_{tc} = \frac{1}{N}(1 - P_{tnc}); \tag{5}$$

where, $P_{tc}$ represents the total collision probability of the vehicle in the studied area accessing the channel, $P_{tnc}$ represents the total non-collision probability of the vehicle in the studied area accessing the channel, $P_{aver-c}$ represents the average collision probability of the vehicle in the studied area accessing the channel.

*2) Average Collision Probability in General Random Access Scheme:* General random access scheme is a simple scheme used by the vehicle to access channel. In the general random access scheme, all the vehicles access the channel with an equal probability that is $1/M$. The average collision probability of the vehicle accessing channel by this scheme is equal to the collision probability, in which the vehicle in any locations accesses any channel. Consequently, the average collision probability model is given by:

$$\begin{aligned} P_{aver-c} &= 1 - \left[(1 - p_e) + p_e(1 - \frac{1}{M})\right]^{N-1} \\ &= 1 - (1 - p_e \frac{1}{M})^{N-1}; \end{aligned} \tag{6}$$

### B. Analysis of Average Throughput

To compare the performance of the general scheme and the proposed scheme, we derive the throughput in these two schemes. Some assumptions are made. First, the channel condition is stable and uniform. Second, the throughput estimated

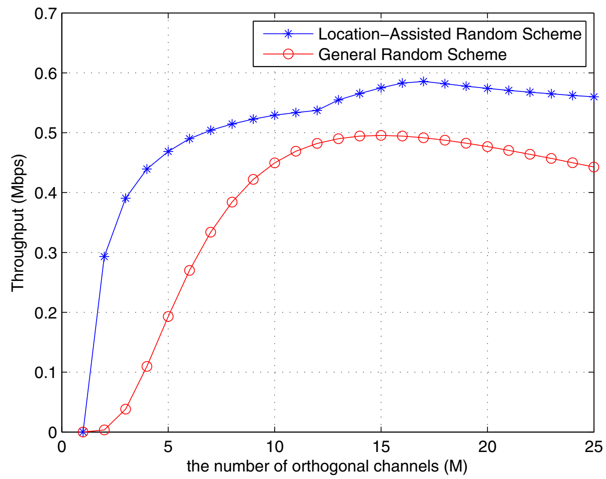


Fig. 4. The average throughput of the channel($N = 50, p_e = 0.3$).

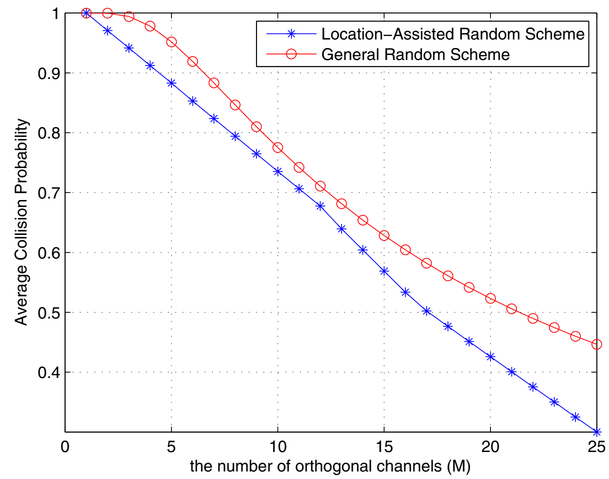


Fig. 5. The average collision probability($N = 50, p_e = 0.3$).

by the average rate of message delivery over the channel which is accessed by the vehicle successfully. Based on these assumptions, the average throughput is obtained by:

$$T_{aver} = \frac{C}{M}(1 - P_{aver-c}); \tag{7}$$

where, $T_{aver}$ denotes the average throughput of the orthogonal channel, $C$ denotes the total channel capacity of the bandwidth, $M$ denotes the number of the orthogonal channel, $P_{aver-c}$ denotes the collision probability when a vehicle access the channel.

## IV. Problem Formulation and Solution

According to (4) and (5), we can see the average collision probability is dependent on the L2C mapping. We should optimize the parameters of the L2C mapping in order to get a minimum average collision probability. The objective function and the constraint conditions of the optimization problem can be written as

(1) Objective function

$$P_{tc} = 1 - P_{tnc} = 1 - \sum_{k=1}^{N}\sum_{i=1}^{M} p_{ki} \prod_{\substack{j=1 \\ j \neq i}}^{N} (1 - p_e p_{ji}); \tag{8}$$

(2) Constraint conditions

$$s.t. \begin{cases} \sum\limits_{j=1}^{M} p_{ij} = 1 & i = 1, 2, \dots, N \\ 0 \leq p_{ij} \leq 1 & j = 1, 2, \dots, M. \end{cases} \quad (M < N) \tag{9}$$

The expression of the total collision probability in the location-assisted random access scheme has multivariable, high-ordered, non-linear characteristic. This challenge makes the optimization process become difficult. Meanwhile, common method to solve the optimization problem can not accomplish the optimality of this model. Genetic Algorithm (GA) optimizer is an adaptive heuristic search algorithm premised on the evolutionary theories of natural selection and genetic, which is an intelligent exploitation of a random search within a defined search space to solve the optimization problem, and can search for approximate global optimal solution.

The basic concept of GA is based on the principle of survival of the fittest by Charles Darwin. According to this principle, GA must perform the following five steps: 1) encode all the parameters in the objective function and construct the individual chromosome; 2) establish and initialize the initial population; 3) assign fitness values to individuals according to the objective function value; 4) duplicate the individuals of high fitness values from the population; 5) achieve the operation of crossover, mutation and recombination among the population to produce individuals of the next generation. Through the reiteration of above genetic operation, a group of individuals will be acquired to make the function of the total collision probability get the minimum value. By the decoding operation, the real values of all the parameters in the function of the total collision probability can be obtained. These real values make the objective function reach the approximate global optimal solution.

## V. Simulation Results

In this section, we present the performance comparison between the two channel access schemes. In the simulation, the Poisson Point Process is used to describe the location distribution of vehicles. The frequency of the change in vehicle topology is much less than the rate of the communications. Therefore, we can observe the distribution in a snapshot and assume that in the snapshot the vehicles evenly distributed in the area randomly. Each vehicle has a unique information of location at any time (i.e., no overlap of location) and the probability that a vehicle appears in a location (i.e., $p_e$) is a constant. Meanwhile, we assume that the connectivity is determined by the distances among vehicles.

To improve the utilization of the wireless channel, the number of orthogonal channels $M$ should be as small as possible. But the smaller the value of $M$, the larger the average

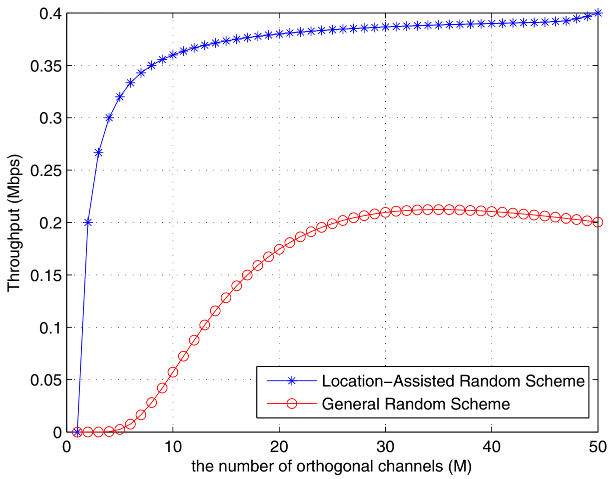


Fig. 6. The average throughput of the channel($N = 50, p_e = 0.7$).

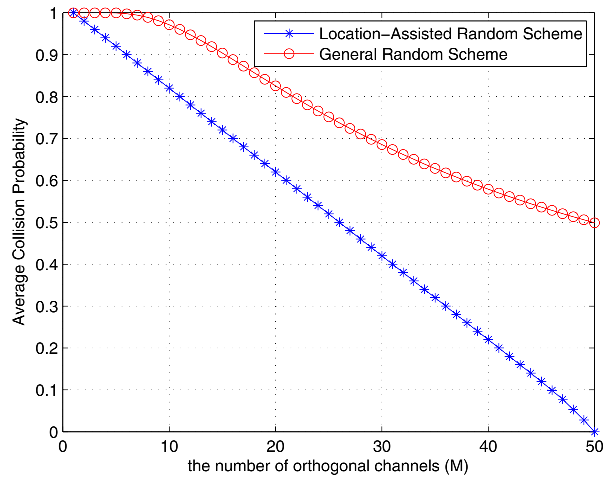


Fig. 7. The average collision probability($N = 50, p_e = 0.7$).

collision probability. The number of the channels $M$ reaches the optimal when it makes the throughput reach maximal. Due to the fact that the vehicles should keep a safety distance between each other when they travel on the road, we set the length of every location as 10 meters. Moreover, in order to ensure that vehicles can communicate with each other effectively, we set the length of the area as 500 meters a typical communication range in IEEE 802.11p. By referring to the DSRC technique, we set the channel capacity $C$ as 20Mbps. Then the location number $N$ is 50. The change of $p_e$ has profound effect on the average probability. We choose two values of $p_e$. The little value of $p_e$ presents that a small number of vehicles appears on the road. The large value of $p_e$ presents that the road is adequately crowd. In the simulation, we set the small and the large value as 0.3 and 0.7, respectively.

In the process of the GA optimization, Gray code coding method is used to achieve the parametric coding and 20 binary bits represent a parameter. In addition, we select the function of the total collision probability as the fitness function and assign fitness values based on the ranking method. The probability of the crossover and the mutation set as 0.7 and 0.035.

First, we fix the probability of the vehicle appearing in a location by $p_e = 0.3$. We observe the variation of the average throughput of the channel and the average collision probability of channel access with the variation of the number of orthogonal channels. From the Fig. 4, we can see that, in the general access scheme, when $M = 15$, the average throughput achieves the maximum. The average throughput in the proposed scheme outperforms out of that in the general scheme by as much as 16%. In the other hand, from Fig. 5 we can see that the average probability in our scheme is always lower than the general scheme. Especially, in the maximum of the throughput (i.e., $M = 17$), the $P_{ave-c}$ decreases by 13.7%. Meanwhile, the throughput in our scheme increases by 19% than the general scheme.

Second, we fix the probability of the vehicle appearing in a location (i.e., $p_e = 0.7$) and observe the variation of the average throughput of the channel and the average collision probability of channel access with the variation of the number of orthogonal channels. From the Fig. 6 we can see that, in the general access scheme, the maximum of the average throughput appears in $M = 35$. At this point, in the location-assisted random access scheme, the average throughput increases by 83% than in the general random access scheme. Meanwhile, form the Fig. 6 we also can see that when $M = 25$, the performance of the average throughput has already reached an remarkable performance. In addition, form the Fig. 7 we can see that $P_{ave-c}$ in our scheme is lower than in the general scheme. Furthermore along with the increase of $M$, the decreasing degree of the average collision probability increases observably.

## VI. Conclusion and Future Work

In this paper, a location-assisted random access scheme is proposed for VANETs. In the scheme, each vehicle node access to the channel according to a L2C mapping table. The average collision probability of channel access is reduced significantly. The average throughput is obviously improved. Simulation results show that the average throughput in our scheme outperforms that in the general random access scheme, when the number of the orthogonal channels is given, especially in the situation of traffic congestion. In our future work, a more practical model for the random distribution of vehicles will be considered. In addition, fading and shadowing effects may be taken into account in the radio propagation model.

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