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Study on Self-Adaptive Message Scheduler Used for the Vehicle Ad-hoc Network*

MINGJIAN LIU+, GUOZHEN TAN, NAN DING AND FUXIN ZANG
The Computer Science Institute
Dalian University of Technology
Dalian, 116024 P.R. China
E-mail: liumingjian@mail.dlut.edu.cn; {gztan; dingnan}@dlut.edu.cn; zhangsw8881@mail.dult.edu.cn

To satisfy the strict demands of VANET (vehicular ad-hoc network) on communication rate, response speed as well as on reliability, a communication sublayer that provides reliable, real-time and qualified communication services for upper applications is constructed in VANET. By using the queuing theory and based on researching the message queues in VANET, the current study designed a scheme for optimizing the communication sublayer, and proposed mechanisms for message compression, sending-frequency self-adaption as well as for data transmission compression, which make up an easy-to-be-deployed framework that provides safe, real-time and standard self-adaptive communication services for upper applications and which solve the problem that previous VANET communication is not reliable and real-time. Through simulation and real vehicle experiments ,we verify that the design can well satisfy the communication requirements of VANET in terms of performance and functionality, bandwidth occupancy decrease by 47.8 % and 11.4% relatively compared with CMS (common message set) and unoptimized MD (message dispatcher) decreased ,compared with CMS and unoptimized MD, the transmission frequency can decrease by 60% and 6.1%, and data compression ratio is 12.3%, thus proving the effectiveness of our scheme.

Keywords: vehicle ad-hoc network, communication layer, queuing theory instantaneity, predictive coding, data compression

1. INTRODUCTION

As the number of vehicles climbs straightly, the rapid development of traffic system brings us convenience, together with, however, traffic jams, accidents, energy crisis and environmental pollution. The cost caused by traffic jams increases year after year. Heavy traffic has now become a major problem that hinders social and economic development. "LOBAL STATUS REPORT ON ROAD SAFETY 2015" shows that the number of road traffic deaths – 1.25 million – has remained fairly constant since 2007 [1] .VANET, a frontier science of transportation in the world, is an effective way to solve urban traffic problems. It can achieve the purpose of cutting traffic congestion, reducing accidents and smoothing the traffic flow as it networks and intelligentizes the physical vehicles under the existing road net [2].

DSRC (Dedicated Short Range Communication) is now attracting attention from gov-

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+ Corresponding author.

ernment regulators, automakers, communications equipment suppliers as well as from academic institutions [3]. It becomes a popular communication standard today in VANET. When deploying the wireless communication system that connects vehicles in a large range, however, consideration must be paid to the contention for the resource of wireless channels. In addition, new applications will generate new data that need to be transmitted. Therefore, a standard communication interface is needed in order to make these systems compatible. One of the challenges is exactly the deployment of the standard system, which can not only make effect use of the limited wireless resource but also give support to future applications. To meet the above requirements, SAE (Society of Automotive Engineers) constructed a united communication sublayer in DSRC's protocol stack to coordinate the information transmission between applications, so as to improve the quality of service (QoS) of VANET, and compiled a united application layer communication protocol: SAE J2735 [4, 5], a dictionary of message sets in DSRC, which describes in detail the field formats of all possible information that might be transmitted between VANET's safe applications. During communication, messages are transmitted in sets.

This method still has disadvantages. Redundant data might be generated from messages during vehicle communication: some data in the fixed messages that transmitted by SAE J2735 protocol are possible useless; in another case, specific applications might need different messages, which, however, may contains some public data. For instance, the data a vehicle's speed may be contained in different messages transmitted by different applications, while those changeless messages don't need to be delivered frequently. Messages are variably used in different cases, which makes it more difficult to standardize the process. Therefore, a fixed message may be very long, or, cannot meet the requirements of all applications. As a result, MD, which can overcome the above defects, came into being, and later, was integrated into the operation of SAE2008 [6]. It is to coordinate the data exchange requests from all applications running on the vehicle. This can be achieved through the interface that connects the communication layer and the application layer. In a safe application, some data to be broadcasted are sent to MD and are collected into a group, which contains the minimal set of the data that need to be transmitted [7]. After the data being grouped, the message will be sent to DSRC's wireless channels, in which, the data are then broadcasted.

MD has now been widely accepted: ① A similar approach has also been used in the Cooperative Intersection Collision Avoidance System (CICAS) project within the Collision Avoidance Metrics Partnership (CAMP); ② Toyota Technical Center has already installed the message scheduler in two cars. In this message scheduler, a feedback mechanism is employed to realize the interaction between applications. After being initialized, applications provides data to MD and also take data from it. During the process of data registry, when an application needs to send data, or, when MD's channels receive the updated data, the application will send feedback to MD, and, hence, MD can arouse the application. However, the development of MD is still in its initial stage. Improvements shall be completed with consideration of following aspects [8, 9]. For safe applications in VANET, the sending frequency shall be increased or decreased according to traffic conditions, which, yet, is not supported by the current structure, namely, the redundant messages cannot be minimized. In other words, there are lacks of a self-adaptive adjustment mechanism for periodic broadcasts and even-triggered communications. The sending frequency cannot be adjusted by itself. When an application is registered to MD, the sending frequency of only the message to be used is defined and cannot be adjusted dynamically. Consequently, this structure lacks of an event trigger mechanism: self-adaptive adjustment cannot be made for both emergencies and non-emergencies, and heartbeat packets may lead to a broadcast storm in the network [10].

In view of the above problems, the queuing theory is used in this article to optimize the communication sublayer when designing MD. First, a safe information sublayer framework that provides real-time and safe communication services for upper applications is designed, which, to some extent, satisfies the VANET's demands for communication services. Second, the loads on channels can be significantly reduced by coding the data in practical applications. Third, an incremental data synchronization strategy is taken at both the sending and receiving terminals of the VANET, which realizes the self-adaptive compression of the transmitted data, builds the encryption and decryption mechanism for the data and improves the quality of service (QoS). Finally, our design is applied to both simulation and actual intersection scheduling. The results show that our design can meet the communication requirements and can be used as reference for the standardization of safe information communication sublayer. In the DSRC protocol stack, the safe information communication sublayer locates somewhere between the application layer and the communication layer, so it can provide services to different upper applications, as shown in Fig. 1.

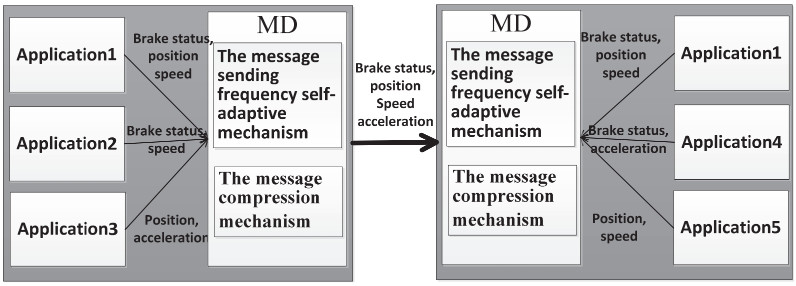


Fig. 1. The structure of optimal designed communication sub-layer.

2. AN OPTIMIZED DESIGN OF SAFETY MESSAGES' COMMUNICATION SUB-LAYER BASED ON QUEUING THEORY

In the DSRC protocol stack, the safe information communication sublayer locates somewhere between the application layer and the communication layer, so it can provide services to different upper applications, as shown in Fig. 2.

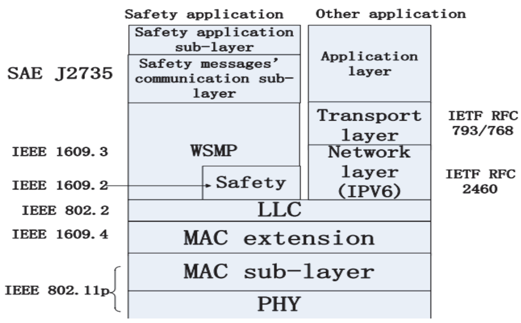


Fig. 2. The DSRC communication protocol stack.

Message in VANET is delivered in the form of message queues, which are processed in the communication sublayer in RSU (Road Side Unit) and OBU (On board Unit). When a message is processed by the sublayer, then a service is provided. According to the queuing theory, the communication sublayer to process messages can be deemed as a single server queuing system.

In the input process and service process of such system, each state is not related to all previous states but only to the last state. According to this trait and the classification of the queueing system, it can be deemed that messages of this system are generated based on $\{M(t), t \geq 0\}$ Poisson flow, of which the mean arrival rate is $\lambda(\lambda > 0)$, namely the number of the newly received messages that need to be processed by the communication sublayer in unit time. The service time of each message follows the independent negative exponential distribution, of which the mean service rate is represented by $\mu(\mu > 0)$, which means the average number of messages that processed in unit time. The maximum number of the messages in the system depends on the queuing capacity designed in the communication sublayer. To demonstrate the waiting characteristic of the messages, the maximum number here is defaulted to infinity (∞) and the number of service window is 1. According to the above analysis, the queue in the communication sublayer can be deemed as a Poisson queuing system that has the Markov characteristic, and can be described by Kendal model as: $M/M/1/\infty$.

The average size of message queue:

$$L = \rho/(1-\rho) = \lambda/(\mu-\lambda). \tag{1}$$

The average spending time of a message:

$$T = L/\lambda = 1/(\mu-\lambda). \tag{2}$$

To make the communication sublayer more real-time as well as to make it to receive and process messages more quickly, the queuing system must be optimized to shorten both the queue length (L) at stable state and the sojourn time (T) of each message waiting in the queuing system. Therefore, the mean process rate μ shall be properly increased and the mean arrival rate λ shall be decreased as well. In the light of the equation, this goal can be achieved by two ways: the message sending frequency self-adaptive mechanism and the message compression mechanism. The former is a mechanism for optimizing retransmission. It is to reduce the transmission frequency with the functions being assured, meanwhile to eliminate the redundant message in the queue, which can therefore cut down the number of the queuing messages to lower λ. The later is to slim the messages themselves to increase the number of the messages process by the communication sublayer in unit time, so as to increase μ.

3. THE MESSAGE SENDING FREQUENCY SELF-ADAPTIVE MECHANISM

In order to save the bandwidth and other resources of VANET, repeated messages should be minimized at the sending terminal of the vehicle and message sequence should be constructed. Besides, the data should be sent at a smaller updating rate. When the density of vehicles is large, the communication sublayer in VANET still may receive a great deal of redundant messages. For an application used to monitoring dangerous vehicle speeds, for example, when the speed does not reach the threshold, messages of vehicle speed are still periodically sent. In this case, the receiving queue in the service terminal of the application may receive a lot of speed messages that don't need to be processed. Consequently, the messages about dangerous speeds cannot be answered in time. In order to ensure that there are not too many redundant message in VANET, the sending frequency shall therefore be reduced when designing the communication sublayer, *i.e.*, λ in Eqs. (1) and (2) shall be lowered down.

J2735 classifies messages into several types, among which the most important one is BSM (basic safety message) that contains core information sent from a vehicle, including position, velocity and size of the vehicle. BSM is a key part of the model that is commonly used in vehicle collision avoidance systems. BSM is designed into two parts. The first part contains core status information that must be updated every time, including the basic information used to predict vehicle tracks, frame types and sequences, which must be sent out by each BSM. The second one is an optional area that contains additional data elements and frames.

When a vehicle is under monitor, the information from BSM, such as position, velocity, steering angle and direction, can be used to predict the track of the vehicle in a period in future. If the track can be precisely predicted, then the status information don't need to be sent frequently, and, if and only if the error of the prediction is "large enough", the data will then be sent out.

3.1 The Tolerable Error

The frequency of sending messages at the vehicle's sending terminal is determined with following three considerations: ① provide precise estimation of the current state to adjacent vehicles, *i.e.*, the state estimation error shall be "tolerable"; ② to ensure that vehicles entering an area receive a timely introduction from their new neighbours; ③ to ensure that neighbours are quickly updated about a state transition.

In the message sending frequency self-adaptive mechanism, data elements are not transmitted at a fixed frequency. Thus, the error of estimating states might be large due to the continuous transmission. For the first consideration, the state estimation error in continuous sampling time interval is used to define the tolerable error. And, the zero order is taken to predict the state at time $k+1$ by using the state at time k, which generates a measurement error at time $k+1$. Then we can obtained the so called "expectation error" by calculating this measurement error. For the second and third considerations under normal transmission frequencies, adjacent vehicles are informed with the current state. Our study stipulates that the data elements must be able to be transmitted at a lower frequency. The frequency we choose is lower than the normal transmission frequencies [11].

3.2 Predictive Coding Transmission Policies Based on the Intersection

Intersections, as the high-accident location where the traffic is heavy, are the bottleneck of the urban road network. For intersections, therefore, the paper designs a predictive coding transmission strategy to improve information distribution and builds a united assessment standard to determine whether the multiple status information of a vehicle needs to be retransmitted. In addition, a mechanism is established for assessing the error of the danger of vehicle collision to determine whether the messages need to be retransmitted or not.

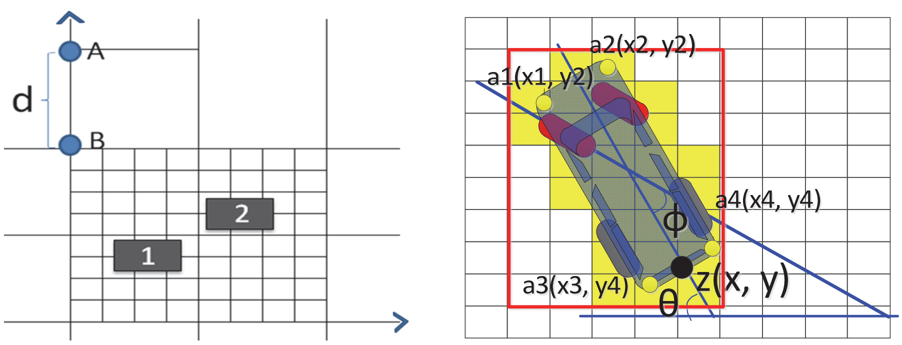
The status information broadcasted from a vehicle is called as beacon [12] (Vehicle ID, location, direction, speed, time stamps, time interval and transmission power value, *etc.*). The most important function of each beacon is to show each vehicle the state of the current traffic network as well as to assist the vehicles to take proper way to transmit messages, so as to avoid network congestion.

3.3 Vehicle Track Prediction

First, the beacon broadcasted from each vehicle needs to be traced to predict whether two vehicle tracks intersect with each other or not, and to calculate the possibility of the vehicle collision at the intersection. Second, a beacon is a broadcast message because of the fast movement of the vehicle, and there is no confirmation mechanism at the receiving terminal of the vehicle. Adjacent vehicles trace the real-time messages from target that sent the beacon. Finally, each vehicle needs to send the beacon of its own state information and, meanwhile, estimate the tracks of other vehicles.

3.3.1 Traffic safety warning method based on space-time grid intersection

The space (S) of the intersection is divided into a $g \times g$ regional net comprising of grids. Whether a collision will happen can be determined by predicting whether a grid (or several grids) will be shared by two vehicles in future [13], as shown in Fig. 3 (a).



(a) Intersection state information. (b) Vehicle state information.
Fig. 3. Meshing at the intersection.

3.3.2 Vehicle state information

By the integrated differential GPS and sensors, the "self estimator" in the vehicle can calculate the information such as the number of the shared grids, the velocity and the direction, *etc.*, at the moment t. These information are collected to make up the state vector of the vehicle ($\hat{v}(t)$ = (k, x, y, h, w, L, v, a, f, θ, φ)), as shown in Fig. 3 (b). The vector is then added into the beacon, in which, k represents the shared grids at moment t; x represents the abscissa and ordinate values of the center of the vehicle's mass under the coordinate system of the intersection; h represents the length and width of the vehicle; L represents the distance from the vehicle's front axle to the rear axle; v represents the velocity; a represents the acceleration; f represents the direction; φ represents the steering angle of the wheels at a certain moment; and θ represents the steering angle of the vehicle body. This vector, which describes the state of the vehicle at moment t, is broadcasted ($\hat{v}(t)$) at the predefined fixed power to all the other adjacent vehicles that has potential risk of collision.

The "self estimator" achieves the prediction of the track of the vehicle itself. Yet, even an accurate prediction of the vehicle itself cannot guarantee the driving safety. Therefore, not only the state of the vehicle itself needs to be predicted, but also the potential collision risk from adjacent vehicles needs to be accurately mastered in time. What's more, the tracks of adjacent vehicles shall also be predicted to determine the possibility of collision. Hence, we set an "adjacent vehicle estimator" in each vehicle to receive the state information $\hat{v}(t)$ from adjacent vehicles, so as to estimate the state of adjacent vehicles. If there are N adjacent vehicles that carry the risk of collision, then N "adjacent vehicle estimators" will be generated.

(1) Vehicle coordinates

When a vehicle enters in the grids of the intersection, its coordinate $Z(x_t, y_t)$ at initial moment t can be obtained by GPS, and the front wheels' steering angle φ, velocity v and acceleration a at this moment can also be obtained by the sensors. The values of h, w and L are already known.

(2) Vehicles with the x axis Angle

The Angle θ calculate Eq. (3), as shown in Fig. 3 (b).

$$\begin{cases} \dfrac{d\theta}{dt} = \dfrac{V\tan\varphi}{L} \\ \dfrac{dx_t}{dt} = V\cos\theta \\ \dfrac{dy_t}{dt} = V\sin\theta \end{cases} \qquad \begin{cases} \theta = \displaystyle\int \dfrac{V\tan\theta}{L}dt \\ \Delta x = \displaystyle\int V\cos\theta(\dfrac{V\tan\varphi}{L}t)dt \\ \Delta y = \displaystyle\int V\sin\theta(\dfrac{V\tan\varphi}{L}t)dt \end{cases} \tag{3}$$

Vehicles in $t + 1$ moment centroid coordinates for $Z(x_{t+1}, y_{t+1})$

$$\begin{cases} x_{t+1} = x_t + \Delta x \\ y_{t+1} = y_t + \Delta y \end{cases}. \tag{4}$$

(3) Vehicle vertex coordinates

Vehicles in t time four vertex coordinates, as shown in Fig. 3.

$$a1(t+1):\left(x_{t+1} - \frac{w}{2\sin\theta} - (h - \frac{w}{2\tan\theta})\cos\theta \text{ , } y_{t+1} + (h - \frac{w}{2\tan\theta})\sin\theta \right)$$

$$a2(t+1):\left(x_{t+1}-\frac{w}{2\sin\theta}-(h-\frac{w}{2\tan\theta})\cos\theta+w\sin\theta, y_{t+1}+(h-\frac{w}{2\tan\theta})\sin\theta+w\cos\theta\right)$$

$$a3(t+1):\left(x_{t+1}-\frac{w}{2}\cos\theta\ , y_{t+1}-\frac{w}{2}\sin\theta\right), a4(t+1):\left(x_{t+1}+\frac{w}{2}\sin\theta\ , y_{t+1}+\frac{w}{2}\cos\theta\right) \quad (5)$$

(4) Vehicles take up the number of grid intersection

According to the obtained coordinate point z and four vertex coordinates of the vehicle at t+1 obtianed by calculation, the number of grids of the vehicle at time t+1 can be calculated, as shown in Fig. 3 (b), the blue box represents vehicles turning a corner; a1, a2, a3 and a4 represent four vertexes of the vehicle. First of all, it extends out from the grids where the four vertexes of the vehicle are located to delimitate a rectangular area in the red box shown in Fig. 6; next, when the vehicles go through the red area, the vehicle occupied grids are marked with yellow, namely the yellow area; then, the sub-grid group of intersection space domain at t+1, $\tilde{k}$:

$$\tilde{k}(t+1) = \{s_k | 1 \le k \le g^2, g \in N^+\}. \quad (6)$$

3.3.3 Vehicle trajectory

Vehicles reach the intersection line of the region, as shown in Fig. 3 (a). A point location, at the moment of v_f speed and acceleration a_f and tt_f, vehicle track prediction can be divided into two parts:

First of all, according to distance (d) of the track from the sidewalk line (Point A in Fig. 3 (a)) to the intersection (Point B in Fig. 3 (a)) together with the velocity (v_f, a_f) of the vehicle at the sidewalk line, we can obtain the velocity (v_d), the time it takes to move from A to B is t_d when the vehicle enters in the intersection.

$$\begin{cases} d = v_f t_d + \frac{1}{2} a_f t_d{}^2 \\ v_d = v_f + a_f t_d \end{cases} \quad (7)$$

Secondly, the driving track of the vehicle in the intersection can be plotted according to the grids occupied by the vehicle at moment tt_0 (in Fig. 3 (a), the vehicle enters in the grids from point B).

$$tt_0 = tt_f + t_d \quad (8)$$

3.4 Traffic Conflict Degree

(1) TTC (Time to collision)

Whether a vehicle will collide with an adjacent one at a future moment t can be estimated by predicting whether the two vehicles will take up the common grids or not. If a collision will happen, then this moment t is defined as the collision time TTC.

(2) TTA (Time to avoidance)

When the warning module receives a warning message from a roadside unit, the driver begins to slow down. In this article, the IEEE802.11p communication protocol is employed.

$$TTA = t_m + t_r + t_b \tag{9}$$

t_m early warning information transmission time, t_r for driver reaction time, t_b for deceleration time. According to the formula of vehicle braking process as well as according to national standards, t_r = 1.5s, t_b contains two parts: t_1 is time needed to increase the braking force, and t_2 is the time for keep the braking after it reaches the maximum. t_1: assume $a = kt_1 = a_{max}$, a_{max} is the maximum deceleration when the driver puts on the brakes to the bottom.

$$v = v_d - \int_0^{t_1} adt = v_d - \int_0^{t_1} ktdt = v_d - \frac{1}{2}a_{\max}t_1 \tag{10}$$

t_2: The time of the deceleration process, starting from the maximum deceleration till the vehicle stops.

In the case that a small car running on a dry bituminous pavement with the deceleration of 7.4m/s², for example, t_b = 0.12+0.14v; the time for transmitting a warning message is t_m = 0.045ms; and TTA = 1.71+0.14v.

(3) Traffic conflict degree

The potential collision risk degree (e) can be obtained by comparing the relation between TTA and TTC.

$$e = \frac{TTC}{TTA} \tag{11}$$

$e > 1$ general (green); $0.5 < e \leq 1$ serious (yellow); $0 < e \leq 0.5$ very serious (red).

3.5 The Degree of Potential Risk of Collision Vehicle Error Estimates

The potential collision risk degree (e) can be obtained by comparing the relation between TTA and TTC, under the condition that the communication is smooths without the loss of the channel signal packets. On an actual intersection, however, there are possibilities that: the communication may not be linked; the channel resources may be competed by several vehicles, and; the signal packets may be lost, *etc.* In this case, the potential collision risk degree (e) obtained by the "self estimator" as well as by "adjacent estimator" cannot reflect the real situation of the collision. In order to accurately estimate e, two devices are added: remote estimator and scheduler. The remote estimator stores the latest movement information of vehicle i that are broadcasted to adjacent vehicles. The remote estimator of vehicle i is represented as RE_i, and the "adjacent estimator" in the adjacent vehicle j used for the vehicle i is represented as NE_{ji}. The purpose of the remote estimator RE_i is to estimate all outputs of NE_{ji}, *i.e.*, it is the estimator of all adjacent estimators.

At any moment t, the communication decisions of vehicle i is make by the scheduler, which receives both the collision degree $e_{ji}(i)$ of adjacent vehicle j that is obtained by the "self estimator" and "adjacent estimator" and the collision degree $e_{ji}(i)$ of adjacent vehicle i that is obtained by the remote estimator. According to Eq. (12), if the error exceeds the acceptable critical value, the vehicle will rebroadcast its state information $\vec{v}(t)$ to predict the vehicle track. If the state information is being accurately accepted, the error at the receiving terminal will be reset to 0.

In this paper, the potential collision risk degree is represented by the proximity rate cp (percentage) of $e_{ji}(i)$ to $e_{ji}(i)$, in which, p is the proximity rate of the collision degree obtained by the remote estimator of vehicle i to the collision degree obtained by both the self and adjacent estimators.

$$cp = \begin{cases} (\frac{1-\gamma}{a}x+\gamma)*100\%, & (e_{ji}(i) \le a) \\ (\frac{\gamma-1}{a}x-\gamma+2)*100\%, & (a < e_{ji}(i) \le 2a) \\ (e^{2a-x}-\gamma)*100\%, & (e_{ji}(i) > 2a) \end{cases} \tag{12}$$

When $e_{ji}(i) \le a$, it is a monotonic increasing function: if the value of $e_{ji}(i)$ is larger, the two collision degrees are more proximate and the error is smaller. When $a < e_{ji}(i) \le 2a$, it is a monotonic decreasing function: the two collision degrees are more proximate if the value of $e_{ji}(i)$ is smaller. When $e_{ji}(i) > 2a$, there is a boundary that the error keeps the same effect on the system, and the error cannot be reduced by adjusting the power. γ is the minimal value.

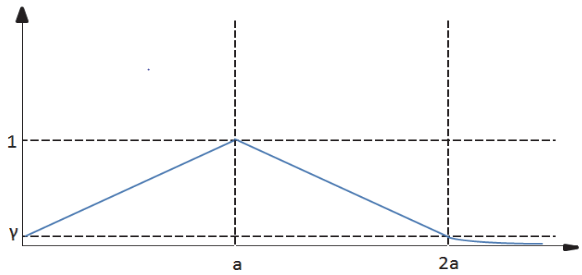


Fig. 4. The degree of potential risk of collision vehicle error estimates.

When the error of the data elements goes beyond the acceptable threshold, these data elements will be transmitted only if $cp \le 0.85$. The interval between transmissions is kept by using the zero order. That is to say, the current data is kept unchanged before a new data is received. When the data needs to be updated, the whole set of the data elements will be sent out, and each element must be transmitted at the frequency of 0.25Hz or above.

4. THE MESSAGE COMPRESSION MECHANISM

A vehicle shall maintain a less complex communication system. This reflects, on the one hand, that the transmission size of the system messages shall be controlled at a lower magnitude, and the number of the system messages shall be lessened, on the other hand. The size of the messages in the communication sublayer can be reduced to some extent when the predictive coding is used for transmission. However, the messages can still be compressed, and the volume of the information transmission can also be cut, to further improve the transmission efficiency, save the communication resources, reduce the cost of the system and increase the μ in the equation. During the process of information transmission, the first and the second parts of BSM can be used for vehicle prediction as well as for data compression before transmission. The network resource can be effectively saved by transmitting only the changed data frames and elements, with the unchanged ones left. Therefore, this article makes use of an incremental data synchronization strategy, the ksync strategy, to avoid retransmitting the great deal of redundant messages, so as to realize the self-adaptive compression of all data [14].

Our idea of ksync is actually inspired by the famous algorithm of rsync, which was originally created by the researchers of the Australian National University in the year of 1996. Rsync provides a very fast method for bringing remote files into synchronization for Unix-like systems The ksync policy actually inherits the core idea of the algorithm of rsync and develops its own way of implementation and optimization.

4.1 Mechanism of Checksum

To each data block, we will assign two checksums when necessary, which are known as the weak checksum and the strong checksum. We will not employ the strong checksum when comparing blocks until the weak checksum matches, mainly because the computing consumption of strong checksum is far more larger than that of weak checksum. For ksync, we compute the weak checksum of a particular k byte data block with the adler32 algorithm, and the strong checksum the md5 algorithm.

4.2 The Comparison Between the Data Blocks

Based on the comparison between data blocks, we obtained a consistent data block sequence and two inconsistent sequences. The ksync strategy functions like this: what maintained by the consistent data block sequence is its index sequence, while the inconsistent sequences maintain the sequence of the original data. Data elements in these two kinds of sequences are marked by specific delimiters. The index sequence of the consistent data blocks shall be transmitted in a strictly increasing order, because in the transmission, only the differentials between the index sequences rather than their original values are transmitted. The data sent by the vehicle at t is N_{src} and the data sent at $t-1$ is N_{dst}. N_{src} and N_{dst} are compared to detect the same and different parts. The same parts are not sent and different parts are not sent. The data sent by the vehicle at t is N_{src} and the data sent at $t-1$ is N_{dst}. N_{src} and N_{dst} are compared to detect the same and different parts. The same parts are not sent and different parts are not sent. Then, divide the data at both the source and target nodes into data blocks, of which the size is k bytes. p is ratio of the consistent data blocks, after N_{src}. N_{dst} being divided, to the N_{dst} data blocks (hereafter referred to as the consistency ratio). c_1 is the mean cost for transmitting the index sequences of the consistent data blocks, and c_2 mean cost for transmitting the sequence delimiters of the inconsistent data blocks. It is easy to know that the total cost for transmitting the index sequences of the consistent data blocks is C_1, and the total cost for transmitting the inconsistent data blocks is C_2.

$$C_1 = c_1(\frac{pN_{dst}}{k}), C_2 = c_2(\frac{pN_{dst}}{k}) + (N_{src} - pN_{dst}) \tag{13}$$

By ksync strategy, therefore, the total cost for the transmission from the source node to the target node is:

$$\begin{aligned} C_{total} &= C_1 + C_2 = c_1(\frac{pN_{dst}}{k}) + c_2(\frac{pN_{dst}}{k}) + (N_{src} - pN_{dst}) \\ &= (\frac{c_1 + c_2}{k} - 1)pN_{dst} + N_{src} \end{aligned} \tag{14}$$

where, the value of c_1 and c_2 is no larger than 6 and 2 bytes, respectively. Hence, it can be reckoned that the inequation is valid if k equals to 32.

$$(\frac{c_1 + c_2}{k} - 1)pN_{dst} + N_{src} \tag{15}$$

Using this relation we know that the consistency ratio p is not 0. As a result, the size of the synchronous data transmitted by the ksync strategy is always less than that of original data from the source node. Even there lacks of a next coding strategy, we can still lower the real cost of data transmission.

4.3 Guarantee Data Consistency

Another feature concerning ksync is its underlying measure to guarantee data consistency, which could be a most important issue with regard to synchronization. Due to this point, both of the source node and the destination node would maintain an Update Sequence Number (USN for abbreviation in the following sections), so as to keep record of the latest version for the data to be s check its own USN with the one sent by the source node for the mirror data copy every time before decoding. Only when those two numbers are strictly equal, would the destination node be allowed to continue with the following synchronization. Otherwise, the destination node would require the source node to retransmit for safety. Both of the two nodes' USNs would be updated as the same after each successful synchronized.

5. RESULTS ANALYSIS

5.1 Simulation Experiment

In this study, the network simulator of NS-3 is used to simulate and assess the optimized communication sublayer. A scheme for assessing the performance of the vehicle experiment is designed. The safe application running in the application layer between

OBU and RSU is used for communication. First, the communication sublayer at the sending terminal completes the construction the message. Second, the message is then delivered to NS-3 to simulate the communication. Finally, NS-3 conducts the simulation of the receiving process in the lower protocol, and the communication sublayer at the receiving terminal receives and processes the message for the upper application.

(1) Experimental scene

In designing the experiment, we construct a bidirectional intersection that contains three lanes, in which, the stopping distance is set to be 1 meter. Vehicles running along all directions follow the Poisson distribution. The volume of the traffic flow on the entire intersection increases from 1000 vehicles/hour to 5000 vehicles/lane/hour. we collect data during the period from the beginning to the moment when the thousandth vehicle passes through the intersection, and use the collected data to make investigation. First, the performance of the message sending frequency self-adaptive mechanism is measured by the index of the mean length. Second, the performance of the message compression mechanism is assessed by the data compression rate. Finally, the mean length (L) of the message queues and the mean sojourn time (T) of the queuing messages are taken as the index to assess the queuing theory-based communication sublayer.

(2) The evaluation index

First, the performance of the message sending frequency self-adaptive mechanism is measured by the index of the mean length. Second, the performance of the message compression mechanism is assessed by the data compression rate. Finally, the mean length (L) of the message queues and the mean sojourn time (T) of the queuing messages are taken as the index to assess the queuing theory-based communication sublayer.

Table 1. The 8 high priority vehicle safety applications listed by VSCC.

Application	Type	Frequency (Hz)
Signal violation alert	R2V	10
Speed alert	R2V	1
Brake lamp	V2V	10
Early awareness collision	V2V	50
Forward collision	V2V	10
Left turn aid	R2V or V2V	10
Change lane alert	V2V	10
Stop sign aid	R2V or V2V	10

(3) The experimental set

① The sending frequency of most safe applications is 10Hz, and only a few applications are sent at a frequency lower or higher than 10Hz. For the purpose of convenience, we assume that the mean sending frequency of all vehicles is 10Hz. ② When the traffic flow is far away from its peak value, the length and the time of the message queue at each terminal is close to 0. For the convenience of observation, the statistical object in the experiment is the sum of the lengths and the time of the message queues at all terminals. ③ The experiment is carried out in two groups. In the first group, the upper application uses the communication sublayer that has not been optimized to send the basic safe messages from the SAE J2735 set. In the second group, the upper application uses the optimized communication sublayer to send and receive messages. For both groups, we make statistics of the mean length and time of the message queues in the communication sublayer under different traffic flows.

The experiment indicates that the mean queuing length in the un-optimized communication sublayer is close to zero when the traffic volume is less than 2000 vehicles/hour/lane, which corresponds to real-time service. After the traffic volume is larger than the threshold of 2000 vehicles/hour/lane, the queuing length increases rapidly, which cannot ensure the quality of service. For the optimized communication sublayer, this threshold rises to 3000 vehicles/hour/lane. This is also the case for the mean sojourn time, as shown in Fig. 5. This is also the case for the mean sojourn time, as shown in Fig. 6.

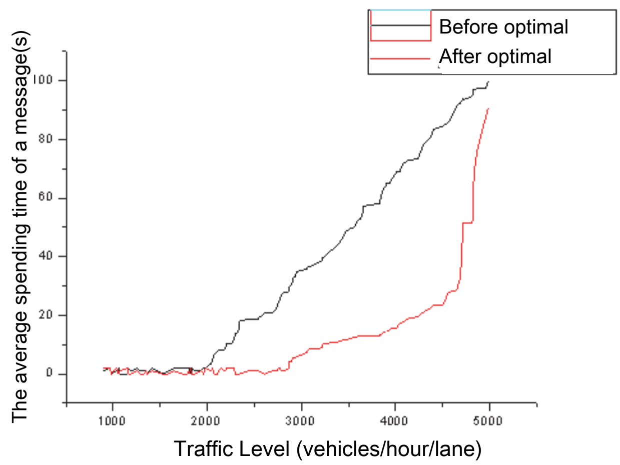


Fig. 5. The simulation results of the message queue's length vs. traffic flow.

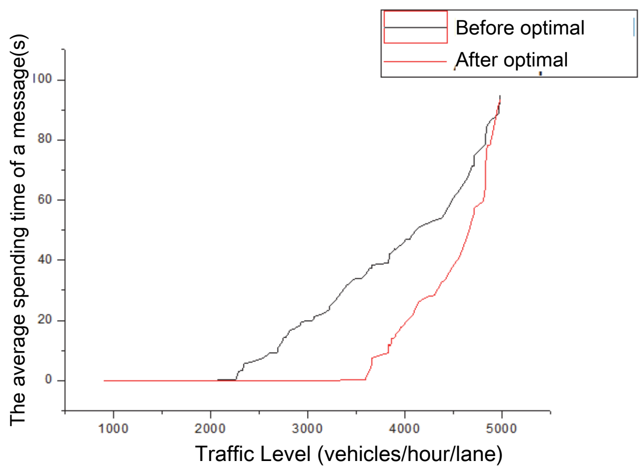


Fig. 6. The simulation results of the message's average wait time vs. traffic flow.

The situation of occupancy channel resources. In this paper, after completing the comparison of message queuing length and average waiting time, the average occupied bandwidth of vehicle in the transmission of data are compared among the optimized and designed MD in this paper, the traditional MD and the common message set (common message set, CMS, CMS architecture is adopted by SAE prior to MD architecture).

The prescript data element size in the Ninth Revision of SAE J2735 is adopted in the experiment, in which, the message size of heartbeat is 25.5 bytes, the warning message of emergency braking is 155.5 bytes, and the warning message of intersection collision is 46.75 bytes. The process of comparison comprises: ① emergency brake warning (EBM), and intersection violation warning (IVM) and all other necessary data elements, and its size is 175.5 bytes; ③ heartbeat message (HBM).

CMS is assumed to be periodically transmitted at 10Hz, which needs a channel rate of 14.1kbps for one vehicle, while the traditional MD only needs a channel rate of 0.6kbps to transmit HBM at the frequency of 3Hz. When IVM event occurs only, channel rate will increase to 3.7kbps; when EBW event occurs only, channel rate will increase to 6.2kbps; when IVM and EBW events simultaneously occur in a vehicle, then under the same conditions, the channel rate and the CMS will use the same channel rate, where it is assumed that every application program is continuously transmitted [3].

The average occupancy bandwidth (kbps) of each vehicle are compared among the designed and optimized MD, conventional MD and CMS under the condition that the traffic flow scale of the entire network area increases from 1000 vehicles/hour/lane to 5000 vehicles/hour/lane size in Fig. 7.

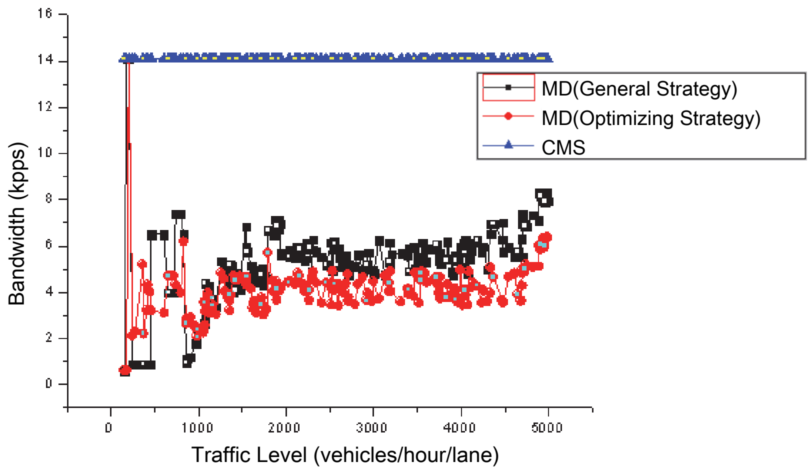


Fig. 7. The average occupancy bandwidth.

Through experimental analysis, with the increase of traffic in the intersection, the average occupancy bandwidth of a vehicle in the optimized and designed MD is significantly lower than that in the conventional MD and CMS. The occupied bandwidth is decreased by 11.4% compared with traditional MD and decreased by 47.8% compared with CMS.

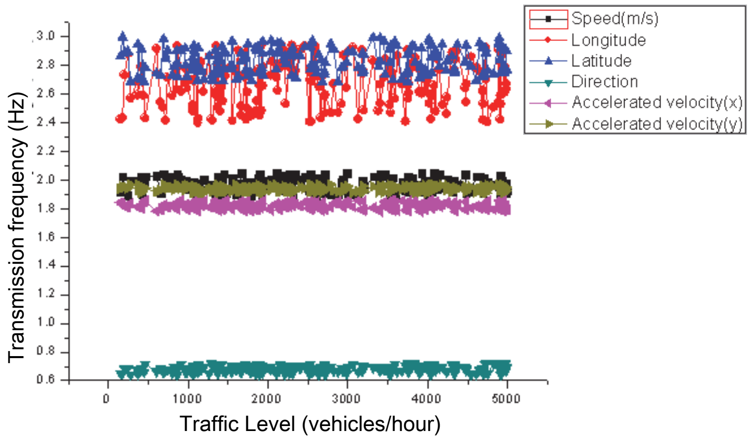


Fig. 8. Message transmission frequency.

Fig. 8 is the adaptive mechanism of message transmission frequency in this paper, which includes the data transmission frequency of speed, latitude, longitude, direction, lateral acceleration and longitudinal acceleration, during the period of the traffic flow scale of the entire network area increasing from 100 trips/hour to 500 trips/lane/hour.

The transmission strategy based on predictive coding is given in literature [3]: ① Policy 1 Data elements are transmitted according to the specified transmission frequency, which is taken as the baseline reference program; ② Policy2 Only when the error value of data element exceeds the acceptable threshold, the data elements will be transmitted. The 0-order hold is used in the transmission interval, that is, the data will remain unchanged before receiving a value, without the use of predictive coding. The complete data elements will be sent when it needs to be updated, and each data element must be transmitted at least at the frequency of 0.25Hz; ③ Policy3 With the exception of adopting predictive model, the rest are the same as the above; the complete data elements will be sent when it needs to be updated, and each data element must be transmitted at least at the frequency of 0.25Hz; ④ Policy4 When updated, a smaller status calibration value would be sent, rather than the complete data, and with the exception of this, the others are the same as the third program.

Table 2 lists the comparison results between the average values of each data obtained from message sending frequency adaptive mechanism in the paper and those of

Table 2. Send frequencies for various data elements under the proposed policies.

Data element	Average transmission frequency (Hz)			
Policy #	Policy 1	Policy 2	Policy 3,4	Paper Policy
Speed (m/s)	5	2.01	1.76	1.748386
Longitude	5	2.9	0.26	0.24981
Latitude	5	2.97	0.27	0.266091
Heading	5	0.69	0.57	0.557898
Accel.x (m/s2)	5	1.83	1.83	1.81881
Accel.y (m/s2)	5	1.95	1.95	1.940167

the above scheme. It can be concluded that the message sending frequency adaptive mechanism in this article can reduce transmission frequency during the process of message transmission, and then reduces the channel load. The sending rate is decreased by 60% compared with Policy 1 and it is decreased by 6.1% compared with Policy 3 and Policy 4.

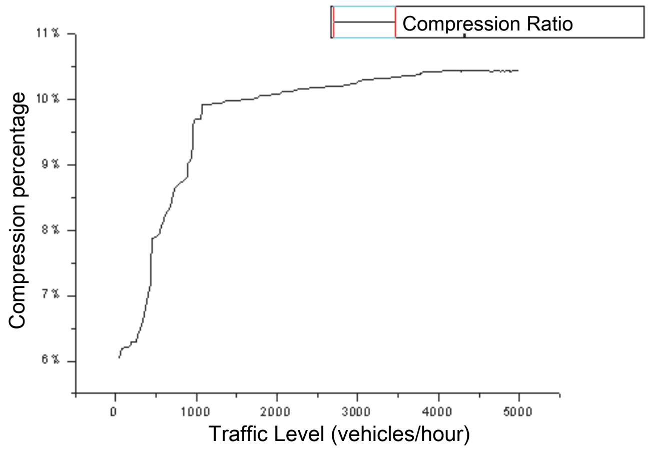


Fig. 9. Message compression quantity.

In the message compression mechanism, the value of k is 16, and the mean data compression rate converges to a certain value as the traffic flow become stable. This convergence can be used to predict the optimal value of k under specific traffic conditions in future. The experiment shows that when the traffic flow is 12 vehicles/hour/lane; the data are compresses and processed at a ratio of 6.04%. As the traffic increases, the data sent are also increased, the data compression ratio is in an increasing trend. When the traffic flow exceeds 1200 vehicles/hour/lane, the data compression ratio is in a stable trend of about 12.3%.

The message compression mechanism in this paper assumes that the vehicle has a high-performance computing ability, and the cost generated from the compression of data is ignored, which needs to be considered in the further work.

It can be known from the result analysis that the optimized communication sublayer can compress the messages and, meanwhile, self-adaptively adjust the sending frequency, which avoid redundancy in communication. Under the above simulation conditions, the peak value of the traffic flow that can be supported by the queuing length and the mean sojourn time is doubled, compared to that before optimization, which improves the performance greatly.

5.2 The Intersection Test

In order to verify the functions of the queuing theory-based communication sublayer under actual conditions, a test is conducted on a real intersection. Test devices include: four cars (Chang'an CS35 and CD101), 1 roadside unit, a highly precise differential GPS and a DSRC communication device. The conditions of the real intersection for test: the east-west width is 16.5m; the north-south width is 7.5m; along the east-west direction is a bidirectional road comprising of four lanes, between which is a green belt with the width of 1.5m; along the north-south direction is a bidirectional road comprising of two lanes; the roadside unit is placed on the southwest part of the intersection; the north-to-south lance is an ascending lane, with the slope of 15°, and; the length of the horizontal section of the ascending lane is about 9m. The experiment scene: the four cars pass across the intersection from four different directions, with the commands form the scheduler program.

In the actual cross road test, two groups of tests are conducts. In one group, message is sent by vehicles in a way of message scheduling; in the other group, sending of vehicle data is not optimized and 10 tests are conducted separately. Vehicles 1, 2, 3 and 4 are driving to the crossroad at a speed of 30-40km/h. When vehicles 1, 2, 3, 4 are entering the area around the intersection, terminals at road sides start to acquire the running status information of vehicles 1, 2, 3, and 4. And the sequence for the vehicles to go through the intersection is given as per the specified rules.

Fig. 10. The experiment site for field test.

The experiment results: in 10 testing experiments, sending of messages in a way of message scheduling is compared with the unoptimized message sending way not optimized.

Experimental results: during the experimental process, although differential GPS and DSRC communication device is adopted and obscured properties and weather will exert influence on communication. It can be found in Tables 3 and 4 that sending of message in a way of message scheduler can decrease the quantity of messaged sent, compared with the sending of unoptimized messages.

Table 3. Message sent by the message scheduling way.

Vehicle ID	Max Dela (ms)	Minimum delay (ms)	Average delay (ms)	Average packet loss probability (%)	Average number of messages sent
1	1011	0	419	30.5699	222
2	3574	10	415	64.4231	231
3	3342	81	272	42.1053	70
4	961	75	193	17.9191	133

Table 4. Sending of unoptimized message.

Vehicle ID	Max Dela (ms)	Minimum delay (ms)	Average delay (ms)	Average packet loss probability (%)	Average number of messages sent
1	1045	4	401	29.7628	235
2	3345	15	425	65.1465	247
3	3402	78	261	41.0076	165
4	975	80	189	17.3695	141

The test is conducted for different velocities, which shows that the optimized communication sublayer can meet the requirement for real-time communication and proves the robustness of our design.

6. CONCLUSIONS

In this paper, a common VANET communication sublayer framework is constructed, in which, the communication protocol is separated from the applications. Besides, the idea of the queuing theory is used to guide the design of the communication sublayer. Our design can eliminate the communication redundancy and ensures that message services can be provided according to the strategies defined by the users themselves, which meets our expected requirements for real-time and qualified services provided by the communication sublayer. Finally, the performance and functions of the optimized communication sublayer is tested in both simulation and real environment. Test results show that the optimized communication sublayer has satisfactory performance and functions. The prediction model in this paper is only a one-dimensional model. In the future, a multidimensional model shall be used to predict the state, and shall be integrated with other multidimensional models. In addition, a fixed value of k is used for the synchronization strategy. In tomorrow, the value of k shall be dynamic to make further extension as well as to improve the performance.

REFERENCES

1. W. H. Organization, "Global status report on road safety 2015," *Injury Prevention*, Vol. 15, 2009, pp. 286-286.
2. H. Hartenstein and K. Laberteaux, *VANET: Vehicular Applications and Inter-Networking Technologies*, Wiley, Chichester, 2009.
3. S. Ucar, S. C. Ergen, and O. Ozkasap, "Multihop-cluster-based IEEE 802.11p and LTE hybrid architecture for VANET safety message dissemination," *IEEE Transactions on Vehicular Technology*, Vol. 65, 2016, pp. 2621-2636.
4. F. Pistorius, A. Lauber, J. Pfau, A. Klimm, and J. Becker, "Development of a latency optimized communication device for WAVE and SAE based V2X-applications," Technical Report, 2016-01-0150, Society of Automotive Engineers, 2016.
5. H. Park, A. Miloslavov, J. Lee, M. Veeraraghavan, B. Park, and B. L. Smith, "Integrated traffic-communication simulation evaluation environment for IntelliDrive applications using SAE J2735 message dets," *Transportation Research Record Journal of the Transportation Research Board*, Vol. 2243, 2011, pp. 117-126.

6. M. Sepulcre and J. Gozalvez, "Contextual and applications-aware communications protocol design for vehicle-to-vehicle communications," *Wireless Personal Communications*, Vol. 70, 2013, pp. 1505-1524.
7. C. Ma and N. Liu, "Traffic-aware data delivery scheme for urban vehicular sensor networks," *International Journal of Distributed Sensor Networks*, 2013, pp. 893-900.
8. C. L. Robinson, L. Caminiti, D. Caveney, and K. Laberteaux, "Efficient coordination and transmission of data for cooperative vehicular safety applications," in *Proceedings of the 3rd International Workshop on Vehicular Ad Hoc Networks*, 2006, pp. 10-19.
9. C. L. Robinson, D. Caveney, L. Caminiti, and G. Baliga, "Efficient message composition and coding for cooperative vehicular safety applications," *IEEE Transactions on Vehicular Technology*, Vol. 56, 2007, pp. 3244-3255.
10. N. Akhtar, S. C. Ergen, and O. Ozkasap, "Vehicle mobility and communication channel models for realistic and efficient highway VANET simulation," *IEEE Transactions on Vehicular Technology*, Vol. 64, 2015, pp. 248-262.
11. F. X. Zhang, G. Z. Tan, C. Yu, N. Ding, and C. X. Song, "Model reference adaptive power control for cooperative vehicle safety systems," *Journal of Information Science and Engineering*, Vol. 32, 2016, pp. 287-308.
12. J. Jeong and E. Lee, "VCPS: Vehicular cyber-physical systems for smart road services," in *Proceedings of Advanced Information Networking and Applications Workshops*, 2014, pp. 133-138.
13. K. Dresner and P. Stone, "A multiagent approach to autonomous intersection management," *Journal of Artificial Intelligence Research*, Vol. 31, 2008, pp. 591-656.
14. J. Yin, T. ElBat, G. Yeung, B. Ryu, S. Habermas, and H. Krishnan, "Performance evaluation of safety applications over DSRC vehicular ad hoc networks," in *Proceedings of the 1st ACM International Workshop on Vehicular Ad Hoc Networks*, 2004, pp. 1-9.

Mingjian Liu (刘明剑) born in 1984, Master candidate at the Department of Computer Science and Technology, Dalian University of Technology. His main research interests include vehicle safety early warning technology.

Guozhen Tan (谭国真) born in 1960, Professor and Ph.D. supervisor, Master candidate at the Department of Computer Science and Technology, Dalian University of Technology. His main research interests include intelligent transportation system.

Nan Ding (丁男) born in 1978. Master candidate at the Department of Computer Science and Technology, Dalian University of Technology. His main research interests include sensing network.

Fuxin Zhang (张福新) received his B.S. and M.S. degrees in Department of Computer Science and Technology from Shandong University of Science and Technology, P.R. China, in 2006 and 2010. He is currently working towards the Ph.D. degree in School of School of Computer Science and Technology at Dalian University of Technology, P.R.C. His research interests include vehicular networking, wireless communication, power control, mobility modeling and cooperative vehicle safety systems (E-mail: zhangsw8881@mail.dlut.edu.cn).