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A Novel Cross-layer Communication Protocol for Vehicular Sensor Networks

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SUMMARY

Communication protocols in Vehicular Sensor Networks (VSNs) in urban areas play an important role in intelligent transport systems applications. Many cross-layer communication protocols studies are originated from topology-based algorithms, which is not suitable for the frequently-changing computational scenario. In addition, the influence factors that have been considered for VSNs routing are not enough. With these aspects in mind, this paper proposes a multi-factor cross-layer position-based routing (MCLPR) protocol for VSNs to improve reliability and efficiency in message delivery. Considering the complex intersection environment, the algorithm for vehicles selection at intersections (called AVSI) is further proposed, in which comprehensive factors are taken into account including the position and direction of vehicle, the vehicle density, the signal-to-noise-plus-interference ratio (SNIR), as well as the frame error rate (FER) in MAC layer. Meanwhile, the dynamic $HELLO\_STREAM$ broadcasting system with the various vehicle speeds is proposed to increase the decisions accuracy. Experimental results in Network Simulator 3 (NS-3) show the advantage of MCLPR protocol over traditional state-of-the-art algorithms in terms of packet delivery ratio (PDR), overhead and the mean end-to-end delay.

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KEY WORDS: VSNs; cross-layer; communication protocols; routing algorithm; NS-3

1. INTRODUCTION

Vehicular Sensor Networks (VSNs) [1, 2] are composed of highly dynamic moving vehicles equipped with on-board communication sensors to relay data messages via wireless communication, which are self-organized with frequent topology changes. VSNs are envisioned to support the variety of urban monitoring and safety applications such as traffic monitoring, prevention of collisions, etc. The performance of VSNs communication protocols plays a key role in data transmission for reliability and efficiency. To some extent, there are two primary functions of this kind of communication protocols: computation, which refers to that all vehicles should evaluate and decide how to route to the next hop in the frequently changing topology with the cooperation with other vehicles; communication, which means that all vehicles work cooperatively according to their own contribution degrees to the objectives, such as cooperative sensing in Wireless Sensor Networks(WSNs) [3, 4].

The majority of researches have focused on network-layer information. On one hand, the active topology-based routing protocol is proposed in [5, 6, 7]. In [6], the sequence information is considered to avoid the loop path error during routing table maintenance. In this type of routing

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protocol, each vehicle must broadcast routing information periodically, as long as there is a data communication request. When the network topology changes, the vehicles update the routing table information, which can not adapt to the rapidly changing topology. To solve this, the on-demand topology-based routing protocol is proposed in [8, 9, 10, 11, 12]. Three nouns are defined in [8] worked by on-demand assignment. This type of protocol process includes route discovery phase and route maintenance phase. However, it will increase the time delay and influence the network transmission efficiency. On the other hand, literature [13, 14, 15, 16, 17, 18] studies the position-based routing protocol. The study in [13] focuses on the greedy forwarding mechanism, mainly considering the position factors. Seminal work on defining reference point factor is carried out in [14]. The selection of forwarding path is determined according to the position of reference point. With the help of GPS and Beidou navigation [19], position sensors and other current advanced positioning equipment, this type of protocol obtains real-time geographical location, speed and direction of movement to find the next hop for forwarding [20]. However, this kind of routing protocol only considers the factors of application layer, and these factors are not enough to select the next hop.

Several studies have suggested the benefit of cross-layer routing protocol [21, 22]. On one hand, the idea of layer integration and new routing protocols is exploited. In [21], DYMO has been proposed, which uses the sequence numbers, to enhance the reliability of information. However, with higher vehicle densities, this routing protocol will cause furthered congestion. In [23], an improve routing protocol, MAR-DYMO, is proposed with higher PDR. However, this will induce a high end-to-end delay. Literature [24] proposes a new routing module integrated layer (RMIL), and redefined the interface standard. RMIL improves the performance of the routing protocol, which causes impact on the overall structure. Literature [25] proposes an integrated approach to design cross-layer routing protocols. The protocol integrates layers on Open System Interconnection (OSI) [26] model, including application layer, network layer, and PHY & MAC layer. However, the dearth of uniform application standards, instigates a lot of difficulties. On the other hand, some researches make use of cross-layer information to obtain the routing protocol. R-AOMDV [27] has been proposed, which merges transmission count and hop counts at the MAC layer, taking into account minimizing delay and performance of intermediate links. However, this routing protocol, based on the neighbors IP addresses, is not suitable for large-scale vehicle application scenario. R-S-AOMDV [28] is an improved routing protocol, taking into account the MAC layer transmission hops and other related indicators. However, the consideration factors are yet not enough and both studies are originated from topology-based AODV algorithms, which is not suitable for VSNs scenarios. DRCV has been proposed to detect of emergency message in [29], which helps in delivering packets with high reliability and with low latency, but the approach is limited to single-hop networks.

To tackle the above mentioned problems, we propose a multi-factor cross-layer position-based routing (MCLPR) protocol for VSNs. We also propose the algorithm for vehicles selection at intersections (AVSI) and algorithm for vehicles selection at non-intersections (AVSNI). The optimal forwarding path is determined using the analytic hierarchy process to calculate the weight value of each factor. The main contributions of this paper are presented as follows:

- The MCLPR protocol takes into account a number of factors to acquire optimal next hop, such as the position and direction information of vehicle, the vehicle density information, signal-to-noise-plus-interference ratio (SNIR), as well as frame error rate (FER) in MAC layer.
- In order to improve the routing performance in vehicles selection strategies, we propose the AVSI and AVSNI separately according to the different characteristics of intersection and non-intersection environments. The consideration is more comprehensive and closer to actual traffic.
- In MCLPR protocol, a dynamic $HELLO\_STREAM$ broadcasting system that considers the vehicle speed is proposed. This can increase the accuracy of decision information and improve routing performance.

The remainder of this article is organized as follows. Section 2 provides the selection of vehicle movement model and wireless transmission model. Section 3 gives the flow of MCLPR protocol

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and the selection in two vehicle algorithms. The proposals are evaluated and analyzed against the reference protocols in Section 4. Finally, Section 5 concludes the paper.

2. PRELIMIARY

This section describes the wireless transmission model and vehicle mobility model and their application. VSNs scenarios and mobility model affect the performance of routing protocol. It is significant to construct vehicle movement model, and wireless transmission model. Furthermore, the commonly used variables are defined in Table I:

Table I. Commonly used variables

Variables	**Specification**
q_i	Vehicle i
RI	The unique identifier of the road section
$P_t(A)$	Random possibility of going straight or turning
$v_r(t)$	The speed of vehicle r at instant t
Q	The set of vehicles
f_{jq_i}	The jth neighbor vehicle of vehicle q_i
F_{q_i}	The set of neighbor vehicles of vehicle q_i
d	The destination vehicle
R	The vehicle communication radius
T_{HELLO_STREAM}	The period of $HELLO\_STREAM$
$Z^d_{q_i f_{jq_i}}$	The weight under intersection environment
$P^d_{q_i f_{jq_i}}$	The probability to character the possibility under non-intersection environment

2.1. Wireless Transmission Model

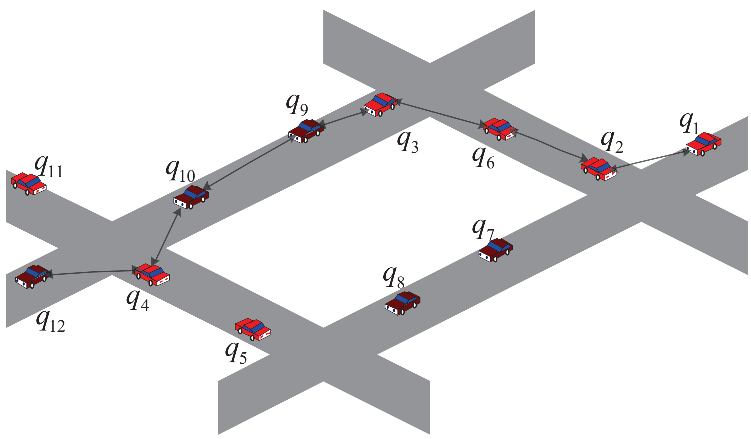

Figure 1. Wireless transmission model

The wireless transmission model, in general, is divided into line-of-sight (LOS) and non-line-of-sight (NLOS) transmission. In this paper, LOS transmission mainly exists in the non-intersections environment. As there are occlusion and other complex situations in the intersection environment, NLOS transmission is used. The transmission path from the source vehicle q_1 to the destination vehicle q_{12} is shown in Figure 1. the data packet will go through three intersections. In the

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intersection environment, if there exists a building block, the vehicle uses NLOS wireless transmission with other vehicles. Without occlusion, the vehicle uses LOS wireless transmission. In the non-intersection environment, LOS is used. In summary, there exists a wireless transmission path, $q_1 \to q_2 \to q_6 \to q_3 \to q_9 \to q_{10} \to q_4 \to q_{12}$. Actually, the LOS and NLOS models are both applied in this path.

2.2. *Mobility Model and Manhattan Mobility Model*

The normal random mobility model does not suit for the proposed situation. On the one hand, the vehicles are not moving irregularly, and their motions are limited to road topologies. On the other hand, these factors need to be considered together, such as the average vehicle speed, and the direction of movement. The road model, which includes several equal size blocks, is named as Manhattan mobility model [30].

Suppose there are N vehicles in Manhattan model denoted as $q_i \in Q, 1 \leq i \leq N$. Q is the set of vehicles $Q = \{q_1, q_2, \ldots, q_i, \ldots, q_N\}$ and each vehicle knows its position information. The neighbor number of q_i is m, and the neighbor vehicle is denoted as f_{jq_i}, $f_{jq_i} \in F_{q_i}$, $1 \leq j \leq m$. F_{q_i} is the set of all neighbor vehicles for q_i, $F_{q_i} = \{f_{1q_i}, f_{2q_i}, \ldots, f_{jq_i}, \ldots, f_{mq_i}\}$. The destination vehicle is denoted as d. The vehicle's communication radius is denoted as R. According to the above assumptions, related concepts are defined as follows.

Definition 1

($Road\ ID$) $Road\ ID$ is the unique identifier of the road section, which is indicated by the street and the intersections, denoted as RI.

Figure 2 shows the RI in 5×5 Manhattan model. There are 25 intersections labeled as I_0, I_1, I_2, $\ldots$, I_{24}. There are 10 streets labeled as S_0, S_1, S_2, $\ldots$, S_9. The RI is denoted as $RI = \{I_m, I_n, S_k\}$, $0 \leq m, n \leq 24$. For example, $RI_{q_1} = \{8, 13, 3\}$ and $RI_d = \{16, 17, 8\}$.

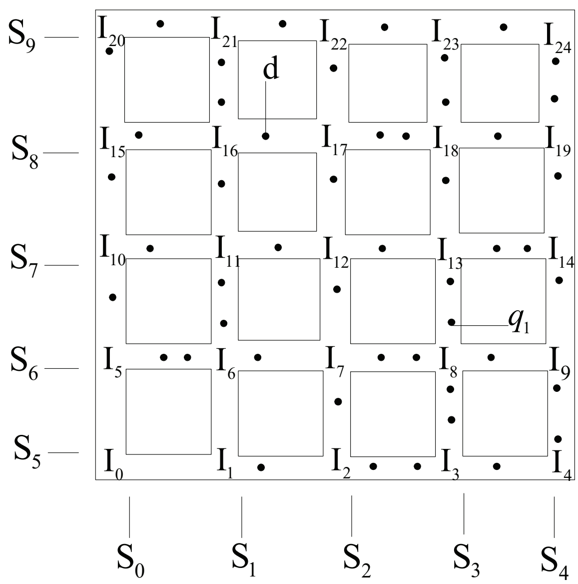

Figure 2. Schematic of Road ID

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Definition 2

($HELLO\_STREAM$ information table) Vehicle q_i broadcasts "HELLO" information to its neighbors periodically. "HELLO" information table is denoted as $HELLO\_STREAM$ $\{$ RI, $Speed$, $Position$, $Number\}$. "HELLO" information includes Road ID, vehicle speed, position and neighbors number.

Definition 3

(The local routing table) To forward the packet along a better path, vehicle q_i keeps a local routing table denoted as $q_i\_STREAM\{d, f_{jq_i}, Number, Z^d_{q_i f_{jq_i}}, P^d_{q_i f_{jq_i}}\}$, where $Z^d_{q_i f_{jq_i}}$ is the weight under intersection environment to find the next hop vehicle. $P^d_{q_i f_{jq_i}}$ is the probability to character the possibility under non-intersection environment.

Definition 4

(The neighbor vehicles table) In order to select the ideal forwarding vehicle, vehicle q_i has a neighbor vehicles table, recording the neighbors information in one hop. The neighbor vehicles table is denoted as $F_{q_i}\_STREAM\{f_{jq_i}, RI_{f_{jq_i}}, Speed, Position, Number\}$. When q_i receives the $HELLO\_STREAM$ from neighbor vehicles, it retrieves $F_{q_i}\_STREAM$ and updates itself.

Definition 5

(Position Feedback System (PFS)) When the information of destination vehicle is unknown, the PFS will get the information of destination of vehicle d, denoted as $PFS\{d, RI_d, Position, Speed\}$.

3. MCLPR PROTOCOL

3.1. Multi-factor cross-layer position-based routing protocol

MCLPR protocol has two phases: the neighbor discovery phase and the packet forwarding phase. The flowchart of MCLPR protocol is shown in Figure 3. In the neighbor discovery phase, it works to capture vehicles and exchange message table to select the next hop vehicle. When vehicle q_i should send data to destination vehicle d, the packet forwarding phase should be switched. According to the position of forwarding vehicle, the phase is divided into two independent mechanisms: intersection forwarding mechanism and non-intersection forwarding mechanism. In the packet forwarding phase, it mainly sends the data packet to the destination vehicle in the most reliable path efficiently. In MCLPR protocol, the communication beacon strategy is adopted in order to get the neighbors information. The vehicle broadcasts the information table periodically, updates

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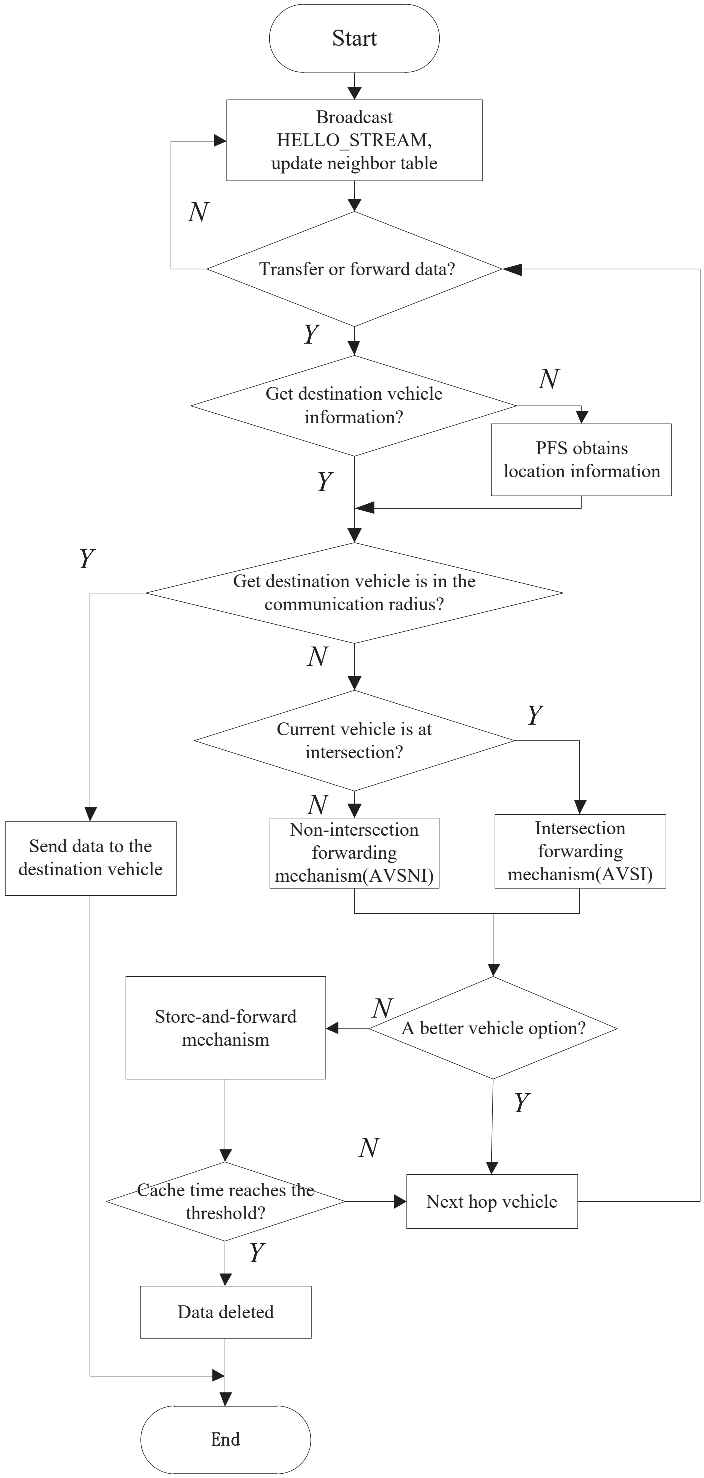

Figure 3. Flowchart of MCLPR protocol

the $HELLO\_STREAM$ information table continuously, and obtains the neighbor vehicle status information in real time. The detail steps are as follows:

(1) The initialization procedure

In this step, the vehicle q_i obtains its own information (Road ID, Position, Speed) by the internal positioning system such as GPS in real time. It will initialize its own neighbor vehicles table and local routing table. The vehicle q_i updates its position information and broadcasts the $HELLO\_STREAM$ information table periodically. This information can be exploited to notice the neighbor f_{jq_i}. The broadcasting period of $HELLO\_STREAM$ information table has certain influence on the performance of routing protocol according to beacons. If the broadcasting period of $HELLO\_STREAM$ is shorter, the information error rate and routing overhead will be higher. Conversely, if the period of $HELLO\_STREAM$ is higher, the related information cannot ensure transmission in real time. Thus, it will affect the selection of next hop or multi-hop vehicle. Therefore, we exploit a dynamic $HELLO\_STREAM$ broadcasting mechanism which considers the factor of vehicle speed, as shown in the Equation (1).

$$T_{HELLO\_STREAM} = \begin{cases} T_{MAX} & v \leq v_{MIN} \\ (T_{MIN} + T_{MAX})/2 & v_{MIN} \leq v \leq v_{MAX} \\ T_{MIN} & v_{MAX} \leq v \end{cases} \tag{1}$$

When vehicle speed is less than v_{MIN}, the period of $HELLO\_STREAM$ is T_{MAX}. When the vehicle speed is bigger than v_{MAX}, the period of $HELLO\_STREAM$ table is T_{MIN}. When the vehicle speed is between v_{MIN} and v_{MAX}, the average is used. In this paper, we set T_{MIN}=1, T_{MAX}=3, v_{MAX}=16 and v_{MIN}=8.

(2) The reception and process of $HELLO\_STREAM$ in neighbor

Neighbor f_{jq_i} receives the $HELLO\_STREAM$ information table from q_i, and the neighbor vehicles table $F_{q_i}\_STREAM$ will be updated. Then, it records the neighbors number in the process. Thus the optimal vehicle will be selected as the forwarding vehicle in the neighbors set $F_{q_i} = \{f_{1q_i}, f_{2q_i} \cdots f_{jq_i} \cdots f_{mq_i}\}$. The remaining vehicles judge whether they have data packet transmitted to d, and check whether they are forwarding vehicles. If not, the vehicle will continue waiting for broadcasting. If so, the vehicle will enter the data forwarding phase.

(3) PFS feedback destination vehicle information

In the neighbor discovery phase, the forwarding vehicle will check itself whether it has obtained the basic information of destination vehicle. If so, the vehicle will forward the data packet directly. On the contrary, the transmitting vehicle sends a request to PFS. After receiving the request, PFS will send the basic information of destination vehicle to the transmitting vehicle.

(4) The determination for intersection and non-intersection forwarding mechanism

In the MCLPR protocol, the data forwarding phase is divided into the intersection forwarding mechanism and the non-intersection forwarding mechanism. The position information of current forwarding vehicle is used to determine the forwarding mechanism. Figure 2 shows the Manhattan model. Every road has a unique RI in this model, which is written into the electronic map. Vehicles in the city obtain their own position. According to the position in the map, the RI will be known. Thus, the RI will be stored in the $HELLO\_STREAM$ information table and be broadcast to the neighbors periodically. If one of $RI_{F_{q_i}}$ is different from the RI_{q_i}, we judge that q_i is in the intersection. Intersection forwarding mechanism will be used to forward data. If all of $RI_{F_{q_i}}$ is the same as q_i, we judge that q_i is in the non-intersection. Non-intersection forwarding mechanism will be used to forward data.

(5) The store-and-forward mechanism

Some factors will lead that the transmission vehicle is unable to select a suitable forwarding vehicle, such as, if the vehicles number is small, the distribution of vehicles is not uniform, vehicles move fast and network connectivity is poor. In addition, the vehicle will also face the local optimization problem. In order to solve the problem, the store-and-forward mechanism is introduced in MCLPR protocol. The date packet will be copied to the sub-optimal neighbor.

(6) Algorithm selection process

In intersection forwarding mechanism, the next hop vehicle is selected by algorithm for vehicles selection at intersections (AVSI). In the non-intersection forwarding mechanism, the next hop vehicle is selected by algorithm for vehicles selection at non-intersections (AVSNI). If the local

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optimal situation is encountered, the store-and-forward mechanism will be used. In TTL time, the vehicle will be chosen as the next hop vehicle. Otherwise, the vehicle will discard packets. The above steps will be repeated until the data packet is transferred to the destination vehicle. Thus, the MCLPR protocol algorithm is shown in Algorithm 1.

Algorithm 1 A Multi-hop Cross-Layer Position-based Routing protocol for VSNs (MCLPR)

step 1 MCLPR initialize, q_i initialize $F_{q_i}\_STREAM$ and local information stream.

step 2

if q_i has packets to send to d; q_i become forwarding vehicle **then**

  if q_i does not know the position of d **then**

    acquire position by Position Feedback System.

  else if $d \in F_{q_i}$ **then**

    q_i send packets to d.

  else if $\exists\, RI_{f_{jq_i}} \neq RI_{q_i}$ **then**

    acquire AVSI.

  else

    acquire AVSNI

  end if

  if no vehicles around or local optimization **then**

    store and forward.

  else

    forward to next hop, go back step4

  end if

else

  go back step 1

end if

3.2. *Algorithm for Vehicles Selection at Non-Intersections (AVSNI)*

Wireless transmission model is a line transmission model. In Two Ray Ground Propagation Loss (TRGPL) transmission model, there are two paths between two vehicles. One is the linear Propagation Path (LPP) and the other is the Ground Return Path (GRP), which is suitable for long distance transmission. Neighbors should be optimized. The optimal vehicle can be select by AVSNI.

The vehicle forwarding probability $P^d_{q_i f_{jq_i}}$ mainly considers the position of vehicle and related mobility information, which is shown in the Equation (2). Thus, the maximum forwarding probability can be obtained.

$$P^d_{q_i f_{jq_i}} = \lambda \cdot \cos\theta_{f_{jq_i} d} + (1-\lambda)\frac{D_{q_i f_{jq_i}}}{R} \tag{2}$$

where $\theta_{f_{jq_i} d}$ is the angle between the moving direction of neighbor f_{jq_i} and the vector from f_{jq_i} to d. $D_{q_i f_{jq_i}}$ is the Euclidean distance between q_i and f_{jq_i}. R is the communication radius and λ is

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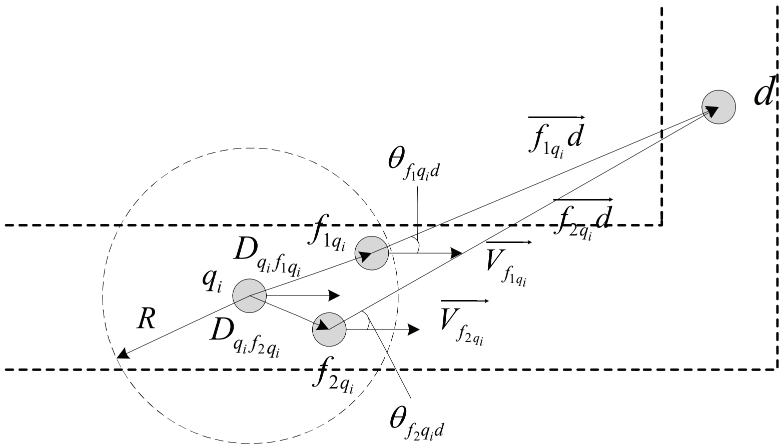

Figure 4. Algorithm for vehicles selection at intersections

the impact factor changed according to the street information. Figure 4 shows the relationship in the algorithm.

3.3. *Algorithm for Vehicles Selection at Intersections (AVSI)*

In this case, there are complicated situations such as occlusion. AVSI considers five factors which effect the next hop for q_i at intersection environments. The main impacts can be divided into three categories: the first is the attributes of vehicle, including the position information, speed and other related information. The second is the intersections information, especially the vehicle density at intersection. In this part, we propose an intersection vehicle density distribution function and calculate the weight value by the vehicle density. The third consists of cross-layer information: the quality of wireless link [31] and the MAC layer information. The quality of wireless link is mainly reflected by the signal-to-noise-interference-power-ratio (SNIR). Thus, the corresponding weight values can be calculated. MAC layer information is mainly reflected by the frame error rate(FER). The three parts are analyzed as follow.

(1)The attributes of vehicle

In Figure 5, the transmitting vehicle q_i is $q_i(x_{q_i}, y_{q_i})$ and the destination vehicle d is $d(x_d, y_d)$. There are three neighbors in the intersection. Their coordinates are $f_{1q_i}(x_{f_{1q_i}}, y_{f_{1q_i}})$, $f_{2q_i}(x_{f_{2q_i}}, y_{f_{2q_i}})$, $f_{3q_i}(x_{f_{3q_i}}, y_{f_{3q_i}})$ computed by the position correction mechanism. The cosine value $\theta_{f_{jq_i} q_i d}$ is computed in Equation (3).

$$
\begin{aligned}
\cos\theta_{f_{jq_i} q_i d} &= \frac{\overrightarrow{q_i f_{jq_i}} \cdot \overrightarrow{q_i d}}{|\overrightarrow{q_i f_{jq_i}}||\overrightarrow{q_i d}|} \\
&= \frac{(x_{f_{jq_i}} - x_{q_i})(x_d - x_{q_i}) + (y_{f_{jq_i}} - y_{q_i})(y_d - y_{q_i})}{\sqrt{(x_{f_{jq_i}} - x_{q_i})^2 + (y_{f_{jq_i}} - y_{q_i})^2} + \sqrt{(x_d - x_{q_i})^2 + (y_d - y_{q_i})^2}}
\end{aligned} \tag{3}
$$

In Equation (3), the relative angle between the moving direction of neighbor q_i and f_{jq_i} is similar to that between q_i and d. As shown in Equation (4), it is the first part in the final weight value calculation.

$$
f(\theta) = -\cos\theta_{f_{jq_i} q_i d} \tag{4}
$$

Under the same scenario in Figure 5, Figure 6 shows the angle between the vehicle speed and the connection from the f_{jq_i} to d at intersection. Similarly, If the direction of f_{jq_i} is more consistent

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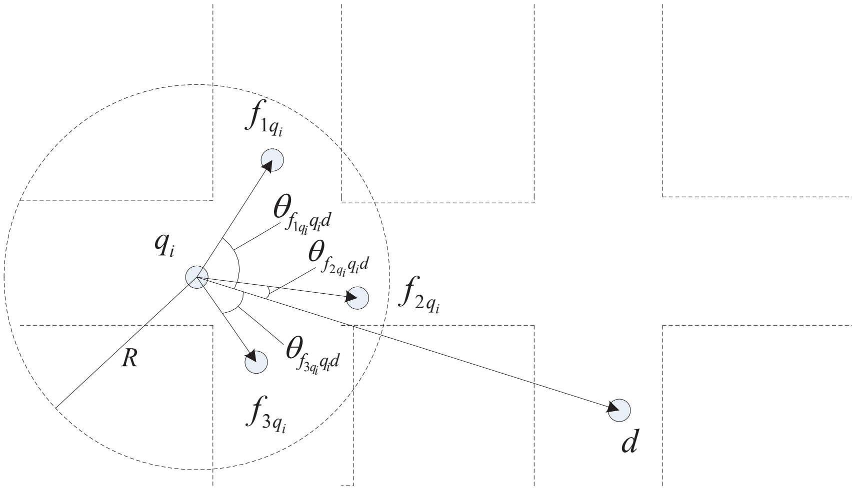

Figure 5. Vehicle position of intersection

with the direction of d, the vehicle will be chosen as the next hop vehicle more easily and the weight will be smaller.

In Figure 6, the speed of f_{jq_i} is known. The coordinates of f_{jq_i} and d are known after the position correction mechanism. Then, weight function is shown in the Equation (5).

$$f(\varphi) = -\cos\varphi_{f_{jq_i}d} = -\frac{\overrightarrow{v_{f_{jq_i}}} \cdot \overrightarrow{f_{jq_i}d}}{|\overrightarrow{v_{f_{jq_i}}}||\overrightarrow{f_{jq_i}d}|} \tag{5}$$

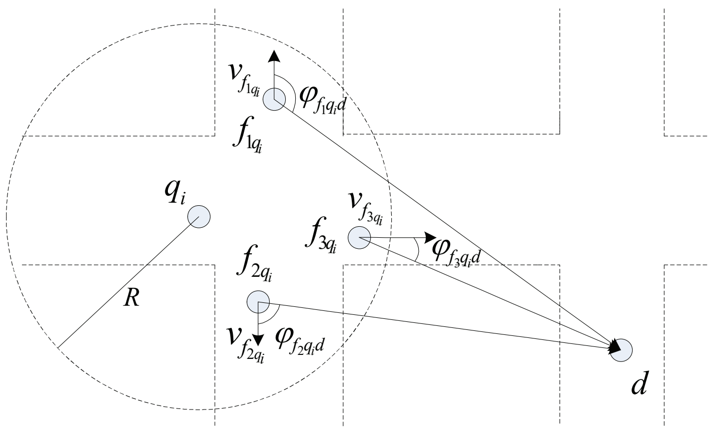

Figure 6. Vehicle position of intersection

(2) The intersection information

With a certain RI, the existing neighbors number in the communication radius of transmitting vehicle q_i is $M_{F_{q_i}}$. According to the neighbors distribution, we propose a normalized intersection density distribution function shown in Equation (6).

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$$f(M_{F_{q_i}}) = \begin{cases} 1 & M_{F_{q_i}} \leq 3 \\ 0.75 & 3 < M_{F_{q_i}} \leq 6 \\ 0.5 & 6 < M_{F_{q_i}} \leq 9 \\ 0.25 & 9 < M_{F_{q_i}} \leq 12 \\ 0 & 12 < M_{F_{q_i}} \end{cases} \tag{6}$$

(3) Quality of wireless link

In the urban traffic environment, the intersection situation is more complicated. This is reflected by $SNIR$. Wireless channel quality $SNIR$ function depends on the characteristics of information transmission. At the intersection environment, the vehicles number is large and the possibility of interference is large. In the communication radius, the remote vehicle is more disturbed than the proximal vehicle and the packet loss rate is increased. Therefore, the $SNIR$ value of vehicles is small. The transmitting vehicle prefers the farthest vehicle with a good quality of wireless link in the communication radius. Wireless link quality information is introduced in MCLPR protocol. We set $SNIR$ a threshold value. When the $SNIR_{q_i}$ is less than $SNIR_0$, the vehicle is located at the far end of communication range. As the poor quality of channel, it has a higher weight value. Thus, if the $SNIR$ is higher, it will give a smaller weight value. In this way, we can select the next hop vehicle to reduce the packet loss rate.

The weight value analysis function of $SNIR$ is shown in the Equation (7). Where α, β, and $SNIR_{min}$ are constants. According to Table II, we take $SNIR_0 = 15$ through the calculation of equal conditions. We take $SNIR_{min} = 9.75$, $\alpha = 0.0009995$ and $\beta = 5.25$ into the Equation (8), as part of the weight value calculation.

$$f(SNIR) = \begin{cases} \alpha u^2 & SNIR < SNIR_0 \\ \beta e^{-u} & SNIR \geq SNIR_0 \end{cases} \qquad (\frac{\alpha}{\beta} = \frac{e^{-u}}{u^2}|_{u=SNIR_0-SNIR_{min}}) \tag{7}$$

$$f(SNIR) = \begin{cases} 0.0009995(SNIR - 9.75)^2 & SNIR < 15 \\ 5.25e^{-(SNIR-9.75)} & SNIR \geq 15 \end{cases} \tag{8}$$

Table II. Threshold for V2V communication simulation

Data transmission rate	**Modulation scheme**	**Coding rate**	**SNIR threshold (dB)**
3	BPSK	1/2	5
4.5	BPSK	3/4	6
6	QPSK	1/2	8
9	QPSK	3/4	11
12	64-QAM	1/2	15
18	64-QAM	3/4	20
24	64-QAM	2/3	25
27	64-QAM	3/4	N/A

(4) MAC layer information

In the urban traffic environment, MAC layer information is reflected in the FER. In the additive Gauss white noise transmission channel, the relationship between bit error rate P_b and signal to noise ratio $\frac{E_b}{n_0}$ is in Equation (9):

$$\begin{aligned} P_b &= G[\frac{2E_b}{n_0}] \\ G(x) &= \int_x^{\infty} \frac{1}{2\pi} e^{\frac{y^2}{2}} dy \end{aligned} \tag{9}$$

The frame error rate FER and bit error rate P_b are as shown in Equation (10), where l_f is the length of frame, represented by the number of bits.

$$f(FER) = 1 - (1 - P_b)^{l_f} \tag{10}$$

(5) Weight analysis

The smaller FER helps select a better next hop. Equation (10) is used to characterize the weight function of FER factor. We can obtain a series of weights correlation function number $f(\theta)$, $f(\varphi)$, $f(M_{F_{q_i}})$, $f(SNIR)$ and $f(FER)$. $weight_1, \ldots, weight_5$ will be given to the corresponding function. The final result will be stored in q_i_STREAM, shown in Equation (11).

$$\begin{aligned} Z^d_{q_i f_{jq_i}} =& weight_1 \times f(\theta) + weight_2 \times f(\varphi) \\ &+ weight_3 \times f(M_{F_{q_i}}) + weight_4 \times f(SNIR) \\ &+ weight_5 \times f(FER) \end{aligned} \tag{11}$$

Weights are not fixed value, which are altered according to the actual situation. To high vehicle density, vehicles have more neighbors, which help vehicle select the optimal next hop vehicle. In this situation, vehicle density factor at intersection has little effect on the performance of the routing protocol. It is possible to preferentially select the vehicle with better communication quality and closer position to the destination vehicle. On the contrary, to low vehicle density, it should be possible to select the vehicle with larger number of neighbors. This will help data packets transmit reliably, reduce the PDR and improve communication connectivity. According to the network conditions, it is possible to achieve the optimal forwarding packet by adjusting these weight factors.

The weight analysis is a multi-factor problem. We use analytic hierarchy process (AHP) to analyze the weight, which contains Hierarchical establishment, judgment matrix construction and evaluation standardization. The process is as follow.

Establishing hierarchy: the factors are divided into different levels. The vehicle position factor is a_1. The speed factor is a_2. The vehicle density is a_3. The $SNIR$ factor is a_4. FRE factor is a_5.

Constructing judgment matrix: the matrix is constructed by comparing the importance among factors. There are five factors to construct a 5×5 matrix, as shown in the Equation (12). Discriminate scaling mechanism is introduced in the discriminate process. If one factor is more important, the weight is more bigger.

$$A_{5\times5} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix} \tag{12}$$

Evaluating the normalized processing: according to the Equation (12), we obtain the normalized feature vector shown in Equation (13). The corresponding feature value will be tested consistently. If the test criterion is satisfied, the normalized feature vector can be used as the weight value.

$$(weight_1, weight_2, \ldots, weight_n)^T = [\frac{w_1}{\sum_i^n w_i}, \frac{w_2}{\sum_i^n w_i}, \ldots, \frac{w_n}{\sum_i^n w_i}]^T \tag{13}$$

4. PERFORMANCE EVALUATION

In this section, we will evaluate our MCLPR protocol through simulation against DSDV, AODV, DSR and GPSR with the different influencing factors. We conducted all simulation studies using network simulator-3 (NS-3).

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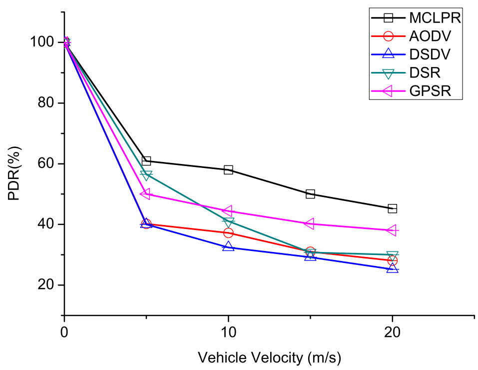
4.1. Scenario Configuration

In this scenario, we consider 10 communication links in Manhattan model. The NS-3 simulation parameters are listed in Table III.

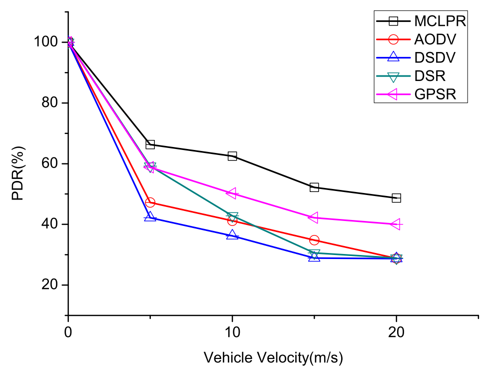
Table III. Simulation Parameters

Parameters	**Settings**
Streets	5×5
Blocks	4×4
Simulation Area	$1600m \times 1600m$
Vehicle Density	50, 100, 150, 200
Vehicle Speed	0m/s, 5m/s, 10m/s, 15m/s, 20m/s
Simulation Time	200s
Pre-simulation Time	600s
$HELLO\_STREAM$	1-3s
Communication Ranges	250m and 500m
Packet Size	512 bytes

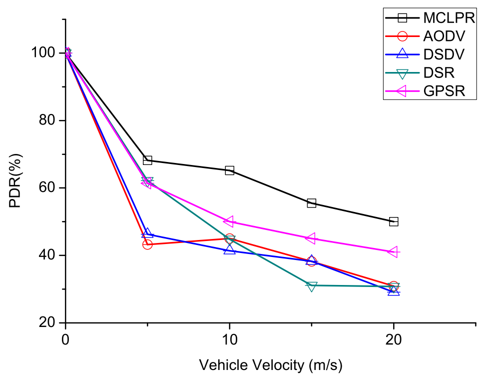
4.2. Analysis of Packet Delivery Ratio



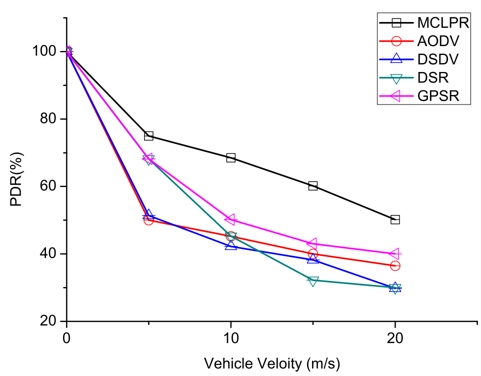
(a) The vehicles number is 50



(b) The vehicles number is 100



(c) The vehicles number is 150



(d) The vehicles number is 200

Figure 7. The trend of PDR with vehicle speed in definite vehicle density

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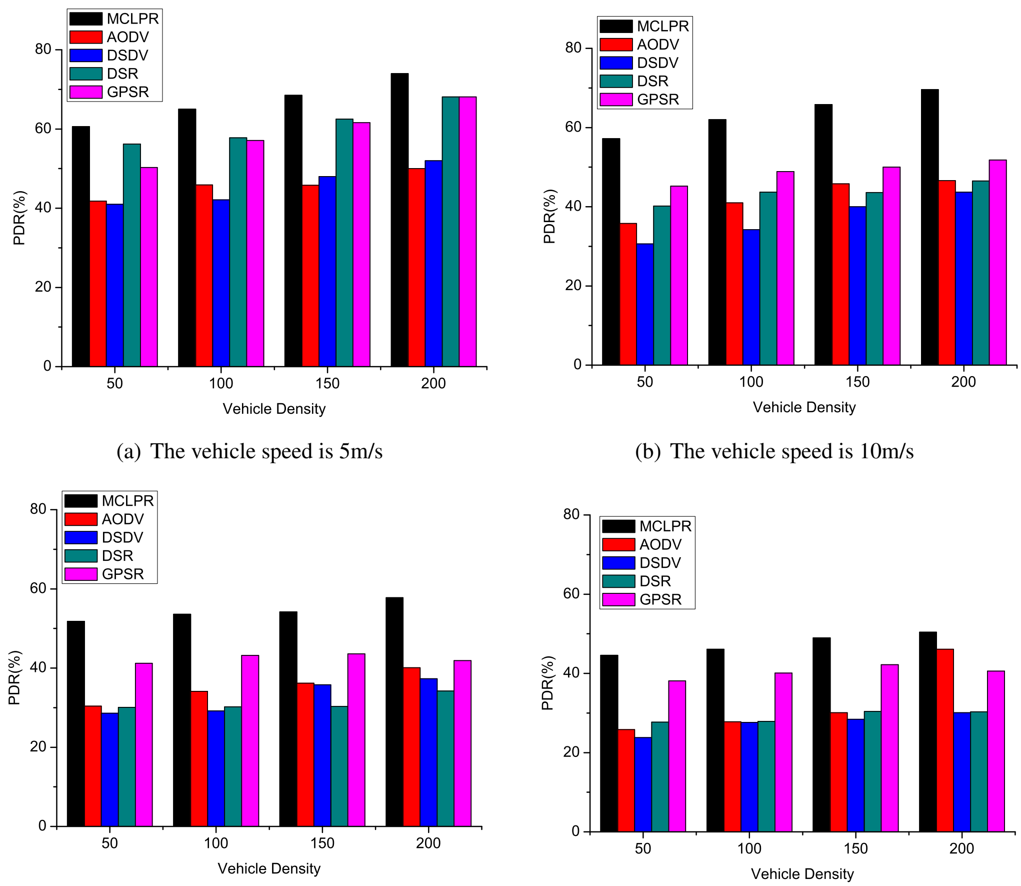


(a) The vehicle speed is 5m/s

(b) The vehicle speed is 10m/s

(c) The vehicle speed is 15m/s

(d) The vehicle speed is 20m/s

Figure 8. The trend of PDR with vehicle density in definite vehicle speed

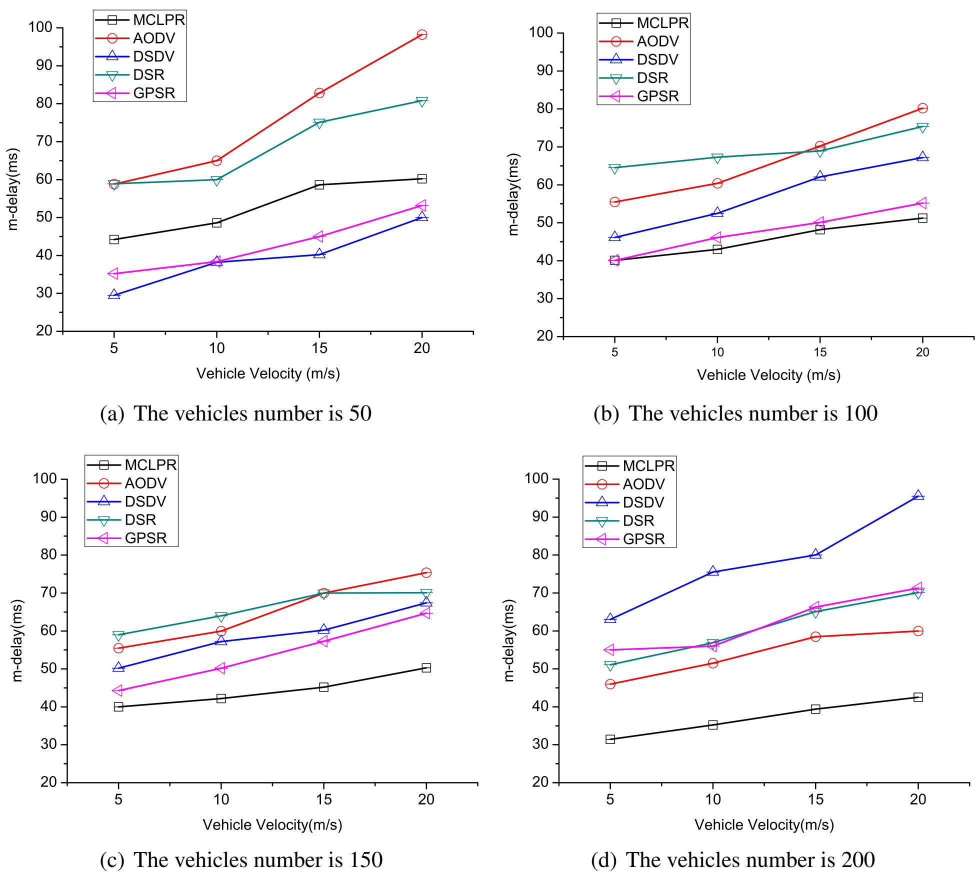
Figure 7 shows the different trends in the packet delivery ratio (PDR) of five protocols with the increasing of vehicle speed when the number of vehicles in the network is 50, 100, 150 and 200. With the increase in vehicle speed, the PDR decreases in all routing protocols. When vehicle speed is slow, the communication links are established quickly and stably. This causes the PDR high. With increase in the vehicle speed, network topology changes frequently. This leads to a rapid decrease in the stability of communication links and the success rate of data transmission. Although the position-based routing protocol, GPSR, can adapt to the change of network topology to a certain extent, it considers fewer factors in the process of selecting vehicles. The mean data transmission rate of MCLPR protocol is higher than others. This is due to the vehicle position information, mobile information, intersection information, and MAC layer information considered in MCLPR protocol. In Figure 7, it is clear that the PDR in MCLPR protocol is higher than others under the same conditions. The PDR in GPSR is lower than the PDR in DSR, only when the vehicles number is 50 and vehicle speed is 10 m/s. The PDR in AODV and DSDV show the similar performance.

Figure 8 shows the influence of vehicle density on the routing protocol packet delivery ratio when the vehicle speed is 5m/s, 10m/s, 15m/s and 20m/s in the network. With different speeds, PDR becomes higher with the increase in vehicle density in the network. The increase in vehicle density makes the number of alternative paths, become much higher and the connectivity become better. Thus, the packet delivery ratio is improved. At different speeds, PDR of the MCLPR protocol is much better than other routing protocols. This is due to MCLPR considering a variety of factors including position, speed, vehicle density, $SNIR$, and FER information.

4.3. The Analysis of Mean End-to-End Delay

Mean end-to-end delay represents the efficiency of routing protocol in data transmission. As shown in the Equation (14), where $\Delta\tau_i$ represents delay time of packet i, $D_{Receive}$ represents the total number of valid received packets, and m_delay reflects the efficiency in the routing protocol. Under certain conditions,the smaller mean end-to-end delay makes the higher transmission efficiency. Figure 9 shows the variation between the mean end-to-end delay and vehicle speed under definite vehicle density. With the increase in vehicle speed, the mean end-to-end delay increases in all routing protocols. When vehicle speed is slow, the communication links are established quickly and stably. This causes the mean end-to-end delay small. With increase in the vehicle speed, the vehicle position information is frequently changed and the wireless links are not stable. This makes the discovery and maintenance process affected. Thus, the mean end-to-end delay increases.

$$m\_delay = \frac{\sum_{i=1}^{n}(\Delta\tau_i)}{D_{Receive}} \qquad i \in \{1, 2, \cdots, n\} \tag{14}$$



(a) The vehicles number is 50
(b) The vehicles number is 100
(c) The vehicles number is 150
(d) The vehicles number is 200

Figure 9. The variation between the mean end-to-end delay and vehicle speed under definite vehicle density

When the vehicles number is 50, the mean end-to-end delay of DSDV routing protocol is the smallest. This is because that DSDV is a proactive routing with fewer routing tables. Similarly, GPSR is better than MCLPR protocol mean end-to-end delay. We do not need to make a selection in more paths when the vehicles number is small. Thus, the MCLPR protocol is not the best choice under low vehicle density. When the vehicle density increases to 100, 150 and 200, MCLPR has a lower mean end-to-end delay. Due to the fewer vehicles in the network, MCLPR protocol also needs

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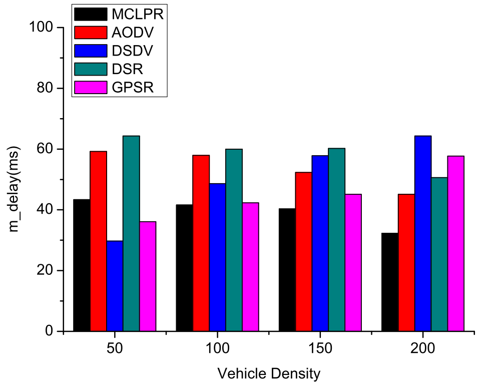
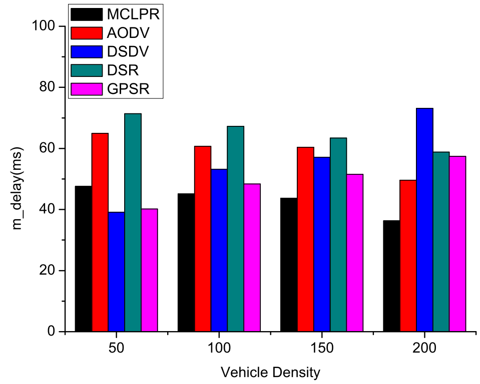
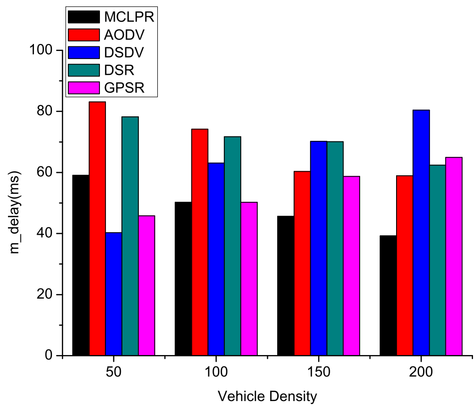


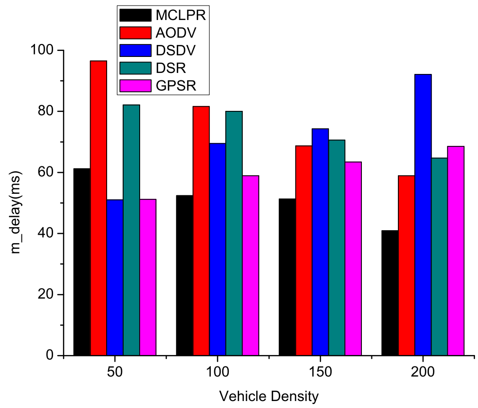
(a) The vehicle speed is 5m/s



(b) The vehicle speed is 10m/s



(c) The vehicle speed is 15m/s



(d) The vehicle speed is 20m/s

Figure 10. The variation between the mean end-to-end delay and vehicle density under definite vehicle speed

to consider five factors. The mean end-to-end delay is high. With increase in number of vehicles, the connectivity is enhanced in MCLPR protocol. Thus, the intersection factor is gradually reduced, and the multi-hop wireless link becomes much better. Therefore, the mean end-to-end delay is small, and the efficiency is high.

Figure 10 shows the variation between the mean end-to-end delay and vehicle density under definite vehicle speed. The mean end-to-end delay decreases with the increase in vehicle density for MCLPR, AODV and DSR. On the contrary, the mean end-to-end delay increases as the vehicle density rises in definite vehicle speed for DSDV and GPSR. The following points illustrate the above results: (1) DSDV is a topology-based routing protocol. When the vehicles number is small, we need to maintain few routing tables. Thus, the routing overhead is small, and the mean end-to-end delay is small. On the contrary, when the network density increases, we need to maintain more routing tables, and the mean end-to-end delay increases greatly. GPSR is a position-based routing protocol. When the vehicles number is small, the wireless link selection is relatively easy and the mean end-to-end delay is high. When the vehicles number increases, the path from q_i to d needs to be selected. This is one of the important factors that cause the mean end-to-end delay. (2) AODV and DSR are both on-demand topology-based routing protocols. When the vehicles number is small, the link quality is poor and the mean end-to-end delay is high. With the number of vehicles increasing, the mean end-to-end delay becomes low. (3) MCLPR is a multi-factor cross-layer position-based routing protocol. It sums up many factors including the vehicle position, speed information, intersection information, wireless link quality and MAC layer information. The position correction mechanism is introduced for intersection vehicles. It introduces the store-and-forward mechanism in the whole process of

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routing. We achieve a global optimization considering a variety of factors. Thus, the mean end-to-end delay is decreasing with the number of vehicles increasing.

5. CONCLUSIONS

In this paper, we have presented a multi-factor cross-layer position-based routing protocol called MCLPR for VSNs to improve reliability and efficiency of message delivery. The protocol takes into account a numbers of factors, such as the information of vehicle, related traffic information, $SNIR$, as well as FER. In MCLPR protocol, we have proposed AVSI to select the optimal next hop vehicle in intersection environment and AVSNI to select the optimal next hop vehicle in non-intersection environment,respectively. We have conducted a comprehensive performance evaluation of the MCLPR protocol utilizing Manhattan model. Simulation results in NS-3 show that the proposed algorithm outperforms existing routing protocols for VSNs in terms of mean end-to-end delay and data transmission.

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