Parallel Swarm Optimization Based Cluster for Emergency Message Dissemination in VANETs

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***Abstract*—In intelligent transportation system, emergency message has to be disseminated rapidly and extensively in order to inform as many vehicles in limited time. Hence, the broadcast storm problem is prone to occur in vehicular ad hoc networks. In the past, several approaches have been proposed to solve the problem. They are counter-, distance-, location-, cluster-, and probabilistic-based schemes. In this paper, we analyze existing cluster based protocols and present a novel scheme that is designed to form stable clusters, reduce the overhead of cluster maintenance during emergency message dissemination. The proposed clustering algorithm uses particle swarm optimization to assigns weight values for different factors during the cluster head election and cluster formation. It ensures the dissemination of the emergency message onto every part of the road, and when there is no relay vehicle, the emergency message will be reactivated. We use the GrooveNet simulator to demonstrate that the proposed scheme has a low collision probability, low overhead, more stable cluster, and a short end-to-end latency.**

***Index Terms*—Emergency Message Dissemination; Rebroadcast Suppression; Cluster; Density Adopted.**

I. INTRODUCTION

Vehicular ad hoc networks (VANETs) are wireless communication networks which do not require fixed infrastructures and provide a novel networking pattern to support cooperative driving applications on the road. VANETs have the following characteristics: (a) road-constrained but frequently changing network topology, (b) constrained speed pattern, (c) time and space varying communication conditions, and (d) no significant power constraints compared with other ad hoc networks [1].

VANETs have many applications [2], such as file sharing, and the obtainment of real-time traffic information. In this paper, we focus on the traffic safety application related time efficient emergency message dissemination.

The requirement for emergency message dissemination is short end-to-end latency [3] and informing as many vehicles as possible within the warning area without the assistance of the infrastructure.

In [4]; all the vehicles within the transmission range will receive the message and rebroadcast it. Hence, a broadcast storm (huge redundancy, contention and massive collisions due to the simultaneous forwarding) will occur [5]. In the past, several schemes have been proposed to reduce the broadcast storm problem. Most of them only validated in simple scenarios such as a highway (several lanes, without crossroads) [6], or with the help of road side units.

Due to the characteristics of VANETs, the flat structure is not an efficient organization in terms of communication between nodes [7, 8]. Instead, many clustering schemes [9, 10, 11] have been proposed to organize a VANET into a hierarchical structure with a view to improve the efficiency of transmission. As the dynamic topology of VANET, robust cluster is needed to reduce the overhead of control message. In this paper, we propose a Particle Swarm Optimization (PSO) based robust cluster for emergency message dissemination scheme. First, the design and calculation of three robust cluster related metrics are proposed, with which the lifespan of clusters can be prolonged. New metric is utilized and proved to have better performance compared with approximate ones. New approaches are proposed to calculate conventional metrics which has been proved to have better performance in simulation study. Second, with the proposed metrics, moving pattern, transmission capability and characters of nodes can be evaluated. Afterwards, we employ PSO to calculate and assign corresponding weights to aforementioned metrics. We then propose a cluster formation mechanism that utilizes the aforementioned weight value to divide the whole network into clusters organized by suitable clusterheads (CHs). Then we deploy the emergency messages dissemination scheme in our proposed cluster environment which guarantees the high dissemination ratio and short end-to-end delay. The performance analysis and simulation study confirms the availability and efficiency of the proposed clustering algorithm in terms of delivery ratio, end to end delay, cluster stability, and overhead.

This paper is organized as follows. Section 2 reviews the related work on the broadcast storm problem in wireless ad hoc networks. Section 3 presents the details of our clustering scheme. Section 4 contains the mathematical analysis to show the function and cost of the proposed scheme. Afterwards, a simulation study is also presented, and Section 5 concludes this paper and discusses the future work.

II. RELATED WORKS

For overcoming the broadcast storm problem, several broadcast schemes have been proposed to reduce the redundant rebroadcast in VANETs. The core technique of them is how to select the correct next rebroadcasting node. Clustering used in many literatures is a predominant technique that brings the following benefits.

- The CH in each cluster elected by clustering algorithm acts as the central unit to collect and analyze data in each cluster. Local topology management can be easily achieved by clustering which benefits the routing, service discovery and data

dissemination, meanwhile reduce overheads caused by global topology management.
- With clustering, steady and durable connection between nodes can be well guaranteed even if in large scale VANETs.

Hence, many clustering schemes have been proposed for VANETs, which aim to meet certain requirements of the system. Those clustering schemes for VANET can be classified in two categories: 1). single factor based clustering and 2). multiple factors based clustering.

In [15] a clustering algorithm is designed for mobile ad hoc networks (MANETs), it also works for VANETs. It is an extension of the Lowest-ID algorithm [16]. In Lowest-ID, each node is assigned a unique ID, and the node with the lowest ID in its two-hop neighboring nodes is elected to be the CH. In MOBIC, an aggregate local mobility factor is the basis for cluster formation instead of node ID. The node with the smallest variance of relative mobility to its neighbors is elected as the CH. Its performance is moderate as it is not designed and optimized for VANETs.

In [17] authors present a direction based clustering algorithm which is designed for urban area. Clusters are formed before road intersections and they are based on the predicted travelling path. The vehicles that take the same direction in the intersection are clustered together. The location, destination and route of the vehicle must be known in advance for the algorithm to work. The vehicle destination is the key factor in this algorithm for clustering decision.

In [12], they proposed an approach for cluster based routing algorithm for hybrid mobility model to regulating the vehicular traffic. It combines the features of static and dynamic clustering. Static clusters are formed around the static sources located at the road signals, street corners and congested places known as static clusterhead. They also used buses as dynamic sources in the algorithm. As they say the buses have predefined path and time chart to handle the high mobility situation. In this scheme, the static cluster requires static infrastructures to be implemented on the specific position. In the dynamic cluster scheme, all the nodes have to know about the detail information about the bus, and update the time chart in real time, which will cause extra overhead. And bus is not an appropriate CH even though it has predefined path and time chart. The relative speed of bus is big comparing with normal vehicles.

In [13] it also used static cluster, but they did not require implementation of static infrastructure. Every node is assumed to know the whole map of the city, as well as each cluster block. And the node located nearest to the midpoint of each cluster block is elected as the cluster. VANETs' high mobility makes CH alternation takes place almost every round.

In [14], the author used weight based CH election. It only takes two parameters to calculate each node's weight value. In this paper, the author did not clearly state how are the weight is calculate, just assign they the value subjectively.

III. PROPOSED SCHEME

In this section, we will explain the proposed scheme step-by-step in detail. It is used to reduce the broadcast storm problem in real urban scenarios. In an urban area at a frequency of 5.8 GHz [4] (the frequency band adopted by the 802.11p standard), radio signals are highly directional and have a very low depth of penetration. Buildings will block the signals at this frequency, which makes communication possible only when the vehicles are in the line-of-sight of each other.

First of all, we will present assumptions.
- There is no requirement of roadside infrastructure in the network.
- The mobility of each node is relatively low compared with the speed of data transmission.
- The transmission range of each node is identical and the transmission is bidirectional.
- A node's neighbouring nodes are defined as the ones residing in the transmission coverage.
- The position and driving direction information of each vehicle is available.

In the proposed clustering scheme is based on the driving direction. This is to solve the intersection problem. For clustering, the PSO is utilized to calculate weight of each node and the node with the smallest weight is elected as a CH in the corresponding cluster. Beside the direction factor, three factors are used for the decision of clustering including Relative Speed (RS), Distance-considered Connectivity (DC), and Reciprocal Mean Expected Transmission Count (RMETX). They represent the capacity of vehicles in VANETs.

First of all, descriptions and calculations of the three parameters are proposed. Then, clustering formation and clustering maintenance processes are proposed.

The relative stability is defined as the stability compared with on-hop neighbours. Considering the frequent change of topology in VANETs, relative stability is more suitable in terms of data transmission. It indicates if the node moves relatively fast or slowly or even stable in the neighbourhood.

$$RS_j = \sum_{i=1}^{N} dv_i \times \frac{1}{N} \quad (1)$$

In Equation 1, N is the number of neighbours, and dv_i is the relative speed to the neighbouring node i. Here the N cannot be 0, if a node has no neighbouring nodes, itself will is the CH.

The second parameter is computed based on the number of a node's neighbouring nodes and its distance from them, which is termed as Distance-considered Connectivity (DC) as shown in Equation 2. A small value of DC is preferred as it can be expected that nodes which are located closer will stay longer within each other's transmission range.

$$DC(i) = \frac{D(i)}{C(i)} \quad (2)$$

$D(i)$ is the distance sum value between node v_i and its neighbours in the vicinity calculated by Equation 3. $C(i)$ is the connectivity degree that is the number of neighbouring nodes of node v_i.

$$D(i) = \sum_{j=1, j\neq i}^{N} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (3)$$

(x_i, y_i) and (x_j, y_j) are the coordinates of node v_i and v_j. If a node has more neighbours, the node resides in a more important position. If a CH has distant member, it is easy to lose the member. Therefore, less distance summation nodes are more preferred. The node with larger number of neighbours and smaller distance from neighbours has higher opportunity to be chosen as a CH.

ETX predicts the number of transmissions required to send a packet over a link. Small ETX not only reduce the overhead, but minimize the end to end delay by reducing the collision as well. The Reciprocal Mean Expected Transmission Count (RMETX) is an adopted version of ETX that considers the characteristic of VANETs. It is a mean of reciprocal links' ETX s in the node's one-hop neighbourhood. The conventional ETX focuses on a link or a path. Our proposed RMETX focuses on a node's transmission capability.

$$\mathrm{RMETX} = \frac{\sum_{i=1}^{N} \mathrm{ETX_i}}{\mathrm{N}} \tag{4}$$

ETX can be calculated by Equation 5. N is the number of links between the node and its one-hop neighbours.

$$\mathrm{ETX} = \frac{1}{\mathrm{d_f} \cdot \mathrm{d_r}} \tag{5}$$

$\mathrm{d_f}$ is the expected forward delivery ratio. $\mathrm{d_r}$ is the reverse delivery ratio. Obviously, $\mathrm{d_f} \cdot \mathrm{d_r}$ represents the likelihood a packet arrives and acknowledged correctly.

We utilize particle swarm optimization (PSO) to compute relative weights of parameters to choose appropriate CHs. Three parameters must be evaluated as to how much they serve the objective of the prolonging the cluster duration.
PSO is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of fitness. In this paper the duration of CH is the fitness. PSO optimizes a problem by having a population of candidate solutions explored the space of possible solutions to the optimization problem of interest. PSO is used to tune the weight values of each parameter.

$$\mathrm{V_{id}(k+1) = wV_{id}(k) + \varphi_1 r_1(k)\big(p_{best_{id}} - X_{id}\big) + \varphi_2 r_2(k)\big(g_{best_{id}} - X_{id}\big)} \tag{6}$$

$$\mathrm{X_{id}(k+1) = X_{id}(k) + V_{id}(k+1)} \tag{7}$$

$\varphi_1$and $\varphi_2$are constants 2, and $\mathrm{r_1(k)}$ and $\mathrm{r_2(k)}$ are random numbers uniformly distributed in [0, 1]. In this paper each particle stands for a possible combination of weights assigned to three parameters, the dimension of particle is three. As the sum of the three weights is 1, the maximum velocity of a particle is 1. When maximum velocity is 1, which is smaller than 2, according to modified particle swarm optimizer, the inertia weight w is set as 1 to avoid the local optimization. The scope for particle is [0, 1], and iteration time is 20. Assigning different weights have direct influence on the suitability of the node to be the CH, further, it influences over the life time of CHs.

$$Wnode_i = w_{RS}RS_i + w_{DC}DC_i + w_{RMETX}RMETX \tag{8}$$

Combining these measures, a weight factor is obtained by Equation 8, which shows the suitability of a node to become a CH. The smaller $Wnode_i$ is, the more qualified it is to be a CH. The value of w_{RS}, w_{DC}, and w_{RMETX} are 0.718, 0.187, and 0.095 respective.

Initially all nodes are in UnClustered state. Then each node broadcasts beacon (HELLO) messages to declare itself and to know about its neighbour nodes, which is used to calculate its weight. The format of the HELLO message is shown in Figure 1.

Cluster ID	Vehicle ID	Position	Speed	Direction	Timestamp

Figure 1: HELLO message format

Upon receiving a HELLO message, a node adds the information into its neighbour node table and recalculates its weight factor. After recalculating the weight value the node the node will set a backoff time proportionally. While waiting for the expiration of the backoff time, if the node receives HELLO message from other nodes. Then it becomes a member node of that CH. When the backoff time expired but not any HELLO message is received, then the node becomes CH. The node changes its state into CH and sets Cluster ID with its own ID.

When a vehicle detects an emergency event, it periodically sends an emergency message. The format of emergency is as shown in Figure 2.

Source ID	Event position	Event time-stamp	Current forwarder ID	Current forwarder location	Current forwarder driving direction

Figure 2: Emergency message format

All the nodes are grouped into clusters based on the driving direction. When a node receives an emergency message, first, it checks whether it is a CH. If it is not a CH and receives the message for the first time, it will calculate whether its CH can receive this message or not. If the CH cannot receive the message, the node will send the message to its CH. If a CH receives this emergency message, it checks whether it receives the message for the first time or not. If not, it will check whether it is located in the warning area. If it is already outside of the warning area, it will erase the emergency message. If it is inside the warning area, it will check is there same emergency event message from other direction. Emergency event is identified by the first, second and the third fields of the emergency message. If there isn't any same emergency event message from other direction, it means hole problem is appeared. The CH will rebroadcast the emergency message periodically until receive the same emergency event message from other direction. This is carry-and-forward mechanism. If the CH receives the message for the first time, it will check the location of the emergency event. If the emergency event is ahead of it, it will rebroadcast it to its member. To ensure the success transmission, we use the negative acknowledgement here. If the node does not hear the rebroadcast of the emergency, which means broadcast failed, the node will rebroadcast it again.

We assign dynamical back-off time depend on the C(i) of the vehicle. When the C(i) is big, we set the back-off time longer to reduce the probability to collision. When the C(i) is small, we set the back-off time short. By doing this the collision and the total end-to-end latency could be reduced.

When two vehicles drive in same direction the back-off time is inverse proportional to the distance between them. When two vehicles driving in different direction, the backoff time is proportional to the distance between them. In inverse directions, their link life time will be very short. If we keep assigning shorter backoff time to the further nodes, the negative acknowledge works not well.

IV. Analysis and Simulation

In this section, first, the mathematical model for message broadcasting delay is presented to analysis the performance of the proposed scheme. And then, the performance comparisons for MOBIC, SAM, LMF and proposed scheme are compared by simulation.

The arrival process of vehicles to the highway can be modeled as a Poisson process with an arrival rate λ_s, which is equal to the traffic density. The probability that there are n vehicles in a road section of length(x) is given by Equation 9

$$\mathrm{P}(N = n) = \frac{(x\lambda_s)^n}{n!} e^{-\lambda_s x} \tag{9}$$

The total broadcasting delay T_D of a message broadcasted from source node to reach the end node in a messaging broadcasting direction opposing the traffic flow is calculated by Equation 10.

$$T_D = T_{1st} + N_C T_{CH} + 2(N_c - 1)T_{GW} \tag{10}$$

N_c is the number of the clusters in the warning area, T_{1st} is the transmission delay from the source node to its CH, T_{CH} is the CH broadcast delay to its gateway node, T_{GW} is the delay of inter-cluster broadcast. For the successful transmission, the distance L between two neighboring nodes should be smaller than transmission range R. Then the Equation 10 becomes $\mathrm{T_D} = (\mathrm{T_{1st}} + \mathrm{N_C T_{CH}} + 2(\mathrm{N_c} - 1)\mathrm{T_{GW}})/(1 - \frac{(\mathrm{x}\lambda_\mathrm{s})^\mathrm{n}}{\mathrm{n}!} \mathrm{e}^{-\lambda_\mathrm{s}\mathrm{x}})$ while considering the probability that there is an empty road section with length R.

Simulation is applied to evaluate the performances of our cluster based emergency message dissemination algorithm. We employ different simulation scenarios to show that our algorithm performs better than other schemes.

Table 1
Simulation Parameters

Parameters	Value
Transmission range	200 meters
Node placement strategy	Real & Virtual
Number of vehicles	30, 60, 150, 200, 250
Speed of vehicles	24-50 miles per hour
Length of the road	1 miles * 3miles

Table I shows the simulation scenario. We implement the algorithm in GrooveNet. The nodes are placed with true trace data and simulated trace data in the area of 1mile * 3miles. The number of nodes is set from 30 to 250. Each node‘s speed spectrum is set as 24 to 50 miles per hour, with the transmission range from 200 meters. In Figure. 3, the simulation scenario is shown. The transmission range is 200 meters. Vehicles exchange their location every second.

Figure. 4 shows the average CH duration. We run the simulation for 20 periods. The proposed scheme outperform MOBIC, SAM, and CMS. In SAM, it uses static cluster structure, and the node located near to the midpoint of the cluster is the CH. The high mobility of VANET causes frequent CH update. Proposed scheme's CH duration is longer, this is because during the clustering, three parameters are taken into account while MOBIC only takes one and CMS takes two parameters. CMS randomly assigned weight value is not as accurate as proposed scheme. The CH duration increases when the number of nodes increases. This is because more nodes give the member nodes more choices which increase the suitability of the member node to the CH. In LMF, it used the static cluster, and all the CHs are static. It causes high maintenance cost and hard to deploy.

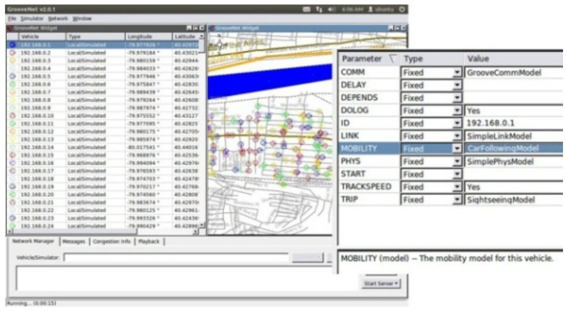

Figure 3: Simulation environment

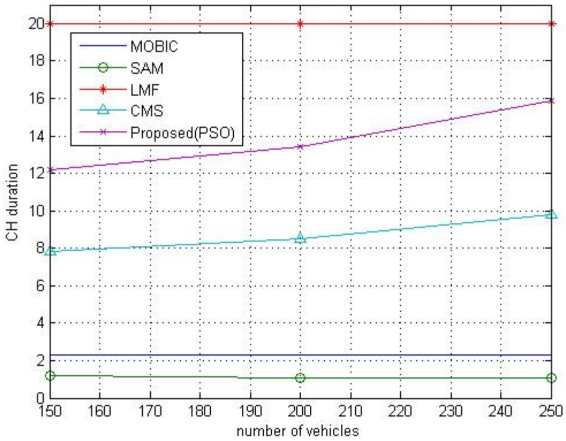

Figure 4: Average CH duration

Figure 5 shows the average cluster member duration. When we see the value specifically, the average member duration is about half long of the average CH duration. This is because after the cluster formation, the CH is stable comparing with the member node. A member node moves to another CH area, and then it will change its CH. But it is much harder for a CH to move to another CH's area. The value of CM duration increases when the number of nodes increases for proposed scheme. This is because more nodes give the member nodes more choices which increase the suitability of the member node to the CH. CMS only consider about two parameters with subjective weight value, make the CH election process is not correct enough. The member nodes change the CH more frequently. In SAM, as their CH duration is nearly one period, the duration of member node is nearly for one period, too. In LMF, with the powerful static CH, the member node duration is longer than other schemes.

Figure 6 shows the overhead of control message comparison between proposed scheme and other schemes in the situation of 200 nodes runs for 10 periods. The clusters form by proposed scheme are more robust other schemes, so the overhead of control messages is also low than other scheme. The only exception is LMF, which use the static infrastructure. Even it has lower overhead, the deployment and implementation of infrastructure has high costs. But the proposed scheme does not require the infrastructure which makes it more practical.

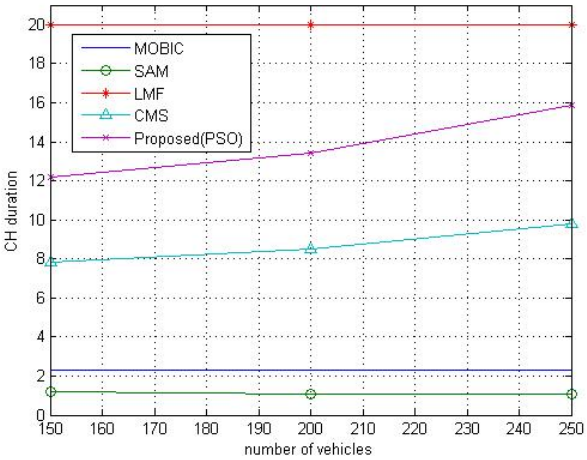

Figure 5: Average cluster member duration

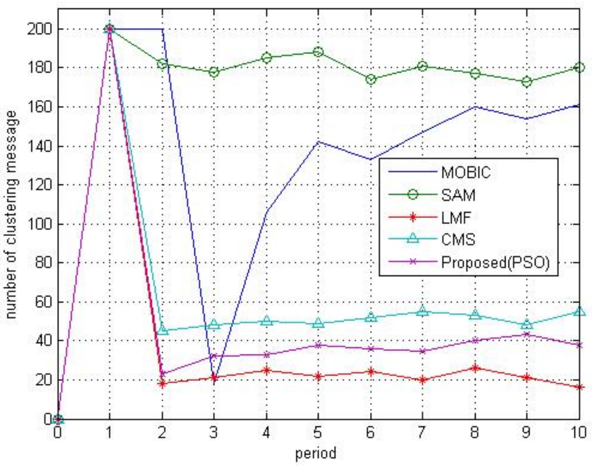

Figure 6: Overhead of control message

Figure 7 shows the delivery ratio of SPP, WPP, cluster based schemes, and proposed scheme. As shown in the figure, the value of delivery ratio increases when the number of nodes increases for all schemes. However, the performance of the proposed scheme is better than the related work WPP and SPP, as the delivery ratio is way bigger than WPP and SPP. This is because the SPP and WPP do not have countermeasure for hole problem or intersection problem. When the message meets a hole or an intersection, either the message stops further transmission or the transmission only cover a small part of the network. On the contrary, the proposed scheme has effective mechanism for those two problems. When the message meets a hole problem, it will launch the carry-and-forward method. And in the intersection area, the message is spread into every direction. In LMF, there delivery ratio is always 100%, due to there is static infrastructure in that scheme. In SAM, the high frequency CH change reduces the delivery ratio.

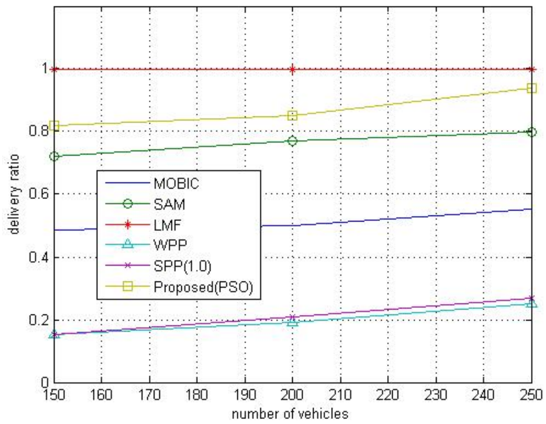

Figure 7: Delivery ratio

V. CONCLUSION

In this paper, a PSO based robust cluster for emergency message dissemination algorithm is proposed for VANETs. The PSO are utilized to calculate weight value for each node in consideration of three factors including relative speed, distance-considered connectivity, and reciprocal mean expected transmission count. The node with the smallest weight value is elected as the CH in the corresponding neighbourhood. Consequently, cluster formation mechanisms are proposed. Then the emergency message dissemination in cluster structure is introduced, which solve the hole and intersection problem in VANETs. The performance analysis and simulation study confirm the availability, high dissemination ratio and efficiency of our scheme.

The core work presented in this paper can be extended in many ways. Even though the proposed methods of this paper incorporate many different parameters of vehicles, such as direction, speed, and transmission capability, application driven methods should be developed in the near future in order to cope with different situations. Social profile of the drivers also can take into account. Road safety and traffic congestion avoidance for example are two different circumstances, with different requirements and limitations in terms of delay, dissemination coverage etc. Clustering parameters must be tuned for different applications that run over the VANETs.

Data dissemination from RSUs is not studied in this paper. RSUs can play an important role in a smart city, covering certain areas and giving accurate information fast. In the future, information from RSUs that are many hops away from the current junction can be exploited. Finally routing information itself can be embedded in the optimization problem of each vehicle giving the method a glance in the near future.

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