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Selective local dynamic map construction based on MEC architecture

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Selective local dynamic map construction based on MEC architecture

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Abstract. In view of the rapid increase of data volume in large-scale intelligent connected vehicle scene, this paper proposes a local dynamic map (LDM) construction method based on the mobile edge computing (MEC) architecture. On this basis, we select key nodes from a large number of vehicles to upload data, reducing system computing pressure, data redundancy and system delay. Moreover, the intelligent connected vehicle simulation tool is used to simulate the intersection with large numbers of intelligent connected vehicles, to verify the advantages of the selective local dynamic map construction method.

1. Introduction

An intelligent connected vehicle is a vehicle that has intelligent driving characteristics and can share information with each other. With the development of intelligent connected vehicle, almost all cars in the future will be replaced by intelligent connected vehicles, which will greatly reduce the incidence of traffic accidents and improve traffic efficiency. However, there are still many problems in the intelligent connected vehicle that need to be solved [1, 2].

In the driving process of intelligent connected vehicle, information collection is extremely important, which is the basis of the driving behavior. And there are two ways for vehicles to obtain the environment information. One is to sense the surroundings through their own radars, cameras and other intelligent sensing devices, and the other is to share data with other intelligent connected vehicles [3, 4].

With the advancement of sensor technology and internet technology, people are paying more and more attention to multi-sensor data fusion. Intelligent connected vehicle fused with the data of multi-sensor will generate a local dynamic map (LDM) for current environment, including surrounding vehicle information, pedestrian information, road information, etc. LDM is very important for intelligent connected vehicle.

However, with the increase of the number of connected vehicles, each vehicle will obtain all information within its communication range. Due to the large numbers of vehicles and high communication frequency (usually 10HZ), the amount of data generated is extremely large. The computational load and processing time for building a local dynamic map will also greatly increase. For intelligent connected vehicles with the requirements of high real-time, the safety and reliability are greatly affected.

Therefore, this paper proposes a local dynamic map construction method based on Mobile Edge Computing (MEC) architecture for an intersection with dense vehicles. On this basis, we select key

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nodes from dense vehicles to upload data, while ensuring local dynamic map integrity, reduce the computational load of the entire system, reduce system computing time, and thus improves system security and reliability.

2. Related work

For the intelligent networked vehicle system with large numbers of vehicles, the amount of data increases sharply because of the fast data interaction. But the limited computing ability of vehicle makes the system overloaded by simply using V2V (vehicle-to-vehicle). Therefore, in the intelligent networked vehicle system with large numbers of vehicles, combining V2I (vehicle-to-infrastructure) with V2V can be adopted to reduce the system load for the powerful computing ability of roadside infrastructure [4].

The cloud computing is first applied in the field of V2I. The cloud server with strong computing and storage capabilities can effectively reduce both the computing and storage pressure of the vehicle. However, with the use of cloud computing, the vehicle and the cloud communication need to add extra time [5].

Therefore, MEC based on the 5G evolution architecture is introduced into the intelligent connected vehicle system. The architecture of MEC is composed of the edge server and the cloud server. The edge server is close to the user and can provide users with low time-delayed and high-performance services. While the cloud server is connected to the Internet with strong computing and storage capabilities, it can achieve deep integration of mobile Internet and IoT services [6]. MEC is gradually translating into multi-access edge computing. However, since current applications are still dominated by mobile scenes, we still call it mobile edge computing.

LDM is a collection of current road environmental factors that can monitor vehicles and road conditions in real time and provide rich services for vehicles [7]. The data of LDM can be divided into four types: static data, semi-static data, semi-dynamic data, and dynamic data [8].

(1) Static data: road and intersection information obtained from static digital maps.

(2) Semi-static data: road signs, landmarks and other information on the road for enriching road data.

(3) Semi-dynamic data: information for temporary changes, such as weather, traffic jams, and traffic light signals.

(4) Dynamic data: dynamic rapidly changing information, such as V2X information (GPS position, speed, heading, etc.)

3. Local dynamic map construction based on MEC architecture

The data in LDM is classified according to the time-delay sensitivity. In vehicle safety applications, static data and dynamic data are required, while semi-static data and semi-dynamic data are required for vehicle development services. In this paper, for intelligent connection vehicle security applications, only static data and dynamic data in LDM are considered.

In V2V, the intelligent connected vehicle can build a LDM through self-vehicle information collection and integration. In V2I, the road side can communicate with vehicles by DSRC/LTE-V technology to obtain the vehicle information, by which the road side can build a LDM. Compared with the LDM built by the vehicle itself, the road side has more complete data, which can effectively reduce the repetitive work of different vehicles and improve system efficiency. In the MEC architecture, the edge server is close to the road, so that it can communicate with the vehicle in time and obtain dynamic data in LDM quickly [9, 10].

Static data in LDM is road data, which is perfect in current electronic map resources. The cloud server of MEC can obtain electronic map resources via the Internet and select the static data needed for LDM. Then, the static data is distributed to each edge server, and the cloud server only sends the related static data to each edge server to build a LDM.

The LDM construction based on the MEC architecture is as show in Figure 1.

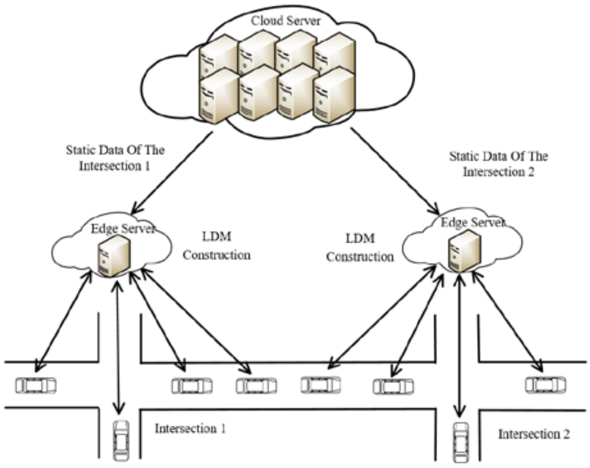

Figure 1. Local dynamic map construction based on MEC architecture.

4. Data volume

In the LDM construction based on MEC architecture, the edge server will obtain data of all vehicles, but data sharing between vehicles causes data to be uploaded repeatedly.

Suppose there are N intelligent connected vehicles and P pedestrians. M vehicles and pedestrians $(i_1, i_2, i_3, ... i_M)$ are in the communication range of the $i-th$ vehicle. The $j-th$ vehicle shares T_j data (position, speed, heading, etc.) with other vehicles, so the total data D_i obtained by the $i-th$ vehicle is:

$$D_i = \sum_{j=i_1}^{i_M} T_j \quad (1)$$

The total data D obtained by N vehicles is:

$$D = \sum_{i=1}^{N} D_i \quad (2)$$

From (1) (2), we can get:

$$D = \sum_{i=1}^{N} \sum_{j=i_1}^{i_M} T_j \quad (3)$$

For LDM construction on the edge server, the minimum required data D_m is:

$$D_m = \sum_{i=1}^{N+P} T_i \quad (4)$$

When the edge server obtains the data volume of D_m, LDM can be built completely. Therefore, the data D of all vehicles uploading to the edge server will cause additional overhead and the overhead ratio K is:

$$K = \frac{D - D_m}{D_m} \quad (5)$$

The overhead ratio K is mainly determined by the number of vehicles and pedestrians M within the range of vehicle communication. Under the circumstance with dense vehicles, M is large, which causes overhead ratio K large. In response to this problem, this paper proposes a selective LDM construction method.

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5. Selective local dynamic map construction

Considering connected vehicle data sharing, key vehicle nodes can be selected for data uploading, and the edge server only uses this part of data for LDM construction.

The driving directions of the vehicles on the road are different, and the relative displacement between the vehicles with the same driving direction is small, which make the selected nodes stable and the number of node replacements small. Therefore, key nodes can be selected in the vehicles with same traveling direction.

For vehicles in the same driving direction, the vehicle communication radius is larger than the road width, so the vehicle node is selected apart a distance d in the driving direction, which is as show in Figure 2.

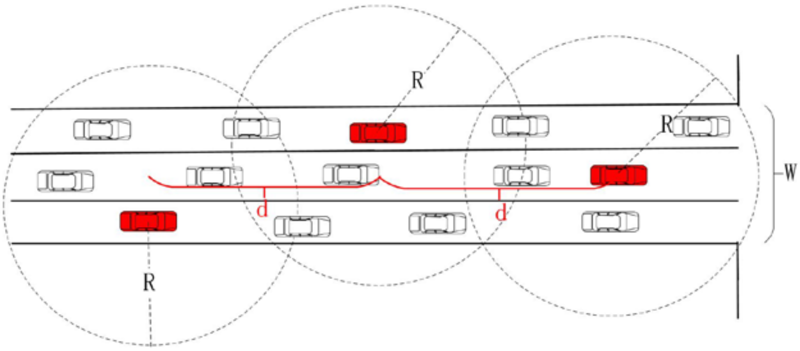

Figure 2. Vehicle nodes selection method.

The selected vehicle nodes can be regarded as a set of two adjacent nodes. Every two adjacent nodes ensure that the vehicles between adjacent nodes can communicate with them.

For two adjacent vehicle nodes, when A vehicle and B vehicle are selected vehicles, the communication radius is R and the road width is W. Set A as the origin of the coordinate system, and the driving direction as the positive direction of the x-axis to create the coordinate system. Set the coordinates of the B vehicles are (x, y) . The intersections of A vehicle communication range and the road boundary are $a(x_1, y_1)$ and $b(x_2, y_2)$ respectively, and the intersections of B vehicle communication range and the road boundary are $c(x_3, y_3)$ and $d(x_4, y_4)$ respectively. In order to ensure that the data of vehicles between A and B can be obtained, the communication range of A and B must cover the road between A and B. Set the distance from the two sides of the road to A vehicle is h and $W-h$, as show in Figure 3.

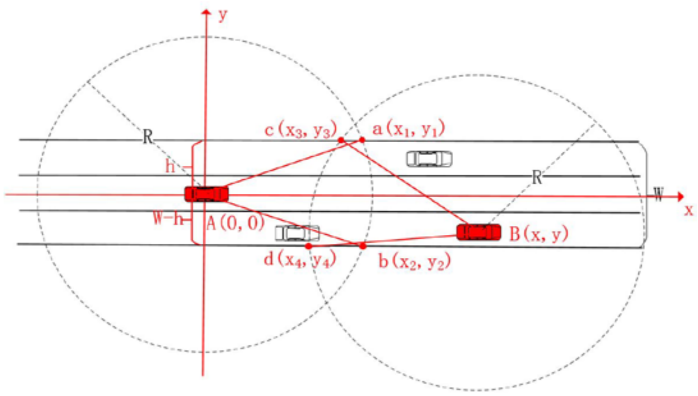

Figure 3. Adjacent two vehicle nodes communication coverage.

For the point c on the upper boundary of the road, it is available from the Pythagorean Theorem:

$$(x - x_3)^2 + (y_3 - y)^2 = R^2 \tag{6}$$

From (6), we can obtain:

$$x = \sqrt{R^2 - (y_3 - y)^2} + x_3 \quad (7)$$

In order to ensure the upper boundary of the road between A and B is completely covered by the communication, we have:

$$x_3 \le x_1 \quad (8)$$

From (7) (8), it can be expressed as:

$$x \le \sqrt{R^2 - (y_3 - y)^2} + x_1 \quad (9)$$

In order to minimize the number of selected vehicle nodes, the distance between the selected vehicles should be maximized. When point a and point c coincide, the distance between A and B is the largest and the road between A and B can be completely covered, so the vehicle selection distance d can be determined as:

$$d = \sqrt{R^2 - (y_3 - y)^2} + x_1 \quad (10)$$

For point a, by the Pythagorean Theorem:

$$x_1^{\,2} + y_1^{\,2} = R^2 \quad (11)$$

The two points a and c are located on the upper boundary of the road, thus:

$$\mathrm{y}_1 = \mathrm{y}_3 = h \quad (12)$$

From (10) (11) (12), we can obtain that:

$$d = \sqrt{R^2 - (h - y)^2} + \sqrt{R^2 - h^2} \quad (13)$$

Since A and B are driving on the road, we have:

$$0 < h \le W \quad (14)$$

$$y \le h \quad (15)$$

From (13) (14) (15), we can get:

$$d \ge 2\sqrt{R^2 - W^2} \quad (16)$$

For the lower boundary of the road, we repeat the above calculation steps for two points b and d, the distance d is the same as that for point a and c.

Because the lanes of A and B are different during driving, the values of h and y are uncertain, which lead to the uncertainty of the value of d. In order to eliminate the influence of the different lane during driving, we choose the distance that is certain to be covered. Consider the upper and lower boundaries of the road, the best value for d is:

$$d = 2\sqrt{R^2 - W^2} \quad (17)$$

6. Simulation

6.1. Local dynamic map construction simulation based on MEC architecture

The intelligent connected vehicle simulation tool is used to simulate an intersection with large numbers of intelligent connected vehicles, including 98 vehicles and 2 pedestrians, which is as show in Figure 4.

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Figure 4. Intersection simulation.

The road data is static data, including the starting position and ending position of each lane. The vehicle data is dynamic data, including the vehicle ID, longitude, latitude, speed and heading, which are uploaded to the MEC edge server in real time. The MEC edge server caches road static data from the cloud server in advance, and then acquires data of 98 vehicles in real time to construct a LDM, which is as show in Figure 5.

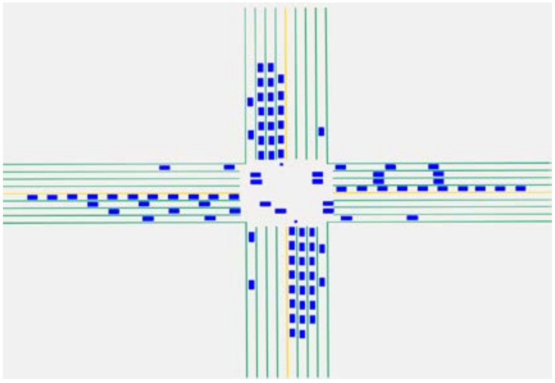

Figure 5. Local dynamic map construction result.

Under normal circumstances, the vehicle communication radius is within 300 meters. In order to facilitate the comparison of simulation results, the vehicle communication radius is set to be 20 meters.

$$R = 20m \tag{18}$$

In the case of a communication radius of 20 meters, the MEC edge server obtains the data uploaded by per vehicle, then counts the number of vehicles and pedestrians M obtained by per vehicle, which is as show in Table 1.

Table 1. Number of vehicles and pedestrians M obtained by per vehicle.

ID	M	ID	M	ID	M	ID	M	ID	M	ID	M	ID	M	ID	M
1	17	14	18	27	10	40	8	53	9	66	18	79	15	92	19
2	15	15	6	28	3	41	8	54	10	67	16	80	15	93	17
3	17	16	14	29	11	42	13	55	16	68	17	81	15	94	17
4	16	17	7	30	7	43	11	56	9	69	17	82	14	95	18
5	11	18	14	31	5	44	10	57	12	70	20	83	12	96	16
6	12	19	13	32	9	45	11	58	9	71	17	84	18	97	15
7	12	20	11	33	11	46	12	59	12	72	17	85	12	98	12
8	12	21	13	34	9	47	12	60	10	73	18	86	18		
9	12	22	8	35	12	48	12	61	11	74	18	87	17		
10	16	23	11	36	8	49	9	62	12	75	17	88	18		
11	15	24	9	37	9	50	3	63	8	76	17	89	16		
12	5	25	10	38	9	51	12	64	17	77	17	90	17		
13	16	26	11	39	4	52	10	65	8	78	16	91	19		

The data shared by the vehicle to the surrounding vehicles are ID, longitude, latitude, speed and heading, and T_j is the data shared by the $j-th$ vehicle, thus:

$$T_j = 5 \tag{19}$$

From (1) (19), the data obtained by the $i-th$ vehicle is:

$$D_i = \sum_{j=i_1}^{i_M} T_j = 5M \tag{20}$$

From (2) (20) and Table 1, the total data volume shared by all vehicles is:

$$D = \sum_{i=1}^{98} D_i = 5\sum_{i=1}^{98} M = 6235 \tag{21}$$

From (4) (19), the minimum data volume required to construct a LDM is:

$$D_m = \sum_{i=1}^{N+P} T_i = \sum_{i=1}^{98+2} 5 = 500 \tag{22}$$

From (5) (21) (22), the overhead ratio K is:

$$K = \frac{D - D_m}{D_m} = 11.47 \tag{23}$$

In the case of a communication radius of 20 meters, uploading all vehicle nodes generates the overhead ratio is 11.47, while in practice, the vehicle communication range is larger and each vehicle obtains more data of vehicles and pedestrians, which generates more overhead.

6.2. Selective local dynamic map construction simulation

There are four driving phases in the simulation, so it is divided into four traffic flows for the vehicle selection. Each traffic flow consists four lanes, and the width of each lane is 3.5 meters, thus the width W is:

$$W = 4 \times 3.5 = 14(m) \tag{24}$$

From (17) (18) (24), we can get:

$$d = 2\sqrt{R^2 - W^2} = 28.57(m) \tag{25}$$

The vehicles selection result is as show in Figure 6.

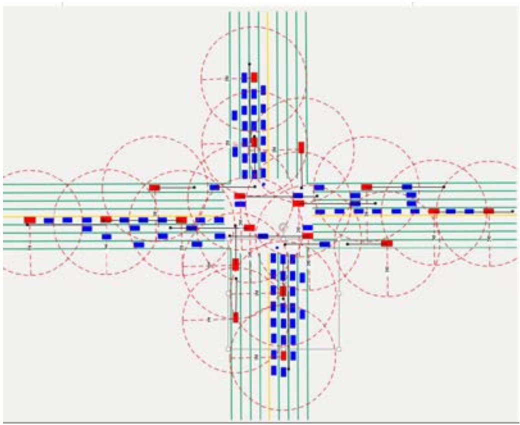

Figure 6. Vehicles selection result.

The selected vehicle IDs are 4, 5, 8, 12, 13, 14, 15, 17, 18, 29, 30, 39, 42, 44, 48, 53, 57, 71, 91, then we use the data of these vehicles to reconstruct LDM, which is as show in Figure 7.

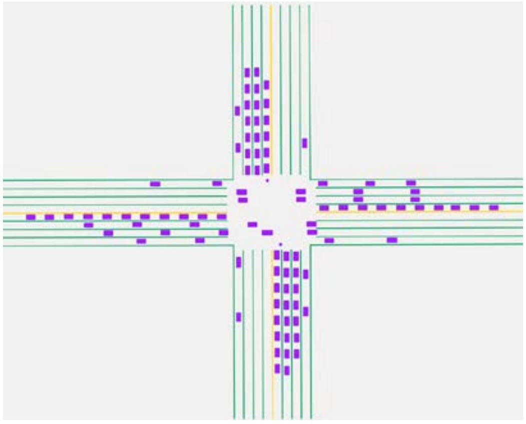

Figure 7. Selective local dynamic map construction result.

Comparing figures 5 and 7, both the selective LDM construction and the traditional method contain the data for 98 vehicles and 2 pedestrians, so the data integrity of selective LDM construction is 100%.

In terms of the amount of data, it can be obtained from Table 1 that the amount of data D' uploaded by the selected vehicles is:

$$D' = \sum T_i = 1095 \tag{26}$$

From (5), the overhead ratio of the selected LDM construction method is:

$$K' = \frac{D' - D_m}{D_m} = 1.19 \tag{27}$$

Compared to the traditional upload method, the reduced percentage of data is:

$$\frac{D - D'}{D} = 89.63\% \tag{28}$$

In the case of a vehicle communication radius of 20 meters, the overhead ratio of the selected LDM construction method is 1.19, which reduces the data redundancy by nearly 90% compared with the traditional upload method. Moreover, it greatly saves the computing and communication resources of the system, which reduces computing and communication time and improves system security and reliability.

7. Conclusion

In view of the rapid increase of data volume in large-scale intelligent connected vehicle scenes, this paper proposes a LDM construction method based on MEC architecture by combining the characteristics of MEC architecture and LDM data. On this basis, we select key nodes to upload data to MEC edge server, which greatly reduces the amount of the data uploaded.

Moreover, the simulation results show that the selective LDM construction method completely constructs the LDM and reduces the data redundancy of nearly 90%, which is an effective solution for the data problem in large-scale intelligent connected vehicle scene.

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