Zooming: A Zoom-Based Approach for Parking Space Availability in VANET

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***Abstract*—In this paper, we propose a zoom-based approach for parking space availability. The main idea of our scheme lies on the fact that drivers near the queried locations are interested in detail (zoomed-in) parking space information, while drivers in a distant place are interested in rough (zoomed-out) information about free parking spaces. Our zooming technique is based on discrete cosine transform. Besides, a winner-take-all scheme is also proposed to further reduce communication overhead in packet loss environment. As compared to previous work, simulation results show that our scheme reduces 40% to 50% communication overhead.**

Index Terms—*Information dissemination, parking space, vehicular ad hoc networks*

I. Introduction

The vehicular ad hoc network (VANET) is a kind of mobile ad hoc networks (MANETs) to provide a platform of car safety and traffic applications. The dissemination of free parking space information is one of the popular applications in VANETs. Previous works on finding free parking spaces can be classified into centralized and distributed schemes. Centralized methods [6] always have a server to store all parking space information gathered by sensor networks (or parking meters (PM)). Drivers connect to server through internet to access the parking space information. Distributed methods [2, 4] use wireless devices on PMs and vehicles to construct a VANET environment and then spread parking space information on VANET. Since there is no central server to dispatch information, dissemination of free parking space information usually results in heavy communication overhead.

In this paper, we propose a distributed zoom-based approach for parking space availability in VANETs. The main idea of our approach is described below. Imagine that a virtual camera is used to snapshot photographs of distribution of free parking spaces in the city. Obviously, we could zoom out the snapshot to have a rough distribution information and zoom in the snapshot to have detail information. In general, drivers far from their destination are interested in rough parking space information of a large region, while drivers near their destination are interested in detail parking space information of a narrow region. Based on the observation, when a driver queries the information of free parking spaces around a specific location, a scrap of zoomed-out snapshot is send to the driver if he is far from the queried location, and a scrap of zoomed-in snapshot is send to the driver else. Our zooming technique is based on a low-computation-cost technique, discrete cosine transform (DCT). By the aid of DCT, detail information of the snapshot is represented by high frequency information. After filtering out high frequency information by DCT, a zoomed out snapshot could be obtained by inverse DCT. Notice that zoomed-out/zoomed-in snapshots keep not only the approximate number of free parking spaces in the region but also the rough distribution of free parking spaces.

Our approach is low-cost. This is because zoomed-out snapshot is not sensitive to small changes, which implies that zoomed-out snapshot has long expiration time. In addition, the same zoomed-out snapshot could be replied to drivers whose queried locations fall in the same large region. That is, if a zoomed-out snapshot has been requested/replied not long ago, the resulting snapshot is also desirable to drivers whose queried locations is also captured in the snapshot, which reduce the number of long-path transmission. Besides, a winner-take-all scheme is also proposed to further reduce communication overhead in packet loss environment. Simulation results show that our approach reduces 40% to 50% communication overhead as compared to previous work. Notice that in our approach, more accurate information is available to driers when they get more close to their queried locations.

Our approach is fault-tolerant. Due to packet loss, free parking space information of certain small regions may not be available. In such a case, it is surprising that a zoomed-out snapshot which captured these small regions is still available. Since the distribution of free parking spaces is similar in near small regions, a prediction of situation of these unknown regions could be obtained by the aid of near regions' information (i.e., filtering out high frequency information of these regions).

The main contributions of this paper are as follows:

1. A distributed zoom-based approach is first proposed, i.e., zoomed-out (i.e. rough) parking space information is available to drivers in a distant place, while zoomed-in (i.e., detail) parking spaces information is available to drivers near the queried locations.
2. Not only the number of free parking spaces but also the distribution of free parking spaces is available to drivers.
3. The proposed approach is fault-tolerant. It is applicable in packet loss environment.
4. Our approach is low-cost. Because the number of long-path transmission is reduced.

The rest of this paper is organized as follows. Section II reviews the related work in this field. The scheme of free parking space dissemination is described in Section III. In Section IV, we evaluate the performance of our protocol using network simulators. Finally, we conclude this paper in Section V.

II. RELATED WORK

In [2], parking meters (PMs) are used to form a network named parking meter network (PMNET). Parking space information is disseminated by the aid of PMNET. Each PM broadcasts its own parking space information to all other PMs in the network. Clearly, the communication overhead is very high in a large network environment. Notice that vehicle-to-vehicle communications is not required. So the networks may be disconnected/partitioned when the density of PMs is low or when there are many obstacles in the environment.

PPDA [4] is based on a multi-level hierarchical structure. In PPDA, a city map is divided into grids and each grid contains several PMs. A PM is assumed to monitor a number of parking spaces. Each PM determines the number of free parking spaces in the grid by aggregating the parking space information from PMs in the same grid. Furthermore, free parking space information of four lower-level grids is aggregated into one higher-level information. PMs use a relevance function to determine the most important (i.e., new and near) information to broadcast.

In [5], the authors propose a scheme to predict the number of free parking spaces when drivers are approaching their queried locations. They estimate the time of vehicle arrival and use probabilistic model to make prediction according to historical data. In [10], the authors introduced a probabilistic approximation scheme for aggregating parking space information.

III. THE PROPOSED APPROACH

In this paper, free parking space information is disseminated by PMs and vehicles. PMs and a certain percentage of vehicles are assumed to have wireless communication ability, computing ability, and storage spaces so that they are able to form the VANET [3, 13]. Besides, PMs are not only able to detect whether the current parking spaces are free or occupied by vehicles, but also have their own IDs and locations.

In this section, we propose a zoomed-based approach for parking space availability. Our approach consists of two parts: parking space dissemination scheme (PSD) and auxiliary communication overhead reduction scheme (COR). PSD is the fundamental part of our approach and COR is applied to PSD for reducing the communication overhead of PSD.

A. Parking Space Dissemination Scheme(*PSD*)

In general, drivers far from their destination are interested in rough parking space information of a large region, while drivers near their destination are interested in detail parking space information of a narrow region. Based on the observation, we introduce a zoom-based approach.

Imagine that it is possible to snapshot photographs of distribution of free parking spaces in the city. When a driver queries the information of free parking spaces around a specific location, a scrap of zoomed-out snapshot (rough information) is send to the driver if he is far from the queried location, and a scrap of zoomed-in snapshot (detail information) is send to the driver else. The detail of our approach is described below.

For ease of the following discussion, we have the following assumption and definition. We assume that there are four kinds of zoom factors: level 0, 1, 2, 3 zoom factors. Snapshots zoomed with level i zoom factor reserves more detail than those zoomed with level i+1 zoom factor. We also define a packet which contains a scrap of the snapshot zoomed with level i zoom factor to be a *level i packet*. Since drivers far from their destination are interested in rough parking space information of a large region, a level i+1 packet contains free parking space information of a larger region than that of a level i packet and is send to drivers farther than drivers which a level i packet is send to.

In order to define level i packets, we assume that a city is divided into several super grids; each super grid is further divide into several grids; a road in a grid is partitioned into several segments; PMs located in the same road segment form a cluster and one of these PMs is chosen as cluster head (CH) by the cluster election schemes such as LEACH [7, 9]. Now we are ready to define level i packets

Level 0 packet: contains the number of free parking spaces monitored by a certain PM.
Level 1 packet: contains the number of free parking spaces in a certain cluster.
Level 2 packet: contains the number of free parking spaces in a certain grid.
Level 3 packet: contains the distribution of free parking spaces in a super grid (i.e., the number of free parking space in grids of a super grid).

Dissemination of packets of various levels is detailed below.

Level 0 packet dissemination. When a PM is aware that the number of free parking spaces monitored by it changes, it sends a level 0 packet, which contains the number of free parking spaces and its ID, to its CH.

Level 1 packet dissemination. When a CH, say p, is aware that the number of parking spaces in its cluster is changed, it broadcasts a level 1 packet to inform other CHs. A level 1 packet contains the total number of free parking spaces in its cluster, its ID, Time to Live (TTL_{L1}), and a time stamp. By the aid of TTL_{L1}, CHs within TTL_{L1}-hop of CH p are able to obtain the free parking space information of p's cluster. Notice that two CHs in the same grid are within TTL_{L1}-hop of each other.

Level 2 packet dissemination. Level 2 packets are exchanged by CHs in the same grid and CHs in the neighboring grids.

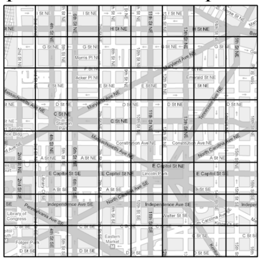
Each CH estimates the total number of free parking spaces in its own grid by its received level 1 packets. And CHs in the same grid exchange their own knowledge about the grid by periodically broadcasting level 2 packets. Due to packet loss and communication holes, level 2 packets of any two CHs in the same grid at the same time may be different. So, a level 2 packet contains the estimated number of free parking spaces in its grid, grid ID, CH's ID, Time to Live (TTL_{L2}), and a time stamp. CHs in the same grid broadcast level 2 packets by turns. Every level 2 packet is disseminated TTL_{L2} hops.

In order to determine level 3 packets, one CH in a grid is chosen to exchange level 2 packets with CHs in other grids. In our protocol, the CH whose level 2 packet has the largest number of free parking spaces is chosen.

Level 3 packet dissemination. Recall that a level 3 packet contains the distribution of free parking spaces in a super grid. In order to reserve the distribution of free parking spaces in a super grid and reduce the packet size and communication overhead, an image compression technique, discrete cosine transform (DCT), is used (simulation results show that 60% communication overhead is saved).

For ease of the following discussion, a super grid is assumed to comprise 8 × 8 grids. Each CH is assumed to have the ID of its own super grid. Each CH receives a number of level 2 packets of grids within its super grid in a period of time. If the number of a CH's new received level 2 packets is larger than a threshold value N_{L2}, the CH aggregate these level 2 packets to form a level 3 packet. Threshold N_{L2} is set to be smaller than 64 (i.e. the number of grids in a super grid) in our simulations. This is because that a CH may not receive all level 2 packets in the same super grid due to the following two reasons: First, by the restriction of TTL_{L2}, a CH may not receive all level 2 packets in the same super grid. Second, there may exist communication holes in a super grid.

A matrix A is used to store the snapshot of a super grid with level 2 zoom factor. Each entry in matrix A denotes the number of free parking spaces in a grid (see Fig. 1). An entry of A is 0 if the level 2 packet of the corresponding grid is not received.



$$\Rightarrow \begin{bmatrix} 52 & 55 & 61 & 66 & 70 & 61 & 64 & 73 \\ 63 & 59 & 55 & 90 & 109 & 85 & 69 & 72 \\ 62 & 59 & 68 & 113 & 144 & 104 & 66 & 73 \\ 63 & 58 & 71 & 122 & 154 & 106 & 70 & 69 \\ 67 & 61 & 68 & 104 & 126 & 88 & 68 & 70 \\ 79 & 65 & 60 & 70 & 77 & 68 & 58 & 75 \\ 85 & 71 & 64 & 59 & 55 & 61 & 65 & 83 \\ 87 & 79 & 69 & 68 & 65 & 76 & 78 & 94 \end{bmatrix}$$

Figure 1. A matrix for recording the distribution of parking spaces in a super grid.

In order to reduce communication overhead, we have the following steps, which are very similar to image compression, is applied to A.

Step 1: Normalize A. Assume that the size of each entry in matrix A is 8-bit (i.e., each grid can represent 0 to 255 number of free parking spaces. If more than 255 free parking spaces, it is recorded as 255). The value of each entry will be shifted to -128 to 127 after normalization (i.e., each entry minus 128) and then we get matrix B.

Step 2: Apply two-dimensional DCT to matrix B to transform B into frequency domain. Each entry in matrix B will be transformed by formula (1). In (1), $C_{u,v}$ denotes the entry at row u, column v of the resulting matrix, $\alpha(u)=\sqrt{1/8}$ if u=0 and $\alpha(u)=\sqrt{2/8}$ else, and $B_{x,y}$ denotes the entry at row x, column y of matrix B.

$$C_{u,v} = \alpha(u)\alpha(v)\sum_{x=0}^{7}\sum_{y=0}^{7} B_{x,y}\cos\left[\frac{\pi}{8}\left(x+\frac{1}{2}\right)u\right]\cos\left[\frac{\pi}{8}\left(y+\frac{1}{2}\right)v\right] \quad (1)$$

Then round off $C_{u,v}$ to obtain a new matrix C. By this step, the frequency spectrum of original matrix A is characterized by the value of every entry.

Step 3. Quantization. According to the definition of DCT, nearby similar entries in matrix B becomes low frequency information in matrix C, while nearby entries with much difference becomes high frequency information in C. In general, the number of free parking spaces in nearby grids is similar. If a grid g has few/much free parking spaces, grids nearby g may have few/much free parking spaces, also. So, high frequency information could be filtered out. The following quantization process is used to filter high frequency information in matrix C. First of all, we need to construct a quantization matrix Q.

$$Q = \begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}$$

Here the classic quantization matrix of JPEG is used to filter lightness information [8]. Maybe there exist more suitable matrices to quantize the distribution of free parking spaces in city, but it is out of the range of this paper, we do not discuss here. To obtain the quantized matrix D, just put the matrix C and Q into the follow formula:

$$D_{j,k} = \mathrm{round}\left(\frac{C_{j,k}}{Q_{j,k}}\right) \text{ for } j = 0,1,2,\cdots,8\,;\, k = 0,1,2,\cdot \quad (2)$$

The quantized matrix D is shown as follow:

$$D = \begin{bmatrix} -26 & -3 & -6 & 2 & 2 & -1 & 0 & 0 \\ 0 & -2 & -4 & 1 & 1 & 0 & 0 & 0 \\ -3 & 1 & 5 & -1 & -1 & 0 & 0 & 0 \\ -4 & 1 & 2 & -1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (3)$$

Step 4. Entropy coding. First, sort matrix D by zigzag to generate a list L_D = {-26, -3, 0, -3, -2, -6, 2, -4, 1, -4, 1, 1, 5, 1, 2, -1, 1, -1, 2, 0, 0, 0, 0, 0, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0}. There is a serious of 0 in the rear of L_D. Because the length of L_D is fixed, 0s after the last nonzero value in L_D could be removed to form a new list L_D'. A level 3 packet contains L_D' (therefore, the size of a level 3 packet will get shorter and reduce the communication overhead).

Recall that in each grid, one CH is chosen (see Section III.B) to exchange its level 2 packet with CHs in other grids. Such chosen CHs also broadcast level 3 packets by turns. Every P_{L3} seconds, a chosen CH broadcast a level 3 packet. A level 3 packet is disseminated TTL_{L3} (= 20 hops in simulations) hops. The value of TTL_{L3} is greater than that of TTL_{L2} and TTL_{L1}, so drivers far away from their queried locations are able to obtain a level 3 packet.

When a CH receives a level 3 packet, it is able to determine an approximate matrix of A by similar steps in reverse order.

IV. Performance Evaluation

In this section, the performance of our protocol and PPDA protocol[4] are compared.

We use VanetMobiSim/ns-2 since it offers the possibility of specifying realistic mobility models, using VanetMobiSim, and communication environments, using ns-2. In our simulations, we consider a 6000 m × 6000 m area with Manhattan-type grid streets and road segment length equal to 200 m. The area is divided into grids with side length 250 m, i.e., there are total 576 grids. There are 870 CHs and each road segment has at most one CH deployed. PMs are uniformly deployed. PMs and 100 vehicles are equipped with wireless devices (802.11). Effective transmission range is 250 m.

In the rest of this section, three sets of experiments are considered: (1) Adjusting values of parameters of our approach, (2) Effects of communication overhead reduction scheme (COR), and

(3) Comparing performance of our approach and PPDA. The metrics for comparing performance are listed below:

Information availability: percentage of available parking space information within a given region. For example, if there are total 10 distinct level *i* packets (i.e., level *i* parking space information) generated within 200 m of a certain CH, and that CH receives 9 of them, we say that level *i* information availability within 200 m is 90%.

Communication overhead: the number of bytes of transmitted packets.

Information accuracy: The difference between the original number of free parking spaces and the number of free parking spaces recorded in packets.

A. Adjusting values of parameters of our approach

In order to realize the performance of our approach, we first determine values of two parameters, TTL_{L2} and N_{L2}, in this sub-section. Recall that TTL_{L2} denotes the Time to Live value of level 2 packet and N_{L2} denotes the minimal number of level 2 packets required to be aggregated in a level 3 packet. Clearly, level 2 information availability depends on TTL_{L2}, i.e., small TTL_{L2} results in that CHs receive less level 2 packets. To achieve the balance between communication overhead and well working of our scheme, TTL_{L2} and N_{L2} are 9 and 45, respectively in the following simulations.

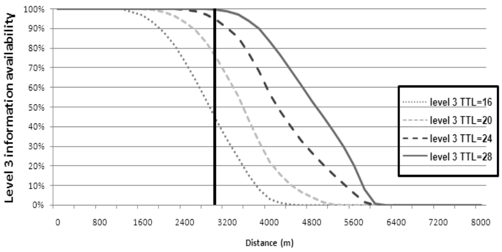
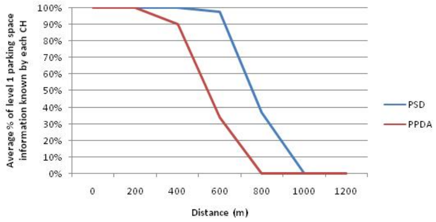


Figure 2. Level 3 information availability with various value of TTL_{L3}.

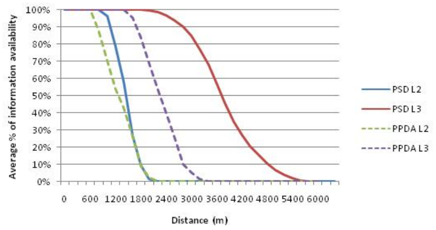
Similarly, level 3 information availability depends on TTL_{L3}, respectively. With larger TTL_{L3}, CHs are able to get more and farther parking space information. However, large TTL_{L3} results in large communication overhead. In Fig. 2, TTL_{L2} and N_{L2} are 9 and 45, respectively. It shows that with increasing TTL_{L3}, level 3 information availability (i.e., the percentage of level 3 packets received by each CH) is also increasing. The value of TTL_{L3} is chosen according to how far is the information that we want to know. For example, if we want to know all parking space information within a radius of 3000 meters (denoted by the vertical line in Fig. 2), we can simply choose TTL_{L3} = 28 to achieve our goal as shown in Fig. 2.

B. Performance comparision

In this experiment, the performance of our protocol and PPDA are compared. PPDA is mainly based on a multi-level hierarchical structure. High level parking space information is the summation of total number of parking spaces of four lower levels. For ease of the comparison, level 2 parking space information is the total number of free parking spaces in a grid (defined in our PSD). Level 3 (level 1) parking space information is the number of free parking spaces in four grids (a sub-grid, where four sub-grids form a grid). Besides, we assume that level *i* packet in PPDA contains level *i* packet space information. There are 1200 sub-grids. PMs periodically broadcast parking space information. The content of each broadcast contains a PM's all knowledge, i.e., the content of a broadcast may contain level 1, level 2, and level 3 parking space information. Broadcast period of PPDA is 10 seconds. There are 870 CHs and 100 vehicles in map. The parameters of our PSD, TTL_{L1}, TTL_{L2}, TTL_{L3}, and N_{L2}, are 4, 9, 20, and 45, respectively.



(a) Average percentage of level 1 parking space information known by each CH



(b) Average percentage of level 2 parking space information known by each CH

Figure 3. Average percentage of parking space information known by each CH

Information availability. Fig. 3 shows information availability. In Fig. 3(a), our PSD has better level 1 information availability than that of PPDA. Level 1 information availability within 600m of our PSD is at least 97%, while that of PPDA is about 30%. Besides, Level 1 information availability within 800 m of our PSD is 35%, while that of PPDA is 0, i.e., in PPDA, CHs are unable to obtain parking space information of sub-grids which are 800m away. Knowing the detail information of parking space within 600 meters is believed to be acceptable by drivers. Fig. 3(b) shows level 2 information availability and level 3 information availability. It is obvious that both our PSD's level 2 information availability and level 3 information availability are better than PPDA's.

Communication overhead. Fig. 4 shows that the communication overhead of our approach is about 40% to 50% of that of PPDA. This is because our COR scheme success in avoiding unnecessary packet dissemination. On the other hand, in PPDA, PMs broadcast all parking space information of it own periodically. So packet size gradually increases because PM receives more and more information (as shown in Fig. 4), which implies the communication overhead gradually increases. If the amount of information is more than maximum packet size (2230 bytes), the PM uses relevance function to determine the most important parts of information to broadcast. Refer to Fig. 4, at the 100th second, packet size in PPDA protocol reaches maximum packet size. Hence the communication overhead after 100th second is the same with that of 100th second.

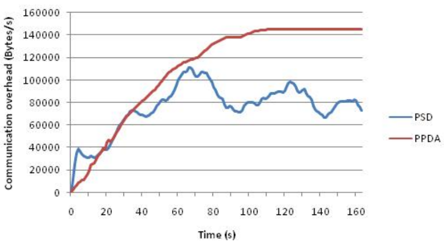


Figure 4. Average communications overhead per second

V. CONCLUSIONS

In order to solve the parking space availability problem in urban cities, we propose a zoom-based approach for parking space availability. In real world, drivers are interested in the detail parking space information when they are near the queried locations. When drivers are far apart from their queried locations, they need a rough spatial distribution of number of free parking spaces and the detail information is unnecessary. Based on the concepts above, we propose a zoom-based approach, i.e., drivers get zoomed in (out) image of parking space distribution when they are near (far apart from) the queried locations. Simulation results show that our approach saves 40% to 50% communication overhead. Our COR scheme is applicable not only to parking space availability, but also in any other traffic information dissemination with similar assumptions.

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