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Reliable Code Disseminations Through Opportunistic Communication in Vehicular Wireless Networks

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ABSTRACT Large numbers of software-defined sensor devices have formed a basic infrastructure for data collection. One of the challenges is how to update the program codes of devices in a low-cost and reliable style. This paper figures that the vehicular wireless networks (VWNs), combined with a base station (BS) platform, can play a significant role in disseminating program codes in a smart city. A code dissemination algorithm that selects vehicles as disseminators is proposed to accomplish the coverage ratio of codes and benefits of vehicular disseminators in a reliable manner and to reduce the costs of the BS. The algorithm targets to make the disseminators to achieve more coverage regions of a code. The benefit distribution method, which targets the improvement of benefits in suburban regions and encourages vehicle owners, is redefined and differs from previous benefit distribution schemes. Through disseminating, the vehicles can obtain more benefits, and the costs of the BS can be reduced. We ultimately simulate the performances of the selection algorithms with GPS datasets to prove the progressiveness of the "Code Disseminations through Opportunistic Communication in Vehicular Wireless Networks" (CD-VWNs) scheme in terms of coverage and benefits. The benefit-ratio performance criterion can be improved by 21.078% over other models. The coverage-ratio performance criterion can result in an improvement of 31.94% over other selection schemes. The evaluation metric $\mathcal{Z}_r$ performance criterion can result in an improvement of approximately 25.256%. With the CD-VWNs scheme, loss of codes can be decreased, and the dissemination system remains reliable and survivable.

INDEX TERMS Vehicular wireless networks, code disseminations, vehicular selections, benefits, coverage, reliable.

I. INTRODUCTION

Recent growth in vehicular and wireless networks have paved the way for them to become fabrics of society and economy [1]–[3]. The ever-increasing penetration rates of mobile telephony, wireless broadband data access and the ubiquities of Wi-Fi are only a few examples of such phenomena. Wireless networks, such as vehicular wireless networks (VWNs), have offered many services and advantages such as extended communication range and operational flexibility [4]–[8]. Therefore, recent studies on VWNs are gaining much attention.

According to [3], because of the low-cost characteristic of sensing devices, they can be widely used in a smart city [9]–[14]. For instance, the sensing devices can be applied to public facilities in a smart city, such as roads, bridges, streetlamps and intelligent garbage cans. Via collecting various data from public facilities, a facility management center such as a base station (BS, or Data Center (DC) [15]–[18]) will receive timely information. After the BS collects the information, it can maintain and support the city public facilities timely. Moreover, such similar appliances are not limited to city public facilities; they can also be utilized with other data-centric equipment such as weather data acquisition, traffic flow monitoring, and long-term monitoring of geological hazards [19]–[21]. There are studies on how data perceived by sensor devices should be routed to the BS in an effective manner, such as [3]. This paper utilized a scheme of opportunistic communications via VWNs to collect data. The essential idea of data collection is that there are many vehicles in a city, and those vehicles travel along an opportunistic route. Moreover, these vehicles can carry a wireless data transceiver with strong functionality. Therefore, the vehicles can be used to collect and disseminate sensor data packets. At the same time, they can save enormous costs by avoiding the need for communication links built between the sensor devices and the BS. Thus, when a vehicle passes through sensing devices, the sensing devices will disseminate the data to vehicles. The vehicles can deliver the data to the BS when they pass through it.

With the rapid development of software-defined technologies, increasing numbers of sensing devices are applied to software-defined devices, indicating that this method makes hardware become "software". In other words, the hardware is widely utilized similarly to software. Via updating the program codes, sensor devices can acquire new functions, and those new functions can be adapted to new requirements and demands in new environments and surroundings. This software-defined-devices method can reduce updating costs and hardware appliance requirements, extend the service life of devices, and enhance the applied aspects. Thus, this technology has powerful prospects for development, which will allow the smart city based on software-defined sensing devices to meet the increasing requirements of providing human comforts. This method proposes the challenge of how to cause the program codes that are generated by the BS to be disseminated to the sensor devices in an effective manner. Addressing this challenge is the research goal of our paper. Although studies exist that have proposed a method for collecting n sensor devices' information, according to our research, there is no research on how to make an economical and reliable method to disseminate program codes to n devices in a reliable manner. Therefore, this paper is the first to develop a method for one-to-n dissemination processes of program codes in VWNs.

This paper presents the following two main challenges: (1) how can the BS communicate with sensing devices at a lower cost, and how can vehicular disseminations achieve more benefits. (2) How can the data or code be reliably disseminated to the sensing devices. Unreliability and failure situations often occur in VWN communication. The unreliability of transmission links can also have a great effect on the quality of code dissemination processes. Therefore, the reliability characteristic is an important factor in the communication quality of the VWNs.

(1) To address the first challenge, this paper proved that using an opportunistic communication method to disseminate program codes is an effective and efficient method using VWNs.

(2) For communications in VWNs, ensuring the reliability of communications involves more-complicated situations. In VWNs, communications usually lack provisioning for network robustness. For example, the battery power [2], [3] and energy issue of the applications [4]–[14] can cause delay situations [15]–[17] and influence network connectivity. The harsh surrounding environments and weather conditions can also interrupt the communications between sensors and sensors if the applications with sensor devices are deployed outdoors. Moreover, the imbalance of information disseminations [18] in vehicular wireless sensor networks (WSNs) [19]–[22] can have a great effect on the services that the networks can provide. The applications might not receive the program codes, which will lead to those sensing devices failing to implement the new functions or communicate with other devices because of inconsistent protocols. This issue thus will lead to communications unreliability in the VWNs, which can influence the survivability of entire systems.

Those failures will definitely affect provisioning for network robustness and services to users in mobile networks [23]. To be specific, VWNs can be used to provide timely services to users, whereas network failures might cause failures to transmit updated information to the sensor nodes and result in code-loss situations. Thus, the reliability of a system cannot be ensured in VWNs, and the availability of the system cannot be guaranteed. In VWNs, there exists one base station (BS), which can generate program codes [24], [25] to update the information or protocols in the sensing applications. However, the applications might fail to receive the program codes for many reasons, such as weather conditions, energy consumption and the mobility characteristic of the VWNs. The effects of this failure could be severe if it affects the connectivity of users who depend upon the updated information or influences the coverage ratio [26], [27] of the program codes in the VWNs. Therefore, these issues emphasize the need to develop a novel program-code dissemination scheme [28] to enhance network communications and connectivity and to sustain the flow characteristic of information to provide better services to users. Thus, the capability of the VWNs to transmit program codes [29] successfully and completely in a timely manner [30], [31] to reduce loss situations and remain reliable and survivable is referred to as a significant characteristic and is addressed in this paper.

In the manuscript, a code dissemination model is proposed which aims to reach the maximum coverage ratio for the BS in VWNs. Our objective is not only limited to obtaining the maximum coverage ratio but includes minimizing the costs of the BS and maximizing the benefits of the disseminators. The coverage can represent the area that is covered by program codes. The larger the coverage ratio is, the more opportunity the sensing applications have to receive program codes. In the VWNs, to disseminate the program codes to the regions, the BS must choose mobile vehicles as disseminators to carry program codes and deliver them to the applications with sensing devices.

In the VWNs, a significant characteristic is mobility. Therefore, some of the applications with sensing devices that are distributed in suburban regions cannot access the program codes because the vehicular disseminators might not pass those regions. Based on coverage, some vehicles are chosen as disseminators to deliver program codes. To ensure that the sensing applications, such as garbage cans or streetlamps, can receive the program codes timely, the vehicular disseminators must be encouraged by improving the benefits of disseminating, particularly in the suburban regions. In addition, it is necessary to build an algorithm to enable the BS to achieve the maximum coverage ratio and let the vehicular disseminators obtain the maximum benefits. Finally, to secure the performance and effectiveness of CD-VWNs methods, the result of metric S_i can evaluate the performances of the algorithm.

With comparisons of other scheme which select vehicles as disseminators with a random manner, the BS can select disseminators based on coverage ratio of each vehicle in the CD-VWNs scheme. To realize more benefits, the opportunity for vehicles to travel in suburban regions is growing. This growth can improve the coverage factor of program codes and increases the benefits factor of vehicular dissemination set. For the BS, growth can let the program codes cover more regions. For the set of vehicular disseminators, growth can realize more benefits by delivering program codes. This approach shows its advantages in both the benefits and the coverage ratio. To show advancements, the performances of vehicular set without utilizing the CD-VWNs scheme are also discussed. The simulation results demonstrate that the CD-VWNs scheme can improve the performances of the vehicular disseminator set in VWNs successfully.

To be specific, the main contributions of this paper include the following:

(1) This paper proposes that disseminating program codes on a large scale is a viable scheme in the VWNs for a smart city and proves that the CD-VWNs scheme is effective even when failures easily occur in the networks, according to real datasets of VWNs.

(2) A reliable code dissemination through opportunistic communication in vehicular wireless networks (CD-VWNs) scheme is proposed in this paper to ensure the efficiency of code disseminations in terms of two evaluation standards: the coverage ratio and the benefits ratio. In other vehicular selection methods, the disseminator vehicles are selected with a random manner, which may cause into the situations that the program codes cannot be delivered to some suburban areas. Therefore, based on the datasets of historical geographical trajectories, a CD-VWNs scheme is proposed to select disseminators. The CD-VWNs scheme is composed of maximizing the coverage ratio for the BS and improving the benefits of the vehicular disseminators. It can also reduce the costs of the BS to some extent. The CD-VWNs model can solve the disadvantages of other selection models as well as providing better and timely services for the users on the VWNs.

(3) The simulation results demonstrate that with the CD-VWNs scheme, the coverage ratio of a dissemination set can result in an improvement of 31.94% over the existing vehicular selection approaches. The benefit ratio can result in an improvement of 21.078% over other vehicular selection approaches. With the CD-VWNs scheme, the results derived that the performances can be improved by 25.256% approximately.

The remainders are organized as follows. In Section II, we introduced the related works. In Section III, the system models and problem statements are discussed. In Section IV, the research motivations are presented. The vehicular selection schemes are described in Section V, and its simulation evaluations are introduced and described in the Section VI. Additionally, Section VII concludes the paper with some future works.

II. RELATED WORK

Recently, because of the developments of the Internet hosts and mobile sensing devices, VWNs have grown into a hot field to research on. As a mobile communication network, the VSNs have considered the mobility characteristic; they disseminate program codes via opportunistic communications. The mobile vehicles can participant in the communication processes via the regular platform provided by the VWNs. In a VWN, a taxi travels along almost the same roadways day after day. When traveling on roads, with sensor devices, the vehicles can be used as disseminators. How to organize those vehicles to disseminate program codes is a significant issue in VWNs. We believe that via disseminating the program codes to update the information in the sensing applications, the users can enjoy better services. Therefore, for the BS, this paper proposes a selection method to choose disseminators as well as satisfying the coverage factor of program code disseminations.

A traditional code dissemination approach includes broadcasting on wireless sensor networks [32]–[35]. In the transitional code dissemination processes, when the BS generates a set of updated codes, the applications with sensing devices can communicate with each other in a peer-to-peer [36]–[39] or multi-hop manner [40]–[43]. However, with the development of Wi-Fi sensing applications and the increasing requirements of users in social networks [44]–[47], static wireless social networks cannot satisfy the demands of users. Therefore, the vehicular social network [48] appears to cope with the issue of mobility. It has broadened the utilization regions of citizens. However, there exist limitations on transmitting regions; some regions, particularly suburban regions, cannot receive the program codes of the BS because of the distance factor. Nowadays, the vehicular social networks have gained increasing interests [49]. For example, paper [50] argued on the conflicting goals of increased network utility and reduced power consumption. The paper proposed a cross-layer rate-effective framework to maximize network utility. Manuscript [51] introduced a new scheme to preserve privacy that was targeted at increasing data availability and reducing data delays; it was intended to provide users better services in the VWNs. Moreover, manuscript [52] proposed a detection and defense scheme targeted at identifying and defending MAC-layer selfish misbehavior and improving resources limitations because of processing capacity and lifetime issues. Paper [53] proposed a method to offload data and allocate tasks from the cloudlet in the vehicular wireless network cloud. Those proposed methods and schemes have great effects on the development of VWNs. However, few of these schemes were targeted at utilizing vehicles as disseminators to transmit the program codes of the BS to the sensing applications in the VWNs.

The vehicles are becoming the format of mobile communications and dissemination equipment. In the VWNs, there are two transmission types, including traditional Vehicle-to-Infrastructure (V2I) [54] and Vehicle-to-Vehicle (V2V) [55] models respectively. In VWNs, the BS generates the codes, aiming to update the information of the sensing applications and provide better services to users who depend upon this information. Various types of applications and equipment are being developed to employ the VWNs. Each vehicle in a smart city can deliver program data and information to the sensing applications, such as the garbage cans or the streetlamps. All of the communications of existing applications and the vehicular disseminations in VWNs are based on Wi-Fi technology.

Therefore, it is significant to develop a novel model to distribute the vehicles of a city and transmit the program codes in the manner of uniform distributions. In the CD-VWNs scheme, vehicles are chosen as disseminators to improve the coverage ratio of program codes in the VWNs. We believe that with the CD-VWNs scheme, the utilization efficiencies of vehicles can be improved. Moreover, via improving the benefits in the suburban regions, the CD-VWNs scheme can encourage the vehicles to travel in more suburban regions, disseminate the program codes in VWNs and provide better services to users.

III. SYSTEM MODEL AND PROBLEM STATEMENT

A. SYSTEM MODEL

In the CD-VWNs scheme, the BS selects several vehicles as code disseminators. Those code disseminators can be influenced by several factors, for example, the speeds of the vehicles, the length of the transmission codes and the set of selected transmission vehicles. Therefore, it is significant to consider the coverage and cost factors. The factor of coverage represents the regions to which the program codes can be transmitted, and the cost factor represents the rewards that the BS should pay for the vehicular dissemination. The CD-VWNs scheme is composed of three models: (1) the city division model, (2) the selection model of vehicular transmissions, and (3) the data-delivery model. The costs of a BS differ from region to region. Fig. 1 depicts the scenario that the garbage cans and the streetlights can receive program codes from the selection set of vehicular disseminators.

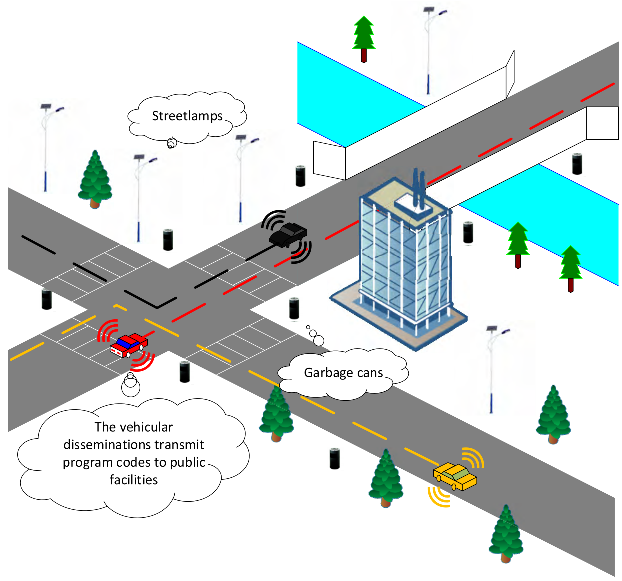


FIGURE 1. Scenario based on system model.

(1) In the city division model, via the historical trajectory datasets of vehicles, the city will be divided into several parts based on the density factor of this city. The number of the division regions is defined as N_r. The costs of BSs differ from region to region. To encourage the vehicles to travel across the suburban regions, the benefits of suburban regions for vehicular disseminations are defined more than are the benefits of urban regions for vehicular disseminations.

(2) In the selection model of vehicular transmissions, those vehicular disseminators are selected according to the coverage aspect and benefit aspect. The transmission vehicular selection model aims to achieve the maximum coverage ratio of the program codes and to achieve the maximum benefits for the vehicles. Based on the region divisions, some GPS points are chosen as the geographical indications. The set of indications is defined as L. The total number of L is defined as $Num(L)$. According to the number of indications that disseminator set V_D covers, the coverage of vehicular transmission set can be derived. The BS aims to maximize the coverage factor of the program codes and to maximize the benefits paid for the vehicles. Via the city division model, the vehicular disseminators in the suburban areas will be paid more than are those in the denser areas. Via the historical datasets, the number of geographical indications of each vehicle can be calculated. With the calculation methods, it is easily to reach the benefits of each vehicular disseminator. With the benefit results, those vehicles with highest value of coverage are chosen as disseminators to transmit program codes. In the CD-VWNs scheme, the vehicular transmission set can maximize the coverage factor; additionally, it can increase the benefits of the vehicular disseminators.

(3) In the data-delivery model, due to the length of the program codes, two situations exist. One is that the program codes can be transmitted once; the other is that the program codes must be transmitted several times.

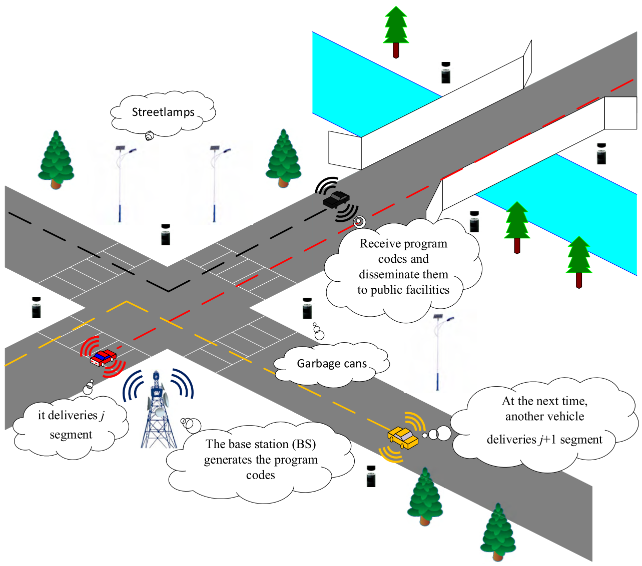


FIGURE 2. Vehicular disseminator cooperates with each other to transmit program codes.

In the second situation, the vehicular transmissions must cooperate with each other and deliver the program codes. Therefore, the data-delivery model divides the program codes into several segments; the number of segments for updated codes i is defined as $\mathcal{S}_i$ $(\mathcal{S}_i = 1, 2, 3, \ldots)$. When a dissemination vehicle encounters the sensing applications, it will transmit a segment of the program codes to them. In the data-delivery model, the cooperation relationships among the vehicular disseminators are important. The basic model of data delivery is shown in Fig. 2.

In addition, it is significant to take the length of program codes into consideration because it can influence delivery performances. With different length codes, the vehicular disseminators are definitely different. Therefore, we also evaluate the performances of the selected disseminator set with different lengths of program codes, which reflects that the CD-VWNs scheme can satisfy the most situations.

B. PROBLEM STATEMENTS

Generally, the largest issue of CD-VWNs model is how to make it effective during the code dissemination processes in the VWNs. The quality of disseminators is evaluated by the code coverage ratio and the delivery time. In addition, in the existing selection scheme for code disseminators, the vehicular disseminator set V_D is determined with a random manner. Thus, if the garbage cans with sensor applications are in the suburban regions, then those cans might not receive the program codes. This result cannot meet the demands of program code disseminations markedly. Thus, to satisfy the coverage evaluation, this problem can be converted into the problem of determine a selection model. The CD-VWNs scheme can figure out vehicles as disseminators to transmit program codes in VWNs.

(1) Improve the coverage ratio

In the VWNs, coverage ratio $\mathcal{C}_i$ of codes i is expected to reach the maximum to ensure the sensing applications can update the information or develop new functions. Therefore, it is significant that the vehicular disseminator set should cover as widely as they can in a smart city, to improve the coverage ratio. In the existing vehicular disseminator scheme, the results cannot reach those qualifications. Some of the sensing applications such as the garbage cans might not receive the program codes. Thus, it is necessary to build an appropriate disseminator selection model on the basis of coverage factor, which targets in improving the coverage of the disseminator set. Via the historical trajectory datasets, some GPS points in the map are randomly chosen to form into the indication set L.

There will be a set of vehicular disseminators to deliver a certain code i. The number of the geographical indications of the code i is set as $\mathbb{N}_i$ and the length of set L is $\mathbb{Q}$. Thus, the coverage $\mathcal{C}_i$ can be derived in Eq. (1).

$$\mathcal{C}_i = \frac{\mathbb{N}_i}{\mathbb{Q}}. \tag{1}$$

If the vehicular disseminator set m is defined, then the number of indications that m cover can be obtained, defined as $\mathbb{N}_m$. We can define the coverage of the disseminator set $\mathcal{C}_m$ in the Eq. (2).

$$\mathcal{C}_m = \frac{\mathbb{N}_m}{\mathbb{Q}}. \tag{2}$$

(2) Maximize the benefits of vehicles

In the code dissemination processes, the BS expects to transmit the program codes to as many areas as there are in the city. However, at the same time, the vehicular disseminators require far more benefits.

In the existing vehicular selection model, the vehicles are randomly chosen as disseminators. The benefits (also called the costs of the BS) to each vehicular disseminator are the same, which might lead to unbalanced coverage ranges of the updated codes. Therefore, this paper proposes a distribution scheme of benefits. The benefits vary from region to region. Based on the historical dataset of vehicles, the benefits of them (also called the costs of the BS) can be obtained, varying from vehicle to vehicle. The experimental results show that this scheme can improve the benefits of the vehicles to some extent.

Via the historical datasets, the city can be divided into several regions based on the density factor. The number of region divisions is $\mathcal{T}$. The benefits of a region differ from another region, defined as follows in Eq. (3):

$$\mathcal{T} = \begin{cases} \mathcal{T}_1, & \textit{the benefits of } \mathcal{T}_1 \textit{ region is } \mathfrak{C}_1 \\ \ldots, \ldots\ldots & \\ \mathcal{T}_k, & \textit{the benefits of } \mathcal{T}_k \textit{ region is } \mathfrak{C}_k \end{cases} \tag{3}$$

The selection set m of vehicular disseminators must cooperate with each other to deliver this message to the garbage cans with sensor devices. The general benefits with selection are defined as $benefit_s$, and the benefits of code disseminators without selection are $benefit_w$. Therefore, for the vehicular dissemination set m, the improvement probability $\mathcal{R}_m$ of benefits for the vehicular disseminators can be defined as Eq. (4)

$$\mathcal{R}_m = \frac{benefit_s - benefit_w}{benefit_s}. \quad (4)$$

(3) Divide the program codes

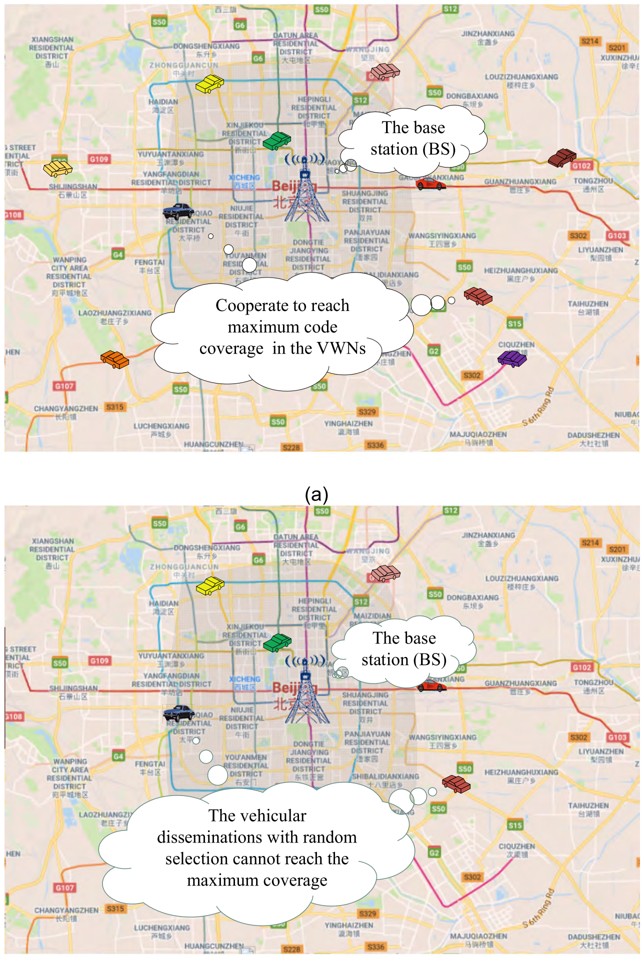
For the updated codes, the length of some codes is short and can be delivered to the sensor applications such as the garbage cans with one delivery time. However, some of the codes cannot be delivered to the BS once because of their length. Even when the program codes can reach the suburban regions, they cannot be delivered completely to the garbage cans with sensor devices, which will definitely increase the difficulties in the code dissemination processes.

The length of codes in one dissemination process can be obtained from the historical datasets. Therefore, in this paper, if a set of program codes can be delivered to the garbage cans once, then there is no need to divide it. In addition, if a set of codes cannot be delivered once, then it will be divided into several segments. The number of segments of a program codes set i can be illustrated as $\mathcal{A}_i$.

IV. RESEARCH MOTIVATION

On the basis of vehicular disseminator models, this paper focus on forming a novel mode of code dissemination to reach maximum coverage areas in future networks.

In modern society, many vehicles with sensing devices can deliver program codes to sensing applications. According to their daily trajectories, they can transmit program codes to the applications with sensing devices, such as the garbage cans or the streetlamps. If the applications with sensing devices receive those program codes, they will update the information and constantly provide the users or the enterprises with higher quality services. Moreover, some program codes might enrich the functions of sensing applications. Therefore, to transmit the program codes as widely as the areas in the city, it is necessary for the BS to decide which vehicle should be selected as disseminator to deliver program codes. In the existing vehicular system, to disseminate codes, the vehicular disseminators are randomly selected. Thus, if a disseminator set is randomly selected, the coverage ratio of this set usually cannot reach the maximum. The set of vehicular disseminators might not pass through some suburban regions of the city. Alternatively, some vehicles might even pass, but the program codes might be not completed transmitted to the sensing applications because of the mobility characteristic of the VWNs, or the program codes could not be delivered successfully within their lifetime. On the other hand, the costs of the BS remain high. To solve those problems, a selection scheme named "Reliable Code Disseminations through Opportunistic Communication in Vehicular Networks" (CD-VWNs scheme) is proposed in this manuscript. The main contributions are shown in the following.



(a)

(b)

FIGURE 3. Comparisons of two coverage ratios: (a) is about coverage of program codes based on the CD-VWNs scheme, and (b) is about coverage of program codes based on a previous scheme.

1) To reach more coverage ratio, the vehicles are required to cooperate with each other to deliver program codes. Several vehicles are selected as disseminators based on coverage factor, which is shown in Fig. 3(a). The set of vehicular disseminators with selections is shown in Fig. 3(b). Then, compare their coverage ratio with the coverage ratios of the randomly selected vehicular disseminators. According to comparisons, the selection set of vehicular disseminators can cover more regions than can the set of random vehicular disseminators, which indicates the coverage ratio has been improved. The program codes can be delivered to a wider area.

2) To improve the benefits of the vehicles, a city can be divided into several areas based on the density degree via the datasets of the historical trajectories. The benefits of one region are different from those of another region. Then, the benefits of the vehicular dissemination set with selections will compare with those of the disseminator set without divisions. According to these comparisons, the benefits of the selection set with divisions can be improved.

TABLE 1. Main notations.

Symbol	Description
i	Updated codes i
$time_a$	Vehicular traveling time in density distribution class a
$\mathcal{S}_i$	Number of segments for codes i
L	Set of geographical indications
V_R	Vehicular dissemination set without selection
V_D	Set of vehicular disseminators with selection
$Num(L)$	Number of geographical indications
$\mathcal{Q}$	Set of benefit classes
$\mathbb{C}$	Set of density classes
$Time_{\mathscr{b}}$	Total trajectory time of vehicle $\mathscr{b}$
$Cor_{\mathscr{b}}$	Coverage ratio of vehicle $\mathscr{b}$
Cor_{V_D}	Coverage ratio of vehicular dissemination set V_D
φ_r	rth time benefit comparison of two set of vehicular disseminators
$Num(V_R)$	Number of geographical indications that vehicular dissemination set with random selection covers
$\mathcal{Z}_r$	evaluation standard of dissemination set comprehensively
$Num(V_D)$	Number of geographical indications that vehicular dissemination set with selection covers

The main issues of CD-VWNs model is how to make it effective and efficient in the dissemination processes in the vehicular systems. Therefore, both the coverage and benefit factors are considered. The BS-VWNs scheme addresses this problem by combining the two factors together and forming them into the vehicular dissemination model to deliver program codes to sensing applications distributed in a modern society.

The main notations used in the experiments are shown in Table 1.

V. CD-VWNs ALGORITHMS

A. TO IMPROVE THE BENEFITS OF THE VEHICLES

1) DIVISION METHODS OF A CITY

Several important factors should be considered when determining how to calculate the benefits from a vehicular disseminator in the code dissemination processes in VWNs, such as the density factor of a city. Via the historical trajectories of the vehicles, there are more vehicles traveling in the denser regions, such as the city center, compared with the sparse regions. Thus, if a sensing application is set in a denser region, then there might be more opportunities for it to receive the program codes from the code transmissions. Once a set of program codes is generated by the BS, the set can be disseminated to the garbage cans in the denser regions of a city immediately. However, if the region density is sparse, then there will be fewer vehicular disseminators passing through those suburban regions, which causes the phenomenon that some garbage cans in the suburban regions cannot receive the program codes. Therefore, the quality of code disseminations is related to the density degree.

In reality, based on the values of longitude and latitude, the city divisions are defined as $\mathbb{C} = \{C_1, C_2, \ldots C_a \ldots, C_{n-1}, C_n$. The benefit value of a disseminator in one density class is different from the benefit value of another density class. To encourage the vehicle traveling in the suburban regions, the benefits of the suburban regions are more than those of the urban regions. If a disseminator passes more regions in the suburban classes, based on the distribution methods of benefits, it can obtain more benefits, which means the BS should pay more to the vehicular disseminators traveling in the suburban regions.

2) CALCULATION METHODS OF BENEFITS BASED ON DENSITY CLASSES

Actually, in the most cases, a disseminator will pass through several density distribution classes. Thus, the benefits of a disseminator should be redefined via the city divisions. And the benefits of a disseminator can also be seen as the costs of the BS. The CD-VWNs model defines the benefits of a vehicular disseminator have relationship with the proportion of time taken in each density class. The most of the GPS devices equipped on disseminators will generate geographical information every one second. Thus, the amount of vehicular geographical data can represent time, one to one.

Based on the density divisions, the benefits of a vehicular disseminator are determined. The density classes are defined as $\mathbb{C} = \{C_1, C_2, \ldots C_a \ldots, C_{n-1}, C_n\}$; thus, the benefits in each density class are defined as

$$\mathcal{Q} = \begin{cases} \mathcal{Q}_1, & \textit{the benefits in the density class } C_1 \\ \ldots, \ldots\ldots & \\ \mathcal{Q}_n, & \textit{the benefits in the density class } C_n. \end{cases} \quad (5)$$

The calculation method determining how the BS should pay for the vehicular dissemination $\mathscr{b}$ (benefits for vehicular disseminator $\mathscr{b}$) is shown in Equation (6):

$$\mathbb{C}_{\mathscr{b}} = \sum_1^n \frac{time_a}{Time_{\mathscr{b}}} \cdot \mathcal{Q}_a = \sum_1^n \frac{count_a}{Count_{\mathscr{b}}} \cdot \mathcal{Q}_{a}. \quad (6)$$

where $\mathbb{C}_{\mathscr{b}}$ is the daily benefits of a vehicular disseminator $\mathscr{b}$, $time_a$ indicates the traveling time of the density class C_a, $Time_{\mathscr{b}}$ is the travelling time of the disseminator $\mathscr{b}$. The symbol $count_a$ represents the number of geographical items when the disseminator is in the density class C_a, $Count_{\mathscr{b}}$ expresses the total number of geographical indications for vehicular disseminator $\mathscr{b}$. In the experiments, Beijing is chosen as the experimental city. Beijing can be spilt into three density classes $\mathbb{C}_i = \{C_1, C_2, C_3\}$ respectively. In the experiments, the class divisions of the benefits are Q = $(\mathcal{Q}_1, \mathcal{Q}_2, \mathcal{Q}_3)$.

Based on the density classes in $\mathbb{C}_i$, the divisions of Beijing are shown in the Fig. 4.

In Fig. 4, the areas with the background color of deepest grey represent the urban regions, the areas with the background color of lighter grey represent the less prosperous

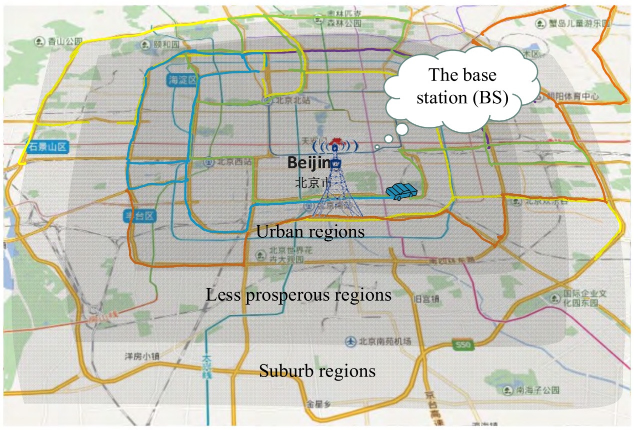


FIGURE 4. Divisions of Beijing.

regions, and the areas with the background color of the lightest grey represent suburban regions.

Based on the calculation methods, it is easily to obtain the benefits of disseminator set with selections. The pseudo codes of the calculation algorithm for benefits is shown in Algorithm 1.

This subsection defines a novel approach to distribute the profits to the vehicular disseminators. The simulation results show that this method can improve the benefits of the disseminators to some extents.

3) OBTAINING THE TRAJECTORY MAP

Via the historical vehicular trajectory datasets, the trajectory routes of a disseminator can be derived and the total historical trajectory graph can be obtained.

There still exist some issues, for example, because the Global Position System (GPS) services is not strong in everywhere. And some phenomena and situations might appear, perhaps some invalid geographical waypoints may happen, which can result in wrong routings. The way to discover an invalid point is to calculate the distances between the current point and the last point. If the result is deviate from the maximum distances, then the current geographical point is incorrect because a disseminator cannot travel such long distances in a very short time interval. It is significant to filter out the invalid geographical points to promise the accuracy of the simulation environment. According to the filtering method, the CD-VWNs scheme can figure out those invalid GPS points in an efficient manner and makes the simulation results more visible.

B. CALCULATION METHODS OF THE COVERAGE RATIO FOR A CODE DISSEMINATION PROCESS

Via the historical geographical datasets of all of the vehicles in a city, the total map can be obtained.

In the coverage calculation model, several points in the historical datasets are selected as geographical indications, which is defined as $L = (l_1, l_2, \ldots\ldots, l_{z-1}, l_z)$, where $l_1 = (x_1, y_1), l_2 = (x_2, y_2) \ldots\ldots l_z = (x_z, y_z)$. The variation of a geographical indication is from 0 to 1, which indicates that if the value of one geographical indication is 1, then all of the vehicular disseminators have passed through this waypoint. If the value of the geographical indication is 0, then none of the vehicular disseminators will pass through this waypoint. The coverage ratio of a vehicle ℓ can be expressed in Equation (7).

Algorithm 1 Algorithm for the Benefits

Input: $p, q, a, \mathcal{Q}_1, \mathcal{Q}_2, \mathcal{Q}_3, v1, v2, v3$
(set three vectors $v1, v2, v3$ to store the number of waypoints)
Output: *benefits*

For(p = 1; p < the length of the disseminator set; p++)
  //choose a vehicular dissemination ℓ in the set
  For(q=1;q< b. length; q++) // b is the historical dataset //of vehicular dissemination ℓ, q is a point in the dataset
   IF b[q].x and b[q].y are distributed in urban areas
     v1 ++ //put this point in v1
   Else if the waypoint is in the less prosperous areas
     v2 ++ //put this point in the v2
   Else//this point is in the class C_3
     v3 ++ //put this point in v3
   End if
  End for
  $\mathcal{Q}_1$ = the value of vector1;
  $\mathcal{Q}_2$ = the value of vector2;
  $\mathcal{Q}_3$ = the value of vector3;
  For(a=1;a<=3;a++)// the three density classes
   $\mathbb{C}_{\ell} = \sum_1^n \frac{time_a}{Time_{\ell}} \cdot \mathcal{Q}_a = \sum_1^n \frac{count_a}{Count_{\ell}} \cdot \mathcal{Q}_a$
   // derive the benefits of dissemination ℓ
  End for
  benefits += $\mathbb{C}_i$ //obtain the benefits of the
   // disseminator set
End for

$$Cor_{\ell} = \frac{Num(\ell)}{Num(L)}. \tag{7}$$

where $Num(\ell)$ is the number of geographical indications with selection that the vehicular disseminator ℓ passes. $Num(L)$ is the total number of geographical indication set with selection.

C. SELECTION METHODS OF THE VEHICLES USED FOR CODE DISSEMINATIONS

To improve the coverage regions of the program codes, it is significant to choose appropriate vehicles that vehicular geographical datasets can best cover. The waypoints in the indication set L are randomly selected. With the calculation methods of the coverage ratio in Equation (3), those vehicles with the highest value of the coverage ratio are selected as the disseminators to deliver program codes to the sensor applications, such as the garbage cans or the streetlamps.

In this paper, we define the length of indications set L as p. If the number of the waypoints of a vehicle is greater than p, then this vehicle is recorded. Otherwise, this vehicle will be filtered out.

According to the coverage ratio, the vehicular disseminator set is determined. With selections, those disseminators in the set should pass through all of the geographical indications in set L. Vehicular disseminators with selection can be defined as $V_D = (v_1, v_2, \ldots\ldots, v_{k-1}, v_k)$. The set V_D is composed of the k vehicles with the highest value of coverage ratio Cor. Based on the previous vehicular selection model, the set of random selection vehicles is defined as $V_R = (v_1, v_2, \ldots\ldots, v_{q-1}, v_q)$.

In this paper, the general coverage ratio of V_D is defined according to the following standards. If one vehicular disseminator in it passing through a geographical indication indicates that this point has been covered, regardless of the length of the program codes. For the set of vehicular disseminators V_D with selection, the coverage ratio is defined in Equation (8).

$$Cor_{V_D} = \frac{Num\,(V_D)}{Num\,(L)}. \tag{8}$$

where $Num\,(V_D)$ indicates the number of indications that the L covers.

Below are the pseudo-codes of selection for vehicular disseminators in the datasets:

After vehicular selection, the disseminator set V_D can obtain a higher value of coverage ratio with comparisons. The selected disseminator set can also go through the suburban regions, which indicates that the program codes can be disseminated to the garbage cans or the streetlamps with sensing applications in the suburban regions. This approach can improve the quality of code disseminations in the opportunistic communications in the VWNs.

D. DIVISION MODEL OF THE PROGRAM CODES

The benefit distribution scheme can improve the benefits of the vehicular disseminators effectively. Moreover, the selection methods of the vehicular disseminators can maximize the coverage ratio of the code disseminations. However, an issue remains – what if a set of program codes cannot be delivered once.

In this subsection, the length of the program codes is discussed based on the two schemes above. If a set of the program codes cannot be delivered once, then it requires cooperation among the vehicular disseminators. In this paper, via the experiments, we can obtain the maximum length of program codes that can be delivered once, which is defined as σ. If the length value of codes is greater than the threshold σ, then this set of codes will be divided into several segments. The number of segments for a set of codes i is defined as $\mathcal{S}_i$. Several vehicular disseminators must cooperate with one another to deliver this set of program codes. For example, a set of codes being divided into four segments (the value of $\mathcal{S}_i$ is 4) indicates that at least four vehicles must pass near a garbage can to deliver this set of program codes. If a garbage receives all marked information segment, then this code set has been delivered successfully. In the experiments, based on different lengths of codes, we discussed the size of the vehicular dissemination set needed for transmitting the codes. The greater the length of program codes, the more vehicular disseminators are required. Moreover, the general benefits of disseminator set have a relationship with the number in the dissemination set. When the number of vehicular disseminators increases, the costs of the BS will definitely increase. We also compare the benefits based on different numbers of vehicular disseminators.

In this paper, the contents of the codes are not considered. Therefore, if $\mathcal{S}_i = 4$, by cooperating with each other,

Algorithm 2 Model to Select Disseminators According to the Factor of Coverage

Input: $p, q, l, x_1, y_1, p, h, vector1$
Output: vehicle number

```
For( p=1; p < the length of V_D; p++)
        //choose disseminators in the historical vehicular set
   For(q = 1; q< the length of geographical indication set of
        this vehicle; q++) //choose an indication
     For(l = 1; l <p. length; l ++)
       p [l].x = x1
       p [l].y = y1
       While |x1-q.x| < e and |y1-q.y| < e
 //if the divisions between the current point q and the last
 //right point l is less than the threshold e,then q is aright
 // GPS point, else the current point q is an invalid one.
         For(t=1; t< L. length; t++)
 //select a geographical indication in the set L
           If |p. x- t. x| < s and |p. y- t. y| < s
 //if this point satisfies this basis standard, then this point
 //can be seen that it has covered the geographical
 //indication t and s are threshold.
             h=h+1; // increase the h
           End if
         End for;
       End while;
     End for
   End for
   vector1.push_back (h);
             // Record the value of h in the vector 1
   h = 0; // initialize the value of h
End for
Utilize the quick sorting method to sort the vector 1 and record the index
Return the highest indexes
   // select the vehicles with the highest coverage ratio
Return vehicle number;
End algorithm 2
```

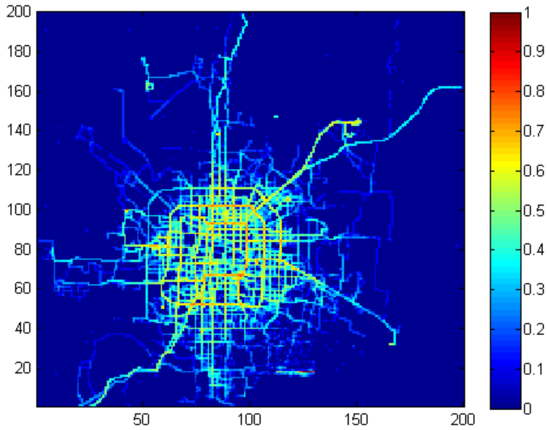


FIGURE 5. Visualizations of T-Drive datasets.

four vehicles can go near a garbage can with sensor devices. This result indicates that this garbage can received this set of codes.

In the following sections, based on different lengths of program codes, the number of sets of vehicular disseminators with selection is compared. The expenses of BSs are discussed at the same time.

To some extents, the code divisions will lead to more costs, because vehicles need to cooperate with each other. Under the same number of disseminators, the CD-VWNs scheme can lead to higher coverage ratio, which indicates the efficiency.

VI. EXPERIMENTAL EVALUATIONS AND RESULTS

A. EXPERIMENT ENVIRONMENTS

To demonstrate the efficiencies of the CD-VWNs methods, the historical datasets of T-Drive provided by MSRA are utilized to make simulations. The trajectory datasets include the trajectories of approximately 10,357 taxis of Beijing, which is recorded by the GPS services. The period ranges from Feb. 2 to Feb. 8, 2008. There are 15 million geographical points in the datasets approximately, which have formed into 9 million kilometers approximately. Fig. 5 shows the T-Drive datasets visually. Deeper color in the Fig. 5 represents the denser regions of Beijing travelling.

To verify the efficiency and performance of the CD-VWNs scheme with the VWNs, three standards must be formulated. According to the benefits, the benefits of V_D with selection are compared with those of randomly disseminator set V_R, expressed in the Equation (9).

$$\varphi_r = \frac{\sum_1^k \mathbb{C}_\ell - \sum_1^q \mathbb{C}_\ell}{\sum_1^k \mathbb{C}_\ell}. \tag{9}$$

where the φ_r represents the rth time comparison of the two sets of vehicular disseminators, $\sum_1^q \mathbb{C}_\ell$ is the total benefits of disseminators in V_R, and $\sum_1^k \mathbb{C}_\ell$ represents the total benefits of disseminators in V_D. The φ_r can reflect that for the vehicular disseminators, the improvement ratio of the benefits after utilizing the CD-VWNs scheme is increased.

On the basis of coverage, the coverage ratio of V_D is compared with that of V_R. The comparisons can be calculated by Equation (10).

$$\omega_r = \frac{Num\,(V_D) - Num\,(V_R)}{Num\,(V_D)}. \tag{10}$$

where $Num\,(V_D)$ is the indication number that set V_D passes, and $Num\,(V_R)$ expresses the indication number that set V_R passes. With comparisons, the ω can reflect that with CD-VWNs scheme, the coverage ratio of the code disseminators can be improved to a large scale in the vehicular networks.

Moreover, for the set of codes i, it is necessary to consider the dissemination quality after being delivered by the vehicular disseminators. If the set of vehicular disseminators has been determined, then the quality of the code dissemination processes is related to the length of program codes. Different lengths of codes can result in different dissemination quality. The quality of a set of codes i has a relationship with the times that the vehicular disseminators pass through. The length of the codes is an important influence factor.

To evaluate the performances of the CD-VWNs scheme comprehensively, $\mathcal{Z}_r$ is defined according to the benefit factor in Equation (9) and the coverage factor in Equation (10). The calculation method of the evaluations $\mathcal{Z}_r$ is shown in Equation (11).

$$\mathcal{Z}_r = \frac{2 \times \varphi_r \times \omega_r}{\varphi_r + \omega_r}. \tag{11}$$

In Equation (11), metric $\mathcal{Z}_r$ combines metric (9) and metric (10). Therefore, according to Equation (11), the performance and effectiveness of the CD-VWNs scheme can be evaluated comprehensively.

B. EXPERIMENT RESULTS

1) GEOGRAPHICAL INDICATIONS

Via the historical geographical datasets of the T-Drives, the total trajectory map of Beijing can be obtained, which is shown in Fig. 5. In the Fig. 5, the deeper color represents the denser classes and the lighter color represents the sparse classes. Based on the map of the geographical waypoints and the division classes $\mathbb{C}_i = \{C_1, C_2, C_3\}$ of Beijing, we select several geographical indications in the map. In class C_1, twenty waypoints are selected as indications; in class C_2, fifteen waypoints are selected as indications; and in class C_3, we randomly select ten waypoints as geographical indications to represent Beijing. Via simulations, we randomly selected 45 geographical points in general as the indication set L. The distribution graph of indication set L is shown in Fig. 6.

Fig. 6 shows the distributions of 45 geographical indications. The coordinates of those points are shown in Table 2.

When plotting the trajectories of each vehicle, some datasets of the vehicles are very sparse because the GPS signal is weak. Therefore, this type vehicle will be filtered out because their sparse datasets cannot provide sufficient trajectory information.

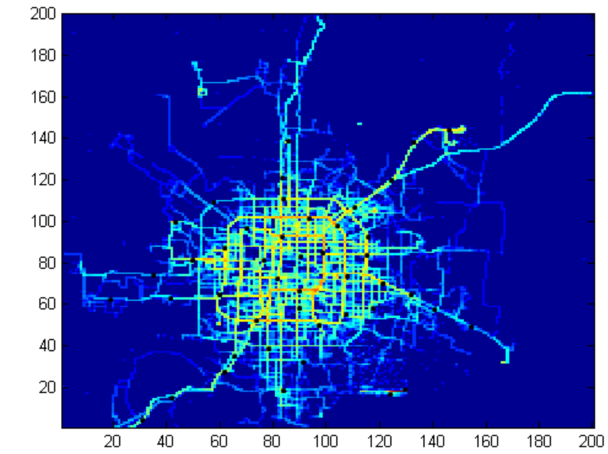


FIGURE 6. Distribution graph of set L.

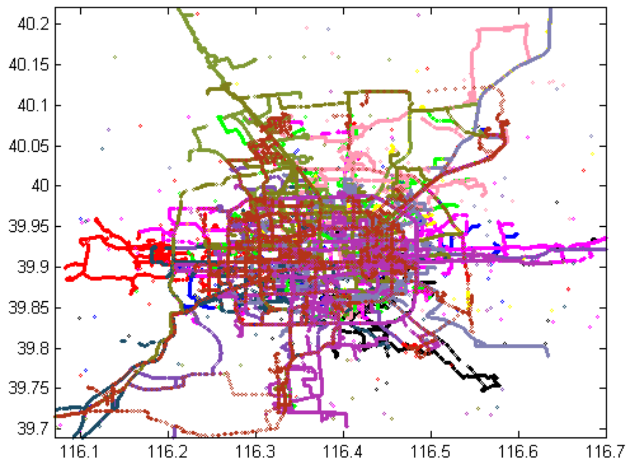


FIGURE 7. Historical map of fourteen disseminators with CD-VWNs scheme.

2) IMPROVEMENTS OF COVERAGE RATIO BASED ON CD-VWNs SCHEME

In the simulations, according to the realistic situations, the divisions of $\mathbb{C}_i$ is shown below.

$$\mathbb{C}_i = \begin{cases} C_1, & \textit{the urban regions} \\ C_2, & \textit{the regions between } C_1 \textit{ and } C_2 \\ C_3, & \textit{the suburb regions} \end{cases} \tag{12}$$

For Beijing, $\mathbb{C}_i$ can be divided via the observations into three parts according to the density distributions. The value of latitude for C_1 class is between 39.85 and 40, the value of longitude is between 116.25 and 116.45. The latitude of C_2 is divided from 39.8 to 39.85 and 40 to 40.05, and the longitude is from 116.45 to 116.5 and 116.2 to 116.25.

Via the CD-VWNs scheme, with the indication set L and the coverage factor, the coverage ratio of all of the vehicles in the datasets can be derived. In this Section, we only consider the phenomenon that the codes can be delivered once; the influence of the length factor of codes is discussed in the 6.3.4 Section. Based on the divisions of Beijing, the coverage ratio of the vehicles in the historical datasets. Several vehicles with the top coverage value will be selected as the disseminators to transmit program codes to sensing applications in a city. The trajectories of the selection set of vehicular disseminators can cover all of Beijing, which is shown in Fig. 7. With selection, the coverage factor of disseminator set can approach 100%, which indicates that set V_D cover the most regions of Beijing. Therefore, the codes can be disseminated to the most regions in the VWNs. In the experiments, there are fourteen vehicles in the dissemination set.

Fig. 7 shows that with selection, the disseminator set can cover more regions. On the basis of coverage, fourteen vehicles are chosen in a random manner to show the performances of CD-VWNs scheme. Fig. 8 indicates the historical trajectories of the fourteen-disseminator set without CD-VWNs scheme.

TABLE 2. Coordinates of garbage cans.

INDICATIONS	Y	X
1	39.92319	116.2555
2	39.9232	116.2566
3	39.96965	116.2987
4	39.92319	116.257
5	39.92291	116.2536
6	39.92275	116.23881
7	39.92271	116.24906
8	39.92189	116.32047
9	39.92221	116.31379
10	39.93154	116.37711
11	39.92249	116.36
12	39.92243	116.356
13	39.899	116.252
14	39.89575	116.256
15	39.89573	116.2756
16	39. 8571	116.4473
17	39.9315	116.3707
18	39.87731	116. 447
19	39.92171	116.3278
20	39.92179	116.3349
21	39.92332	116.28221
22	40.06301	116.5742
23	39.8341	116.2133
24	39.88538	116.39368
25	39.81425	116.21975
26	39.83239	116.2216
27	39.82065	116.2482
28	39.81	116.2337
29	39.8217	116.50077
30	39.83558	116.49825
31	39.81932	116.30416
32	39.84997	116.41106
33	39.8325	116.43164
34	39.81	116.5
35	39.84734	116.45925
36	39.88315	116.46
37	39.897	116.47913
38	40.0515	116.23733
39	39.98052	116.50991
40	39.83	116.41984
41	40.07726	116.33092
42	40.10397	116.52
43	40.10211	116.26359
44	39.825	116.2215
45	39.88793	116.53147

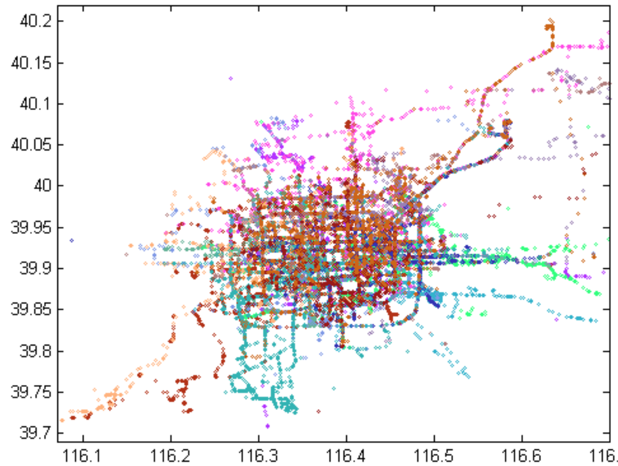


FIGURE 8. Historical map of fourteen disseminators without CD-VWNs scheme.

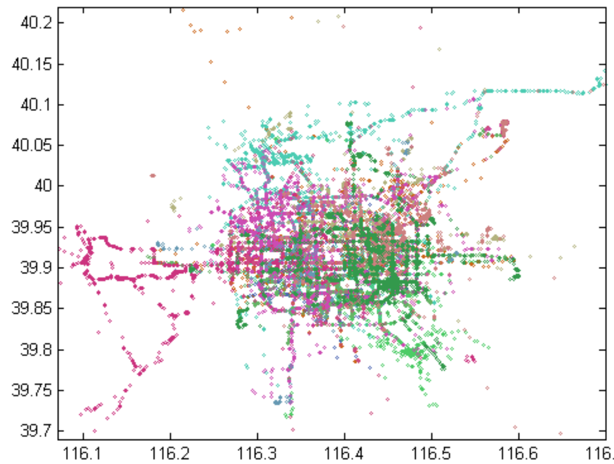


FIGURE 9. Trajectory map of fourteen randomly vehicular disseminators.

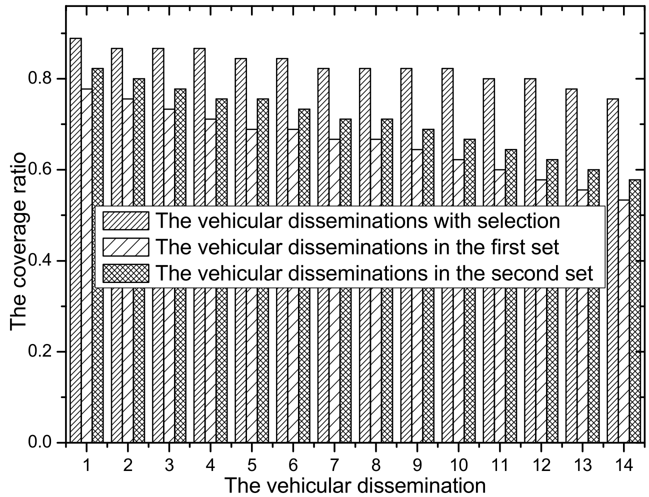


FIGURE 10. Comparisons of the coverage ratio for each vehicular disseminator.

In Fig. 8, the disseminator set can cover 32 geographical indications. Thus, via calculations, the coverage of this set is 71.11%, which is less than that of the dissemination set with CD-VWNs scheme by approximately 29.89%.

On the basis of coverage factor, to further demonstrate the effectiveness of the vehicular disseminators with selection model in CD-VWNs scheme, another disseminator set is randomly chosen to have a comparison with the former one. The trajectory map of V_R is shown in Fig. 9. In Fig. 9, the number of geographical indications that the set of random vehicular disseminators covers is 33. Via calculations, the second disseminator set without CD-VWNs scheme can cover 73.33% approximately, which is less than that of the selected vehicular dissemination set by approximately 26.67%.

In general, without selection models, the mean coverage rating of those two sets is approximately 72.22%. Via experiments with the CD-VWNs scheme, the coverage factor of the disseminator set can result in an improvement of approximately 27.78%.

From the comparisons in Fig. 7, Fig. 8 and Fig. 9 and based on the CD-VWNs scheme, the coverage ratio of the vehicular dissemination set with selection increases because with selection, the vehicles with the highest coverage ratio are chosen as the disseminators to transmit the codes. A set of vehicles is chosen to go through the indications in the set L. Therefore, the set V_D can achieve more coverage ratio.

With the CD-VWNs scheme, the program codes can be transmitted to the most regions of Beijing by the set of vehicular disseminators in the VWNs. For the three sets of vehicular disseminators, based on Equation (7), the comparisons of coverage ratio of each vehicle are shown in Fig. 10.

In Fig. 10, based on the CD-VWNs scheme, there is an increasing tendency on the coverage ratio of the disseminator set, compared with the set of vehicular disseminators with random selection. This increase proves the efficiency of the CD-VWNs scheme because the vehicles with the highest value of coverage ratio are selected to form into the vehicular dissemination set. The CD-VWNs scheme selects vehicles as disseminations via the historical trajectory datasets. After training the datasets, the set of vehicular disseminations can be decided. Therefore, the vehicular dissemination set can satisfy the time demands.

3) IMPROVEMENT RATIO OF THE BENEFITS BASED ON CD-VWNs SCHEME

In the previous distribution scheme of benefits, the BS will pay each vehicular disseminator the same benefits; in other words, each vehicular disseminator will receive the same rewards regardless of where they travel. That approach might result in fewer vehicles passing through the suburban regions, and the program codes could not be delivered to the sensing applications in the suburban regions. Thus, in the CD-VWNs scheme, the benefits of a vehicular disseminator are distributed according to the density. Via the CD-VWN scheme, the benefits of a disseminator have relationship with region

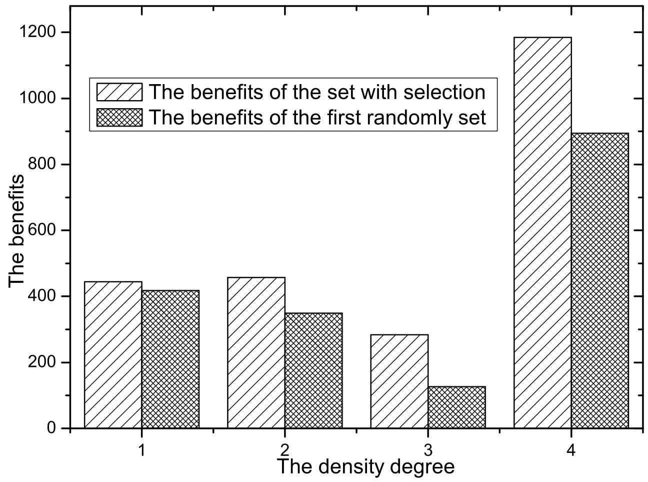


FIGURE 11. Comparisons of the benefits.

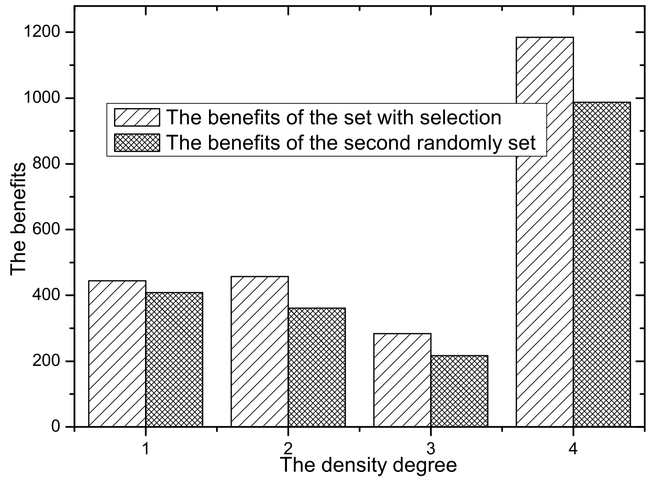


FIGURE 12. Comparisons of the benefits.

division $\mathbb{C}_i$. Via the realistic situations, Beijing will be divided into three regions based on the density degrees. Thus, on the basis of the region divisions, the benefits of each division class are different, as shown below:

$$\mathcal{Q} = \begin{cases} 80, & \textit{the costs of DC in the density class } C_1 \\ 110, & \textit{the costs of DC in the density class } C_2 \\ 150, & \textit{the costs of DC in the density class } C_3 \end{cases}$$

Thus, according to the historical trajectories of each vehicle and the value of $\mathcal{Q}$, the benefits of each vehicle (also known as the costs of the BS for each vehicle) in the dissemination set can be derived. For each density degree, the benefits of the selection set of vehicular disseminators are compared with that of the first random dissemination set; the comparisons are shown in Fig. 11.

Fig. 11 shows that in the urban regions, the benefits of the vehicular set with selection are similar to those of the first randomly selected set because almost every vehicle will pass through the urban regions. Moreover, the benefit gaps of sets C_2 and C_3 are growing larger. To encourage the vehicular disseminators traveling across suburban regions and to improve the coverage ratio, it is necessary to improve the benefits in the suburban regions. In general, compared with the first randomly selected set, the dissemination set with selection can improve the benefit ratio by 24.549%.

To prove the advantages of the CD-VWNs scheme, we then choose another disseminator set without utilizing the CD-VWNs scheme. The benefit comparisons are shown in the Fig. 12.

The tendency in Fig. 12 is the same as that in Fig. 11, indicating that with the CD-VWNs scheme, the disseminations can improve the benefit ratio. To summarize, the benefits of the dissemination set with selection can be increased by 16.673%, compared with other disseminator sets. In general, based on the CD-VWNs scheme, the benefits of disseminator set can result in an improvement of 20.611%.

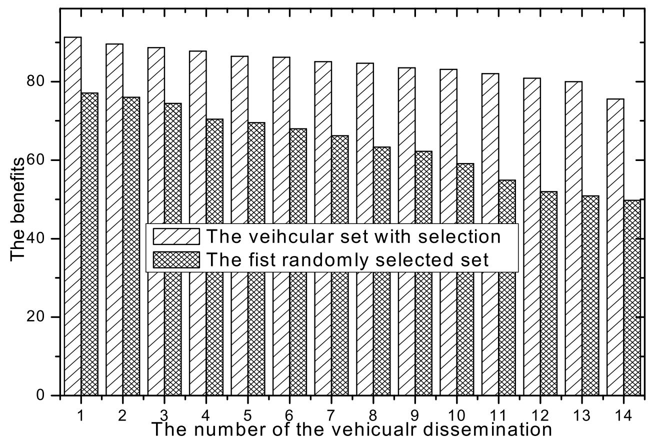


FIGURE 13. Comparisons of the benefits for each vehicular disseminator.

On the basis of a disseminator in different selection manner, the comparisons are shown in Fig. 13.

Fig. 13 shows that with the CD-VWNs scheme, the value of benefits for a disseminator in the V_D are more than that of a disseminator in a random vehicular dissemination set. It is because the benefits distributed in the suburban regions are more than those in the urban regions. Therefore, to achieve more benefits, more vehicles tend to come across the suburban regions if they are convenient. Therefore, the benefits of each vehicular disseminator in the CD-VWNs scheme are more than those without selections.

Moreover, the benefits of each vehicular disseminator in the V_D are compared with those of each vehicular disseminator in the second randomly selected set; the comparisons of benefits are shown in Fig. 14.

In Fig. 14, the tendency of benefits is the same as that in the Fig. 13. This difference exists because the disseminator set with the CD-VWNs scheme can reach the suburban regions, and the benefits in the suburban regions are greater than are those in the urban regions. Therefore, they can obtain more benefits compared with the vehicles traveling more in urban regions.

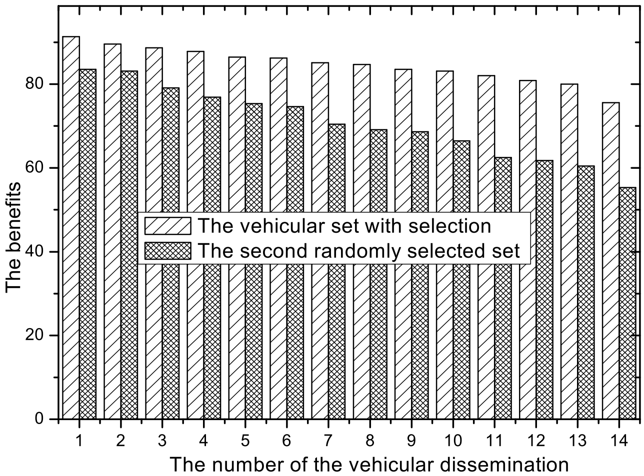


FIGURE 14. Comparisons of the benefits for each vehicular disseminator.

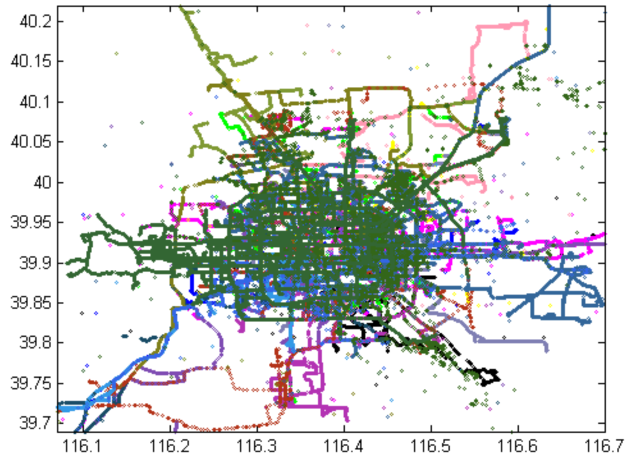


FIGURE 15. Historical map of disseminators with CD-VWNs scheme when $\mathcal{S}_i = 2$.

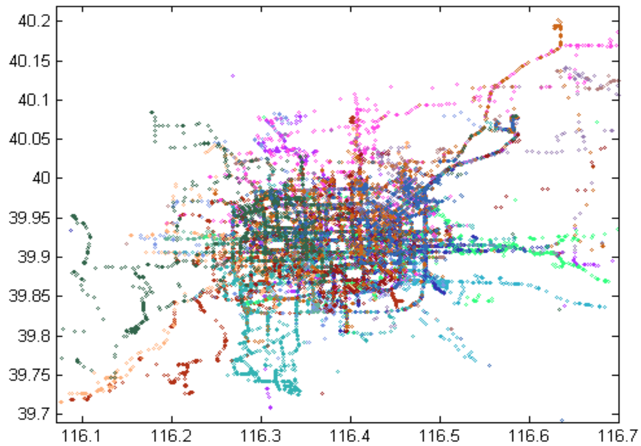


FIGURE 16. Historical map of disseminators without CD-VWNs scheme when $\mathcal{S}_i = 2$.

Moreover, via the CD-VWNs scheme, the set of disseminators with selection can achieve more benefits, compared with other disseminator sets. According to the CD-VWNs scheme, vehicles with the maximum coverage ratio are determined as disseminators. Those vehicles tend to pass through the suburban regions more. Moreover, to encourage the vehicles passing through the suburban regions to disseminate the codes, the benefits in the suburban regions are high. Therefore, the CD-VWNs scheme can improve the benefits of the vehicular disseminators.

4) INFLUENCE FACTOR OF LENGTH OF THE CODES

In the CD-VWNS scheme, the length of program codes is an important factor that can influence the quality of dissemination processes. In the above subsections, we assume that a set of codes can be disseminated once. Therefore, the vehicular disseminator passing sensing applications such as the garbage cans once indicates that the program codes have been delivered to the garbage cans. However, in reality, the program codes might not be transmitted in one pass because of the length factor. Moreover, because of the mobility characteristic in the VWNs, the speed of the vehicular disseminators determines the lengths of codes that could be delivered once. In the experiments, we define that the speeds of the vehicular disseminations are the same. Therefore, if they pass near a garbage can, the length of program codes that they can disseminate is the same. The experiments in the subsections above assume that a set of codes can be delivered once.

In this subsection, the influence factor—length of codes—is considered. The speed of each vehicular disseminator is the same; therefore, if the length of the program codes is longer than the length that a vehicular disseminator could deliver once, then this code will be divided into several segments $\mathcal{S}_i$. In this paper, we do not concentrate on the content of the program codes. Therefore, for example, a set of codes is divided into two segments. Then, two vehicle disseminators passing near a garbage can means that the garbage can has received the set of program codes. The greater the number of division segments, the more disseminations were required to transmit program codes.

Thus, the extra experiments are performed based on $\mathcal{S}_i = 2$ and $\mathcal{S}_i = 3$. When $\mathcal{S}_i = 2$, based on the CD-VWNs scheme, the historical trajectory graph of the disseminator set is shown in Fig. 15.

In Fig. 15, with selection, sixteen vehicles are chosen as the disseminators when the number of segments $\mathcal{S}_i = 2$. This dissemination set can cover 100%. There are 45 geographical indications in set L, which means that the number of garbage cans is 45. With the CD-VWNs scheme, each garbage can will be covered at least twice by the vehicular disseminations; therefore, the set of program codes can be delivered to the garbage cans. Based on the previous scheme, sixteen vehicles are randomly selected to form into the dissemination set. The trajectory map of the randomly selected set is shown in Fig. 16.

When $\mathcal{S}_i = 2$, the comparisons of benefits are shown in the Fig. 17. It can be seen that the benefits of CD-VWNs scheme are better than those of the previous scheme.

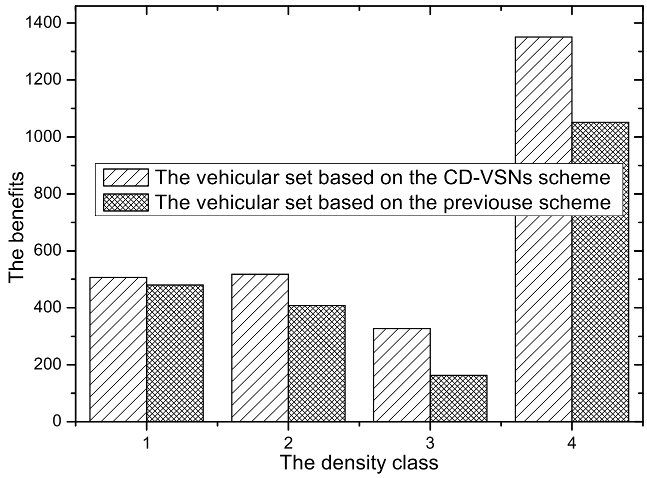


FIGURE 17. Comparisons of benefits when $\mathcal{S}_i = 2$.

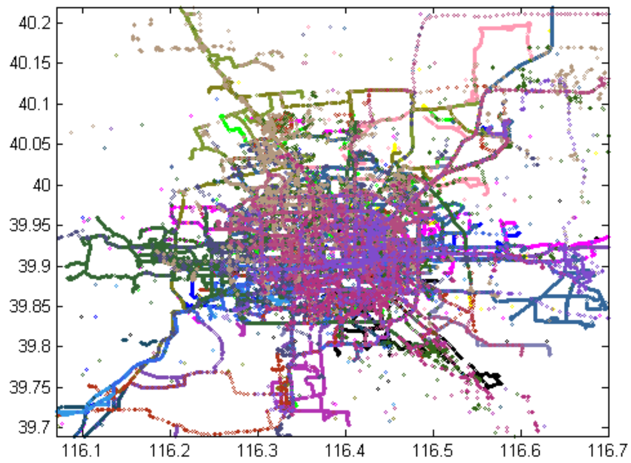


FIGURE 19. Trajectory map of the vehicular set with selection when $\mathcal{S}_i = 3$.

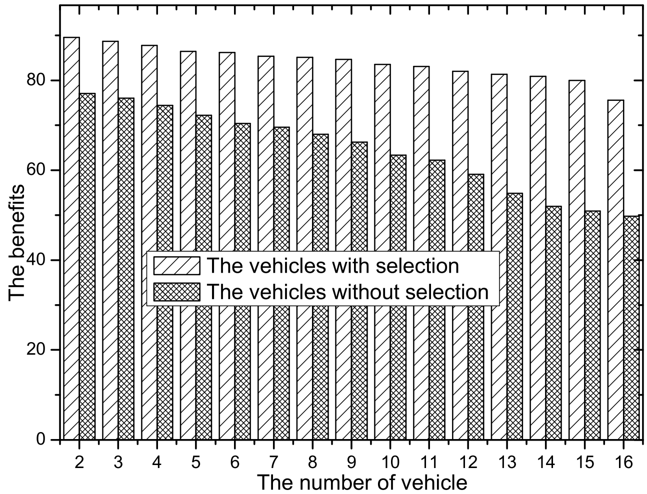


FIGURE 18. Comparisons of benefits of each vehicular disseminator when $\mathcal{S}_i = 2$.

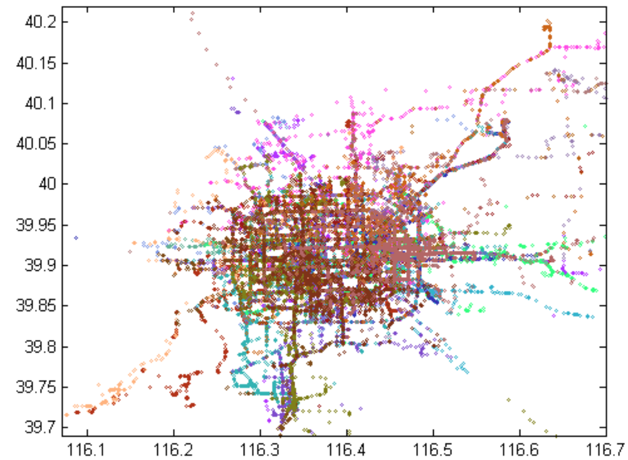


FIGURE 20. Historical map of disseminators without CD-VWNs scheme when $\mathcal{S}_i = 3$.

The benefits of each vehicular disseminator with selection are compared with those of each vehicular disseminator without selection; the comparisons are shown in Fig. 18.

Fig. 18 shows that the benefits of the vehicles with selection are higher than are those of the vehicles without selection, which shows the efficiency of the CD-VWNs scheme.

To prove the advantages of the CD-VWNs methods, when $\mathcal{S}_i = 3$, the coverage ratio and benefit factor of the disseminator set with selection are compared with the other disseminator sets. Based on the CD-VWNs scheme, the general map of the disseminators set is shown in Fig. 19.

When the value of $\mathcal{S}_i$ is 3, to cover each garbage can at least three times, twenty vehicles are selected as the disseminators, as shown in Fig. 19. When the value of $\mathcal{S}_i$ increases, the number of disseminators required to transmit the program codes will increase. The main issue is how to cover the garbage cans in the suburban regions. Based on the CD-VWNs scheme, vehicular disseminators are selected according to the coverage ratio of each vehicle. Therefore, with selection, the vehicles with the highest value of coverage ratio are selected to form into the set. With the CD-VWNs scheme, the codes can be delivered to 45 garbage cans completely. The coverage ratio is 100%. Based on the previous schemes, the trajectory map of twenty vehicles with random selection is shown in Fig. 20.

In Fig. 20, the coverage ratio of the disseminators without CD-VWNs scheme is clearly lower than that of V_D. When $\mathcal{S}_i = 3$, the set of vehicular disseminators without selection can cover 30 garbage cans. If a garbage cannot be passed by at least three times, then the set of program codes will not be delivered to this garbage can successfully because of its incompleteness. When $\mathcal{S}_i = 3$, the disseminator set can cover 66.67% regions of Beijing, lower than when $\mathcal{S}_i = 2$. With the segments $\mathcal{S}_i$ increasing, some program codes cannot be delivered to the garbage cans completely. That phenomenon is considered failure in our paper. However, with the CD-VWNs scheme, the vehicles with selection can cooperate with each other to pass near the garbage cans to deliver the

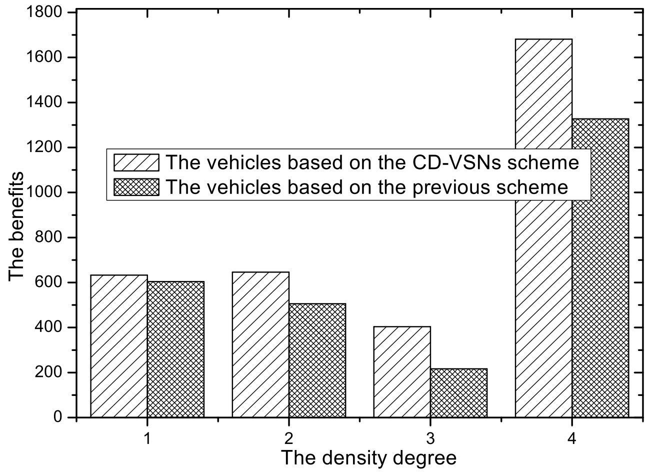


FIGURE 21. Comparisons of benefits when $\mathcal{S}_i = 3$.

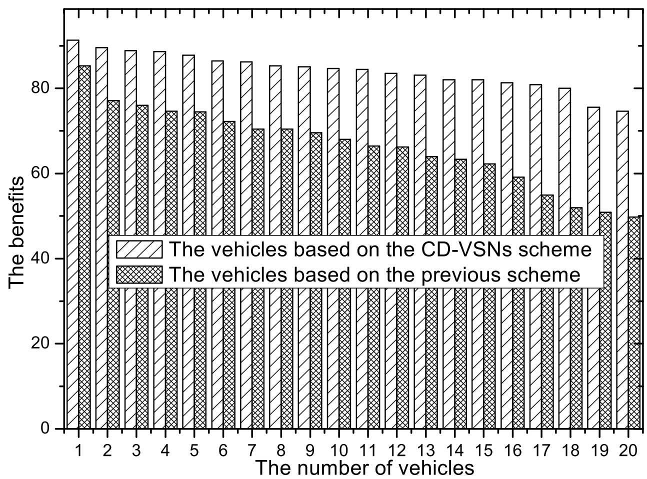


FIGURE 22. Comparisons of benefits of each vehicular disseminator when $\mathcal{S}_i = 3$.

code segments successfully. Then the benefits of the two-disseminator set are compared; the comparisons are shown in Fig. 21.

Fig. 21 shows that the benefits of the vehicular disseminators with selection are greater than are those without selection. The tendency of the benefits in Fig. 21 for each density class is the same as the tendency in Fig. 17. A comparison of benefits is shown in Fig. 22 for each vehicular disseminator as follows.

To summarize, when $\mathcal{S}_i$ is 3, based on the CD-VWNs model, the dissemination set V_D can obtain more rewards by 21.078% approximately, compared with those of the dissemination set based on the previous schemes.

In addition, the program code length is a significant issue, which can influence the performance of the code disseminations in the VWNs. In this subsection, based on different values of $\mathcal{S}_i$, the performance of the CD-VWNs scheme is evaluated and compared with the previous vehicular selection schemes. The comparison shows the efficiency of the CD-VWNs scheme. With the value of $\mathcal{S}_i$ increasing, the

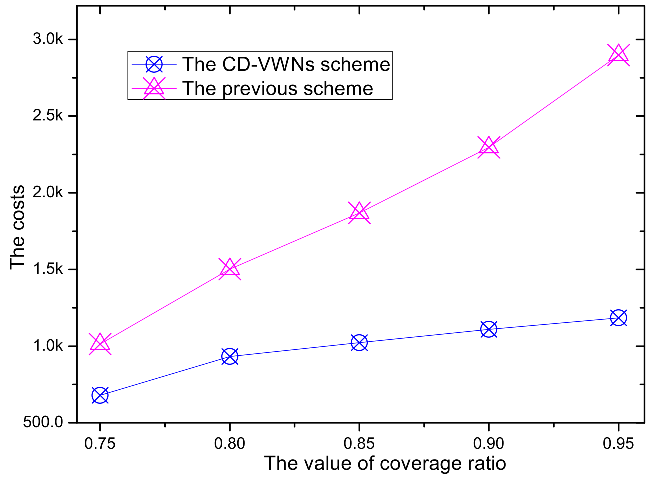


FIGURE 23. Comparisons of the BS' costs.

coverage ratio of the vehicular dissemination set based on the previous schemes might decrease. Although based on the CD-VWNs scheme, the coverage ratio of the vehicle dissemination set can remain stable, which reflects the effectiveness of the CD-VWNs scheme.

In addition, the performances of the costs are evaluated to prove the efficiency of proposed scheme. To achieve the performances, the costs of CD-VWNs scheme are less than the previous scheme according to the experimental results. In the previous schemes, the vehicles are randomly chosen as disseminations. Therefore, to achieve the coverage ratio in the CD-VWNs scheme, the previous scheme need to choose more vehicles. Thus, the costs of BS will increase. The comparisons are shown in the Figure 23.

In the Fig. 23, to reach a similar coverage ratio, the costs of BS in the CD-VWNs scheme are smaller than those in the previous scheme. In the previous scheme, the vehicles are chosen based on the trajectory length or random selection. Thus, this will influence the coverage ratio of the information. With the value of coverage ratio increases, the gap between those two selection methods increases. It is because that, the suburb regions are difficult to be covered. With the coverage ratio increases, the CD-VWNs scheme can observe the vehicles which have more probability to come across those regions which aren't covered yet. The vehicles chosen as disseminators have directive characteristic in the CD-VWNs scheme. However, the regions that the random-selection vehicular disseminators cover cannot be predicted and controlled. Therefore, redundant disseminators are chosen to transmit the program codes. The costs of BS will markedly increase. With the value of coverage increasing, the value of costs is stable based on the CD-VWNs scheme, which means the CD-VWNs scheme can choose less vehicles to reach more coverage areas. The comparisons of BS's costs indicate the efficiency of the proposed scheme.

5) PERFORMANCE OF THE CD-VWNs SCHEME

In this subsection, on the basis of factor of coverage and factor of benefit, the CD-VWNs scheme is evaluated

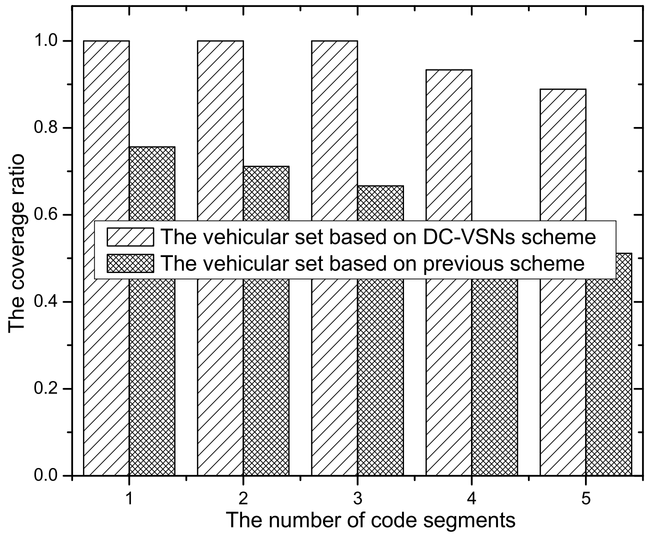


FIGURE 24. Coverage ratio of the vehicular set when $\mathcal{S}_i = 1, 2, 3, 4, 5$.

TABLE 3. Experimental results of ω_r, φ_r, $\mathcal{Z}_r$.

Evaluation	$\mathcal{S}_i = 1$	$\mathcal{S}_i = 2$	$\mathcal{S}_i = 3$	$\mathcal{S}_i = 4$	$\mathcal{S}_i = 5$
ω_r	0.244	0.28889	0.3333	0.35333	0.3778
φ_r	0.21078	0.21078	0.21078	0.21078	0.21078
$\mathcal{Z}_r$	0.22617	0.24373	0.25824	0.26404	0.270593

comprehensively. With the CD-VWNs scheme, the two factors of the disseminators can be improved on a large scale, based on different values of $\mathcal{S}_i$. The program codes can be transmitted to most garbage cans distributed in a city; thus, the benefits of the vehicular disseminators have increased, compared with those of the vehicular disseminators without utilizing the CD-VWNs scheme. With the value of $\mathcal{S}_i$ increasing, on the basis of the previous selection model, the efficiencies of the vehicular disseminators will remain stable or even degrade because some program codes cannot be delivered to the garbage cans completely.

In this section, we utilize the set of vehicular disseminations when $\mathcal{S}_i = 3$ to evaluate the performances of the CD-VWNs scheme. Based on the value of $\mathcal{S}_i = 1$, $\mathcal{S}_i = 2$, $\mathcal{S}_i = 3$, $\mathcal{S}_i = 4$ and $\mathcal{S}_i = 5$, the coverage ratio of the dissemination set based on the CD-VWNs scheme is compared with that of the dissemination set with the previous methods, as shown in Fig. 24.

Fig. 24 shows that with the number of segments $\mathcal{S}_i$ increasing, the tendency of coverage for the disseminator set on the basis of the previous schemes will decrease. However, based on the CD-VWNs scheme, the coverage factor of the disseminator set will remain stable to some extent, when the number of garbage cans is 45.

When the vehicular disseminators are defined, their benefits are the same.

Via Equation (7), under the coverage and benefit factor, the performances of the CD-VWNs is evaluated comprehensively. In general, via the selection models in the CD-VWNS scheme, the coverage ratio of program codes can result in an improvement of approximately 31.94%, and the benefits can result in an improvement of approximately 21.078%. The value of metric $\mathcal{Z}_r$ is improved by approximately 25.256%. Based on $\mathcal{S}_i = 1, 2, 3, 4, 5$ respectively, the experimental results of ω_r, φ_r, and $\mathcal{Z}_r$ are evaluated, respectively. The evaluations are shown in Table 3 as follows.

VII. CONCLUSIONS

This paper proposed a novel approach to select mobile vehicles as disseminators to transmit program codes to applications with sensing devices, such as garbage cans or streetlamps, to update the information in them or to enrich their functions to provide people better services. The selection scheme can improve the coverage ratio of the program codes and let the sensing applications in the suburban regions receive the information timely. This approach can reduce the loss phenomenon in an effective manner, keep the entire system reliable and survivable and encourage the vehicular disseminators to pass through the suburban regions. Based on the density degree, the benefits of disseminators differ from degree to degree. In addition, the set of vehicular disseminators based on the CD-VWNs scheme travel more in the suburban regions, compared with the set based on the previous schemes. Thus, via disseminating program codes, the benefits of the vehicular disseminators can be improved. The simulation results demonstrated that the CD-VWNs scheme can overcome the weaknesses of existing disseminator selection models as well as obtaining better performances, which have achieved the original expectations and purposes. The proposed selection CD-VWNs scheme is implemented on the basis of real-world datasets. With the CD-VWNs scheme, both the benefits and the coverage ratio can be improved. Additionally, the CD-VWNs scheme can satisfy the demands of the BS to expand the coverage regions of the program codes. Future work will include considering the routing factor in VWNs.

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