Periodic Sweep Coverage Scheme Based on Periodic Vehicle Routing Problem

Li Shu [1], Ke-wei Cheng [1], Xiao-wen Zhang [2], and Ji-liu Zhou [1*]
1. School of Computer Science, Sichuan University, Chengdu, China
2. Dept. of Computer Science, College of Staten Island / CUNY, New York, USA
[*]Corresponding author, Email: shuli@scu.edu.cn, chengkw@scu.edu.cn, xiaowen.zhang@csi.cuny.edu, zhoujl@scu.edu.cn

***Abstract*—We provide a sweep coverage algorithm for routing mobile sensors that communicate with a central data sink. This algorithm improves on its predecessors by reducing the number of unnecessary scans when different points of interest (POIs) have different requirements for the time interval within which they must be scanned (sweep period). Most sweep coverage algorithms seek to minimize the number of sensors required to cover a given collection of POIs. When POIs have different sweep period requirements, existing algorithms will produce solutions in which sensors visit some POIs much more frequently than is necessary. We define this as the POI Over-Coverage problem. In order to address this problem we develop a Periodic Sweep Coverage (PSC) scheme based on a well-known solution to the Periodic Vehicle Routing Problem (PVRP). Our algorithm seeks a route for the mobile sensors that minimizes the number of unnecessary visits to each POI. To verify and test the proposed scheme we implemented a C++ simulation and ran scenarios with a variety of POI topologies (number and distribution of the POIs) and the speed at which sensors could travel. The simulation results show that the PSC algorithm outperforms other sweep coverage algorithms such as CSweep and Vehicle Routing Problem Sweep Coverage (VRPSC) on both the average number of sensors in a solution and in the computational time required to find a solution. Our results also demonstrate that the PSC scheme is more suitable for the sweep coverage scenarios in which higher speed mobile sensors are used.**

***Index Terms*—Wireless Sensor Networks; Sweep Coverage; Coverage Control; Period Vehicle Routing Problem**

I. Introduction

The coverage problem is one of the fundamental challenges in wireless sensor networks (WSNs). In a WSN the coverage affects not only the quality of service, but the task performance as well [1]. Therefore, the coverage problem has attracted the extensive attention of researchers since the inception of WSN. Researchers have suggested numerous coverage schemes for various application scenarios. Based on the different coverage objectives, these traditional schemes are usually classified into three categories: area coverage [2], barrier coverage [3], and point coverage [4]. For the most part, these schemes realize the uninterrupted continuous coverage or monitoring of the targets through the collaboration of the sensor nodes.

Further study of WSN technologies and applications shows that in the situations like forest fire prevention, battlefield patrol, and other application scenarios the incidents are easier to be triggered in some places than in other monitoring areas. For example, some places are prone to fire in a forest, and certain locations are strategically significant in a battlefield. Such places or locations which are subject to frequent incidents are called the points of interest (POIs). In these scenarios, sensor nodes only need to cover the POIs in some given time intervals to ensure the information perception and acquisition of the monitoring points. Obviously, it is a waste of network resources if we deploy a huge number of stationary sensor nodes at all POIs for the complete coverage.

A. Sweep Coverage and Related Works

By introducing the mobile sensor nodes and controlling their movement strategically to guarantee the periodic coverage of the POIs, the number of sensor nodes and node resources can be dramatically reduced. To address these application requirements, Cheng et al [5] and Xi et al [6] first introduced the concept of sweep coverage in WSN. To meet the POIs' coverage intervals, the sweep coverage aims to effectively and efficiently control the mobile sensor nodes for the periodical visits to the POIs, to ultimately reduce the number of sensors and the application cost.

Sweep coverage in WSN utilizes the mobility of the mobile sensor nodes to cover the POIs periodically in order to reduce the total number of sensor nodes and the overall network cost. In sweep coverage scheme designs, therefore, the major research foci are on how to generate and schedule the moving paths for mobile sensors and how to use as few mobile sensors as possible to meet all POIs coverage requirements. The task of determining the minimum number of sensor codes to meet the POIs' coverage requirements is known as the min-sensor sweep-coverage problem [6]. In solving the min-sensor sweep-coverage problem the number of mobile sensors is used as a main performance measure. By reducing the travelling salesman problem (TSP) to it [5, 6], the min-sensor sweep-coverage problem is proved to be NP-hard.

With the advent of the sweep coverage, researchers quickly realized that there was now a totally new

doi:10.4304/jnw.9.3.726-732

coverage problem. Sweep coverage has become an active area of research in WSN coverage control technology. There are already quite a few sweep coverage schemes proposed in the literature. A centralized mobile sensors control scheme CSweep (centralized sweep) and a distributed mobile sensors scheme DSweep (distributed sweep) are proposed in [5] and [6], respectively. Using the polynomial-time approximation scheme (PTAS) algorithm CSweep calculates a shortest path that traverses all POIs. And then CSweep divides the path into equal-length segments. The POIs in each segment are covered by a mobile sensor moving back and forth. DSweep is an algorithm that uses only local information. Each time information is collected at a POI, the mobile sensor decides and chooses the next POI to move to according to its local coverage information. A distributed sweep coverage scheme based on local gradients is proposed by Xi et al [7], in which the static sensors are placed at POIs. When the sensors detect the occurrence of an incident at their POI, the sensors increase their gradients, and broadcast them to the neighbor sensors at the same time. The gradient of a static sensor is the sum of the gradients of all its static neighbor sensors.

Towards the POI, a mobile sensor moves from lower to higher gradient static sensor nodes, and collects information from the static nodes. To improve the CSweep scheme results Du et al [8] proposed two different path creation algorithms, called MinExpand and OSweep, to create the moving paths for mobile sensors in sweep coverage. Their simulation shows that, to a certain extent, these two approaches outperform CSweep. In an earlier study we proposed a vehicle routing problem based sweep coverage (VRPSC) scheme [9], in which we reduced the vehicle routing problem (VRP) to the min-sensor sweep-coverage problem to obtain the solution. We used the simulated annealing algorithm to create the moving paths of the mobile sensors. Given POI positions and coverage interval requirements, all aforementioned sweep coverage schemes will construct moving paths for the mobile sensors.

B. POI Over-coverage Problem

In the application scenarios of sweep coverage, it is typical that different POIs have different coverage requirements. For example, in the forest fire prevention WSN monitoring system which is based on sweep coverage technology, the POI coverage frequency in the bush fire prone area should be much higher than that of the other common areas. For another example, in the mountain landslide and debris flow monitoring system, which is also based on the sweep coverage, the POI coverage frequency should be higher in the geologically loose area caused by previous land collapses. We found that in sweep coverage the number of mobile sensors in the moving paths and the coverage frequency that mobile sensors visit are determined by the POI with the minimum required coverage interval.

Let us assume that in a sweep coverage a set of n mobile sensors $S=\{s_1,s_2,...,s_n\}$ are used to monitor k points of interest $P=\{p_1,p_2,...,p_k\}$ in a flat two-dimensional area with a sink node p_0. A POI p_i has a required coverage interval T_i, which means that the p_i is scanned at least once every T_i time interval by any mobile sensor. In a path shown in Figure 1, there are the three POIs p_1, p_2, p_3 with three corresponding required coverage intervals T_1, T_2, T_3. Without loss of generality, we assume that p_2 has the minimum required coverage interval T_2, and further suppose that the coverage intervals T_1 and T_2 satisfy the relation of $T_1 = mT_2$, where $m>1$.

Obviously, no matter how large the m is, the mobile sensors will cover the p_2 with the coverage frequency of $1/T_2$, and p_1 with the coverage frequency of $1/(mT_2)$. Given the coverage interval T_i of the POI p_i we define its coverage frequency as $1/T_i$. It is clear that the POI p_1 is over-covered, i.e., $(m-1)$ out of m times of coverage are not necessary, which may cause a huge waste of resources if m is a huge number. We call this the *POI over-coverage problem*. To our best knowledge, no existing sweep coverage schemes have addressed the POI over-coverage problem.

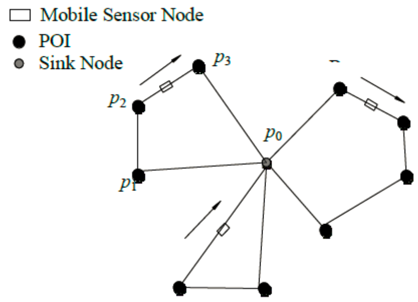

Figure 1. Moving paths of the mobile sensor nodes in sweep coverage

C. Our Contributions

We formally introduce the POI Over-Coverage Problem in sweep coverage. Based on the ideas of how to solving the Periodic Vehicle Routing Problem (PVRP) we propose the PSC scheme to resolve the POI over-coverage problem. We prove a theorem for dealing with assigning time slots to POIs. We design the POI time slot assignment algorithm in detail, and then use it in the PSC scheme implementation. We write a computer program in Microsoft Visual C++ to simulate and verify the PSC. Results show that in terms of the number of mobile sensors and the algorithm running time the PSC is better than other sweep algorithms, such as our VRPSC. VRPSC is better than CSweep [9]; therefore PSC is better than CSweep as well.

To the sweep coverage scenarios in which different POIs require different coverage intervals, this paper, starting from the periodic vehicle routing problem (PVRP) which is the extension of VRP, proposes the PSC scheme to solve the POI over-coverage problem in sweep coverage path planning. The rest of the paper is organized as follows. Section II illustrates the periodic sweep coverage scheme. Section III handles the time slot assignment algorithm for PSC. Section IV details the simulation of the PSC scheme and the results. And Section V concludes the paper.

II. Periodic Sweep Coverage Scheme

A. Review of PVRP Problem

First proposed by Beltrami and Bodin [10], the PVRP was another extension of the VRP on the service time. Standard VRP research focuses on the optimization of the customer service path within one day. The PVRP extends the time interval to T days, focuses on meeting customers' demand for T days' service frequency, and completes the service in the given T days. For a typical example of PVRP, in the process of logistics distribution, a large supermarket requires the delivery once a day, and a small grocery store needs the delivery only once a week. In the social and economic activities that require periodic service, the PVRP has been widely used. The common applications of PVRP include: waste collection [10], logistics distribution [11], elevator maintenance and repair [12], and vending machine and automated teller machine (ATM) replenishment [13], etc.

Compared with the standard VRP, in addition to the load constraint PVRP also defines a periodic access frequency constraint, namely, the number of accesses in a given time interval for satisfying every customer's requirement.

PVRP is essentially a multi-level optimization problem. There are already solutions to the PVRP [10-12]. In general a PVRP solution consists of two steps.

Step1: assign a customer to a certain day according to his service frequency requirement, thus obtaining the daily delivery combination within the period of T days.

Step2: dispatch vehicles for the daily delivery combination. Obviously, solving the problem in step 2 is to solve a standard VRP.

B. Basic Ideas of PSC Scheme

Based on the PVRP model, PSC, a sweep coverage scheme is proposed in this paper to solve the POI over-coverage problem. As shown by the above analysis, the POI over-coverage problem is caused by the different POI coverage intervals required by different POIs. As an extension of VRP, PVRP extends the planning period to T days. And within the T days, the PVRP completes service according to each customer's own required service frequency. Different customer with different service frequencies can be thought of as different POI with different coverage intervals. This inspires our study of PSC scheme in this paper.

By defining a coverage period, the PSC scheme converts the sweep coverage problem into a periodic coverage problem. It divides the coverage period into fixed time slots. From the required coverage intervals the coverage frequencies of the POIs can be calculated. Then the POIs with the same coverage frequency are assigned to one time slot. For the different POI combination in each time slot, the moving path of mobile sensors can be obtained by running the traditional sweep coverage algorithm. Figure 2 shows sample moving paths of mobile sensors in the PSC scheme with a coverage period of three time slots.

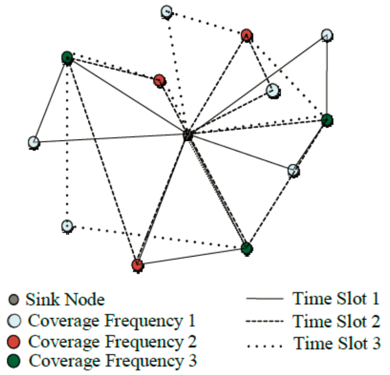

Figure 2. Sample moving paths of mobile sensors in the PSC scheme

PSC scheme assigns a POI to a given fixed time slot according to its coverage requirement in the network; creates different POI combinations for each time slot; carries out the path planning according to different POI combinations; and finally generates the moving paths for mobile sensors. The PSC scheme can not only effectively avoid the POI over-coverage problem, but also effectively reduce the scale of the problem involved in path creation algorithms. The problem scale reduction is done by transferring the one-time creation of the moving paths for all POIs into many creations of the moving paths for the subsets of different POIs in the network. These measures can assuredly reduce the running time of the algorithm and maybe the number of mobile sensors needed for completing coverage. The word "maybe" is used here because when a POI is assigned to a time slot, the POI coverage is required to be completed in this time slot. This shortens the POI coverage requirement. Therefore, some extra mobile sensors may be needed to complete the coverage for this POI.

C. Defining the Coverage Period

The coverage period occurs many times in the sweep coverage. The coverage period can be classified into three categories: single POI coverage period, path coverage period, and network coverage period. Here we will distinguish each one of them.

Single POI coverage period. In the sweep coverage, each POI p_i has its own coverage period. For example, if the periodic coverage requirement of POI is a time interval T_i, a mobile sensor must scan the p_i at least once every T_i.

Path coverage period. In the sweep coverage scheme, after the completion of the moving path planning for the mobile sensors, the mobile sensors periodically scan the POIs on the moving path. A path coverage period is a round-trip time interval in which a mobile sensor starts from a sink to scan the POIs on the path and then returns to the sink. The path coverage period is determined by the minimum single POI coverage period on the path.

Network coverage period. In order to solve the POI over-coverage problem in the sweep coverage scenarios where the different (single POI) coverage periods are required for the different POIs, we introduce the concept of network coverage period in the PSC scheme. By default, all the coverage periods discussed in this paper are the network coverage periods. We define the network coverage period as follows: under the condition of meeting all coverage requirements of all POIs, the time intervals in which all POIs in the network are scanned by at least one mobile sensor at least once. According to this definition, the length of the network coverage period L is:

$L \le \max(T_i),\ \ i = 1,...,N$

Obviously, for the sweep coverage scheme, once the moving path planning S of mobile sensor network in one coverage period is determined, in all future coverage periods the mobile sensors scan POIs according to the S.

In the sweep coverage scheme, it is inappropriate to use days as the time slot unit for the service or coverage period as what is in the PVRP. We can only create the coverage period according to different coverage requirements of POIs in the network in different application scenarios. In PSC scheme, we define the coverage period length L as:

$$L = m * \min(T_i) \quad (1)$$

where, m is the coefficient of the coverage period, and determined by the following equation:

$$m = floor(\frac{\max(T_i)}{\min(T_i)}). \quad (2)$$

Therefore, we have a coverage period of length L, which consists of m time slots, and the length of each time slot is $\min(T_i)$.

III. Time Slot Assignment Algorithm in PSC

After the completion of the coverage period creation, the POIs in the network need to be respectively assigned to the time slots according to the different coverage requirements. This will create different POI service compositions for different time slots.

First, we transfer the coverage interval requirements of POIs in the network into the coverage time slot intervals. For the POI $p_i\ (i \ne 0)$, its coverage time slot interval σ_i is:

$$\sigma_i = floor(\frac{T_i}{\min(T_i)}). \quad (3)$$

From the above definition, we can see clearly that $1 \le \sigma_i \le m$. To meet the coverage requirement one time slot within σ_i time slots must be assigned to the POI p_i. Then, in the coverage period of m time slots, the number of assigned time slots to $p_i\ (i \ne 0)$ is:

$$\rho_i = floor(\frac{m}{\sigma_i}). \quad (4)$$

Therefore, the time slot assignment algorithm for the POI $p_i\ (i \ne 0)$ is as follows. In a coverage period which builds m time slots, we pick up the α_i th slot from the first σ_i time slots as p_i's first time slot, then successively assign $\alpha_i + \sigma_i$, $\alpha_i + 2\sigma_i$,…, $\alpha_i + (\rho_i - 1)\sigma_i$ time slots to $p_i\ (i \ne 0)$. The time slots assignment to $p_i\ (i \ne 0)$ be shown in Figure 3.

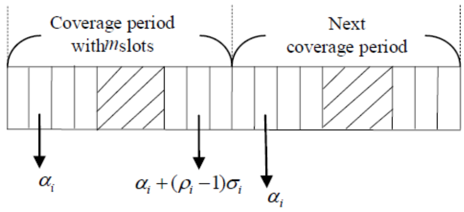

Figure 3. The time slot assignment in coverage period

However, if we consider two consecutive coverage periods (as shown in Figure 3) and if $m \bmod \sigma_i \ne 0$, it may occur that the interval between the last time slot $\alpha_i + (\rho_i - 1)\sigma_i$ of the first coverage period and the first time slot of the second coverage period is larger than σ_i.Therefore the coverage constraint of POIs cannot be guaranteed during these two time slots. When considering two consecutive coverage periods, the number of time slot during the interval between the first time slot assigned to p_i in the second coverage period and the last time slot assigned to p_i in the first coverage period can be expressed as follows:

$$\begin{aligned}&(m + \alpha_i) - (\alpha_i + (\rho_i - 1)\sigma_i)\\&= m - (\rho_i - 1)\sigma_i\\&= \rho_i\sigma_i + m\%\sigma_i - (\rho_i - 1)\sigma_i\\&= \sigma_i + m\%\sigma_i \ge \sigma_i\end{aligned}$$

Therefore, in order to ensure the coverage constraint of the POIs, if $m\%\sigma_i \ne 0$ (i.e., $m \bmod \sigma_i \ne 0$), a time slot must be assigned to p_i during the interval between the last time slot assigned to p_i in the first coverage period and the first time slot assigned to p_i in the second coverage period. Therefore, we correct formula (4) as follows:

$$\rho_i = ceil(\frac{m}{\sigma_i}) \quad (5)$$

Theorem: In PSC time slot assignment, when POI p_i meets the condition $m\%\sigma_i \ne 0$, the last time slot assigned to p_i in the coverage period can be chosen arbitrarily between $[m - (\sigma_i - \alpha_i), m]$ and $[1, \alpha_i + (\rho_i - 1)\sigma_i - m]$.

Prove:

If the condition $m\%\sigma_i = 0$ holds for the POI p_i, by the equation (5) we have $\rho_i = m / \sigma_i$. It follows that the number of time slots between the time slot $\alpha_i + (\rho_i - 1)\sigma_i$

in the first coverage period and the time slot α_i in the second coverage period is always σ_i. Therefore, for such POI the last time slot assigned in each coverage period must be $\alpha_i+(\rho_i-1)\sigma_i$.

For the POI p_i meeting the condition of $m\%\sigma_i \neq 0$, by the time slot assignment algorithm, it follows that the purpose of assigning the last time slot is to meet the condition that there is no contrary to the coverage constraint of POI during the two consecutive coverage periods. Let x th slot ($x \le m$) be the current time slot.

When considering two consecutive coverage periods, x must be in between the time slot $\alpha_i+(\rho_i-2)\sigma_i$ of the first coverage period and the time slot α_i of the second coverage period. Thus, the range of x is bounded in the following range

$$\alpha_i+(\rho_i-2)\sigma_i < x \le m \text{ or } 1 \le x < \alpha_i$$

By the equation (5) and the POI assignment algorithm, when $m\%\sigma_i \neq 0$, the following relations always hold:

$$\begin{cases} m-(\alpha_i+(\rho_i-2)\sigma_i) < \sigma_i \\ \alpha_i \le \sigma_i \end{cases}$$

Because of $\alpha_i+(\rho_i-2)\sigma_i < x \le m$, according to the above formula, we only require

$$m+\alpha_i-x \le \sigma_i$$

That is, the interval between x and the time slot α_i in the second coverage period is less than σ_i. We simplify the above formula as:

$$x \ge m-(\sigma_i-\alpha_i)$$

It follows

$$m-(\sigma_i-\alpha_i) \le x \le m$$

When considering the case $1 \le x < \alpha_i$, it requires

$$m+x-(\alpha_i+(\rho_i-2)\sigma_i) \le \sigma_i$$

That is the interval between x and the time slot $\alpha_i+(\rho_i-2)\sigma_i$ in the first coverage period is shorter than σ_i. Simplify the above formula:

$$x \le \alpha_i+(\rho_i-1)\sigma_i-m$$

It follows

$$1 \le x \le \alpha_i+(\rho_i-1)\sigma_i-m$$

From the above theorem, it is known that in the case of $m\%\sigma_i \neq 0$ the last time slot assigned to the POI p_i in each coverage period can be selected flexibly.

Based on the above analysis, we give the POI time slot assignment algorithm in the PSC scheme in Figure 4. We assign the equal number of POIs in each time slot, which is the criterion how a POI is assigned to a time slot. Therefore, the time slot with the minimum number of POIs in the first σ_i time slots of the coverage period shall be selected as the first assigned time slot for the POI p_i.

The complete algorithm flow of the PSC scheme is shown in Figure 5. The algorithm will first sort all POIs. The sorting not only helps the quick finding of $T_{\min}=\min(T_i)$ and $T_{\max}=\max(T_i)$, but also ensures that the POI with smaller T_i has higher priority in assigning a POI to the corresponding time slot. This is because the larger the T_i, the larger the σ_i. Larger σ_i means more candidate time slots that can be assigned to p_i. This helps to improve the overall performance of the algorithm.

Assign(p_i)
Input: POI p_i to be assigned
Step 1: compute the corresponding σ_i and ρ_i for p_i.
Step 2: in the first σ_i time slots, select the time slot α_i which contains the minimum number of assigned POIs .
Step3: add p_i into the POI combinations in time slots α_i, $\alpha_i+\sigma_i$, …, $\alpha_i+(\rho_i-2)\sigma_i$ in turn.
Step 4: if $m\%\sigma_i \neq 0$, go to Step 5; else go to Step 6.
Step 5: from the range of time slots $[m-(\sigma_i-\alpha_i), m]$ and $[1, \alpha_i+(\rho_i-1)\sigma_i-m]$ select the time slot with the minimum number of POIs, add p_i into the POI combination of this time slot. Go to Step 7.
Step 6: add p_i into the POI combination of time slot $\alpha_i+(\rho_i-1)\sigma_i$.
Step 7: algorithm ends, return the update POI combination to each time slot.

Figure 4. The POI time slot assignment algorithm in flow chart

Step 1: sort POIs according to the ascending order of T_i.
Step 2: determine coverage period coefficient $m=T_{\max}/T_{\min}$, and the coverage period with the length of $mT_{\min}$.
Step 3: for all POIs run the time slot assignment algorithm (as shown in Figure 4) in turn, then generate the POI combinations for each time slot.
Step 4: for the POI combination in each time slot, set the POI coverage period as $T_i=T_{\min}$, generate the mobile sensor moving paths by using existing sweep coverage scheme.

Figure 5. The PSC scheme in flow chart

IV. Simulation of the PSC Scheme

In order to verify the PSC scheme and test its performance, we design and implement a computer program to simulate the proposed scheme by using the Microsoft Visual C++ (VC++). We use the VRPSC scheme [9] to create moving paths for mobile sensors in each time slot in the PSC scheme. In the simulation process, we deploy one stationary sink node and several POIs randomly in a monitoring area of 500m × 500m. The single POI coverage periods of the POIs are randomly distributed in [100s, 500s]. The buffer size of the mobile sensors is 560 bytes, and the data generation rate at each POI is 10 bytes per coverage period. By changing the number of POIs in the monitoring area, the program independently generates 12 different POI topologies. The operating environment for the simulation is shown in Table 1. At the same time, we also run VRPSC scheme as a direct comparison in the same simulation environment and simulation scenarios. The parameter settings of the simulated annealing in the VRPSC scheme is the same as in [9].

The main purpose of the sweep coverage scheme is to create the moving paths for the mobile sensors. Given a specific network environment / configuration, the moving speed of the mobile sensors plays a decisive role on the path creation. In the simulation, we mainly examine the influence of the scheme performance caused by the changes of the speed of the mobile sensors. We choose three indicators, which include the number of mobile sensors, the algorithm convergence time and the length of the mobile sensors' moving path, as the performance indices for evaluating the PSC scheme.

TABLE I. SIMULATION ENVIRONMENT

Host	HP 8280 Elite
CPU	Core i7-2600, 3.4GHZ
RAM	8GB
OS	Windows 7 Professional

Figure 6 shows the number of required mobile sensors in PSC and VRPSC scheme, respectively. Two mobile sensor moving speeds used in the results are 5 m/s and 10 m/s. Due to the different POI combinations in different time slots, the number of required mobile sensors is different in each slot. Therefore, we choose the maximum number of mobile sensors in all time slots as the number of required mobile sensors in the PSC scheme. As shown in Figure 6, in most network scenarios if the mobile sensors move at the same speed, the number of required mobile sensors in the PSC is less than that in VRPSC.

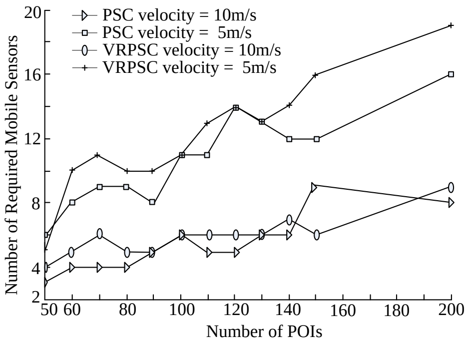

Figure 6. The influence of the moving speed of mobile sensors on the number of required mobile sensors

Next, we examine the running time of the algorithm. Figure 7 shows the effect of changing the moving speed of the mobile sensors on the running time of the PSC scheme.

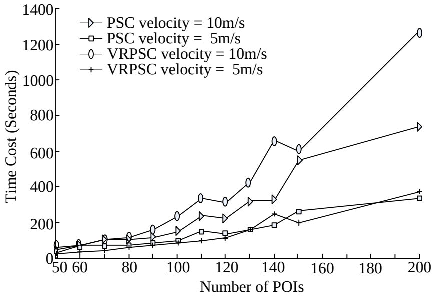

Figure 7. The effect of the moving speed of the mobile sensors on the running times of PSC scheme

It can be seen from Figure 7 that if the mobile sensors move at a lower speed, the running times of the PSC and VRPSC are similar. If the sensors' moving speed is higher, in terms of running time the PSC scheme algorithm outperforms the VRPSC significantly. This shows that the PSC scheme is more suitable for the sweep coverage scenarios equipped with fast moving mobile sensors.

Figure 8 shows the moving distances within a coverage period for PSC and VRPSC scheme under the condition of different moving speeds. For calculating the moving distance of the mobile sensors in VRPSC scheme, we take the following approach:

$$\sum_{i=1}^{S}\left(\frac{A_i \times K_i}{C_i} \times L\right). \quad (6)$$

where, S is the number of paths, A_i is the length of path i , K_i is the number of mobiles sensors on path i , C_i is the minimum coverage interval of the POIs in path i .

The computation of the moving distance in PSC scheme is as follows:

$$\sum_{i=1}^{m}\sum_{k=1}^{S_i}(A_i \times K_i)\,. \quad (7)$$

where, S_i is the number of paths in i th time slot.

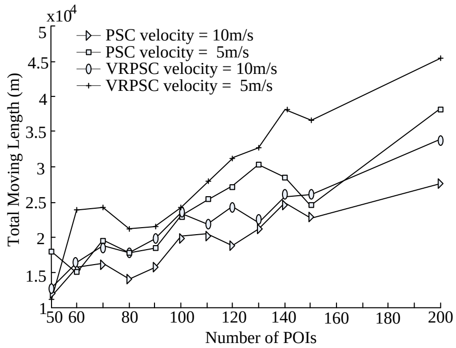

Figure 8. The effect of mobile sensor buffer size on the number of required mobile sensors in PSC scheme

As shown in Figure 8, under the condition of the same moving speed of the mobile sensors, the moving distance of mobile sensors in the PSC scheme is substantially less than that in the VRPSC scheme. This shows that the PSC scheme's design ideas of assigning the POIs to different time slots according to the required coverage periods succeeds in reducing the needless higher coverage frequencies for the POIs with longer coverage periods. Thereby we achieve the goal of reducing the unnecessary movement of mobile sensors in the network, and avoiding the over-coverage problem.

V. CONCLUSIONS

In this paper we propose a periodic sweep coverage scheme to address the POI over-coverage problem occurred in the creation of moving paths for mobile sensors in the existing sweep coverage schemes used in cases where the different POIs have different coverage periods. The PSC scheme is based on the ideas of solving PVRPs. In the PSC scheme, we first obtain a coverage period according to the required minimum and maximum coverage intervals of the POIs in the network. And then we divide the period into several time slots with each time slot having the minimum coverage interval of all POIs. Then, based on the different coverage requirements for different POIs, we assign the POIs to different time slots to generate the different POI combinations for each time slot. Finally we generate the moving paths of the mobile sensors in each time slot according to the different POI combination. Simulation results show that the use of the PSC scheme can reduce the needless higher coverage frequencies for some POIs with longer coverage intervals under the premise of meeting the applications' coverage requirements. As a result the unnecessary movement of mobile sensors in the network is reduced, and the over-coverage problem is effectively eliminated. In terms of performance PSC beats VRPSC which beats CSweep, therefore PSC also beats CSweep.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (Grant No. 61272448), the Ph.D. Programs Foundation of Ministry of Education of China (Grant No.20110181130007), and the Science and Technology Support Plan Foundation of Sichuan Province, China (Grant No. 2012GZ0005). Zhang was supported in part by the PSC-CUNY Research Award 66621-0044.

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