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Two-phase scale-based reduction method for fulfilling monitoring service on mobile devices[‡]

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SUMMARY

One of the general location-based services (LBSs) is the monitoring of real-time locations of moving objects. When the number of moving objects is large and the task of monitoring is carried out on mobile devices, the monitoring service suffers from constraints of screen size, computing speed, and network bandwidth. In the present paper, a two-phase scale-based reduction method (SRM) consisting of a zoom phase and a mosaic phase, is proposed to overcome these constraints. The zoom phase reduces the original monitoring area which, in turn, undergoes further reduction in the mosaic phase. The performance was measured with the use of two ratios: the reduction ratio (*RRatio*) and the transmission ratio (*TRatio*). From the experimental results, the lowest *RRatio* was 52%, i.e. almost half of the original data size was reduced. The lowest average *TRatio* was also 52% for the worst case, i.e. the entire original monitoring area was displayed on the mobile device. Moreover, the display time was shortened from 14.3 to 0.7 s. These results show that the use of the two-phase SRM is practical and efficient when applied to the monitoring service on mobile devices. Copyright © 2006 John Wiley & Sons, Ltd.

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KEY WORDS: location-based service; mobile service; data reduction; mobile computing

1. INTRODUCTION

The widespread use of wireless networks and mobile devices have popularized the mobile information services. However, the development of such services is constrained mainly by four factors: storage,

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‡The sample program can be accessed from the anonymous FTP site seafood.csie.cyut.edu.tw under the directory 'TwoPhaseSRM'.

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computing speed, screen size, and network bandwidth. For example, a current Pocket PC is equipped with a 400 MHz CPU and 64 MB or 128 MB of memory. Its screen size is 240×320 pixels, while the bandwidth of the IEEE 802.11 g wireless network is 54 Mbps. Thus, many of these services would need special designs in order to meet the above-mentioned constraints.

Alternatively, the locations of moving objects can be acquired from positioning devices. These devices can be classified into two categories: outdoor and indoor. Although the global positioning system (GPS) is the most popular outdoor positioning device, it cannot be used in an indoor environment. Many indoor positioning technologies have already been proposed that rely on various types of technology, such as the RFID, ultra wideband, wireless LAN, or even Bluetooth [1–4].

Many researchers have focused their attention on location-related topics. For example, Banerjee *et al*. proposed a location-aware system architecture called Rover [5] which is designed to scale up to large user populations. When a user moves from the service domain of one Rover to another, the user's profile—preference, device capability, etc.—can be transmitted to the target Rover. Thus, the target Rover can provide the service without interruption.

Some researchers have focused on location management. For instance, Lo *et al*. [6] proposed a method to solve the performance problem of location management for personal communication services (PCSs). In Lo's proposed method, a user's movement behavior is associated with a set of regions. The registration process in the same region can be eliminated so that the cost of location management can be reduced significantly. Lee *et al*. [7] clarified many things related to the location-dependent information service (LDIS) and included issues such as location-dependent data placement, replication, indexing, caching, broadcasting, query scheduling, etc. In addition, Bauer *et al*. [8] focused on the location model and derived the requirements for a general location modeling language for ubiquitous computing called Augmented World Modeling Language (AWML) and Augmented World Querying Language (AWQL).

Many researchers have also studied how to identify the location of a user by basing it on the user's movement behavior, the cell ID in a GSM cellular network, or the signal strength in a wireless network [9–11]. Harri *et al*. [12] focused on the location-dependent query. An example of a location-dependent query would be, 'Please list taxis within five miles.' Since the query results have to be updated continuously, an agent technology is used to improve the updating efficiency [12]. Prabhakar *et al*. [13] proposed another solution to overcome the same problem.

The popularity of mobile devices has caused more and more location-related services (LBSs) to be utilized on these types of device. One of the basic services is to monitor the locations of moving objects. The locations should be updated continuously while the update interval should also be short enough to reflect the real-time locations of the moving objects. However, when the number of objects and the monitoring area are both large, the monitoring service encounters the constraints of screen size, computing speed, and network bandwidth. According to our estimates, the time it takes for displaying 10 000 locations on a Pocket PC is about 14.3 s. This means that the update interval must be larger than 14.3 s. This makes it impractical to provide a monitoring service on mobile devices.

In order to overcome the above-mentioned constraints, a two-phase scale-based reduction method (SRM) is proposed. It consists of a zoom phase and a mosaic phase. The purpose of the zoom phase is to reduce the original monitoring area which, in turn, is reduced to a small area based on a first scale called the area scale (*AS*). The purpose of the mosaic phase is to reduce the display quality on the screen of mobile devices in order to display the data faster. Thus, the small area is reduced further, based on a second scale called the screen scale (*SS*).

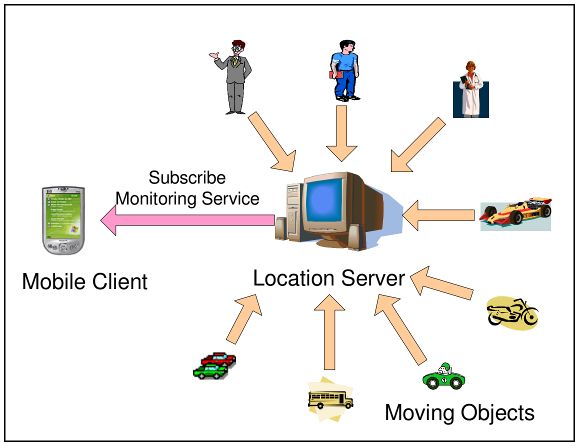

Figure 1. A scenario of a mobile monitoring service.

Scaling is an obvious way of overcoming screen size constraint. According to the scaling concept, the data size can be reduced using the proposed method in order to address the network bandwidth constraint. The execution of the two-phase SRM is on the server side only in order to decrease the computation load on mobile clients and to allow the monitoring service of a large number of moving objects on mobile devices.

In Section 2, the reduction principle of the two-phase SRM is presented. The simulation is presented in Section 3, while the experimental metrics and results are presented in Section 4. Section 5 summarizes the conclusion and proposes possible future works.

2. METHOD

The scenario of a monitoring service is shown in Figure 1. Assume that all the moving objects such as people, cars, etc., are equipped with positioning devices and wireless communication capability. The real-time locations of these objects are transmitted to and stored in a location server. Thus, a mobile client can use a device to subscribe to a monitoring service from the server. The real-time locations of these moving objects are displayed on the mobile device and are updated continuously.

A two-phase SRM is proposed to resolve the constraints discussed earlier. It consists of a *zoom phase* and a *mosaic phase*. The purpose of the zoom phase is to reduce the original monitoring area in order to minimize the data size. This phase is also referred to as *area reduction*. On the other hand, the purpose of the mosaic phase is to reduce the display quality on the screen of the mobile devices in order to display the data faster. This phase is also called *screen reduction*. These two phases are illustrated in Figure 2.

In Figure 2, the bottom gray area is the original monitoring area. The location of a moving object is a point on the area. After the zoom phase, the original monitoring area is reduced, based on the first

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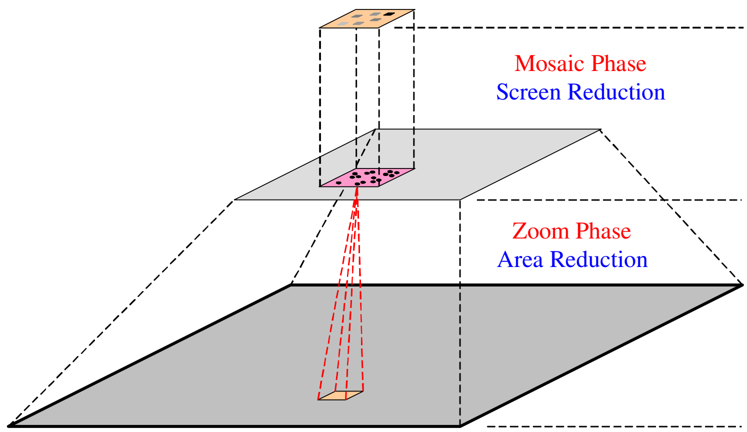

Figure 2. A representation of the two-phase SRM.

scale, the *AS*. The reduced area is presented in the middle layer. The scale is a ratio of the middle layer to the bottom layer. If the scale is 1:1, the reduced area is the same as the original area. If the scale is 1:2, the reduced area is only one-fourth of the original area. Thus, those points or locations within a small area in the bottom layer are reduced to just one point in the middle layer.

In the mosaic phase, the middle layer is processed further according to the second scale, the *SS*. A user can adjust the visible area in the middle layer. The visible area is the same as the area of the top layer and the screen on the mobile device. This area is reduced to a mosaic, which is formed by a set of square pieces called mosaic pieces. The *SS* determines the area of a mosaic piece. The area mapped by a mosaic piece in the middle layer is reduced and represented as a mosaic piece in the top layer. The number of locations in the area of a mosaic piece determines the gray level of the mosaic piece as shown in Figure 2.

Hence, a small area in the original monitoring area is reduced to one point in the middle layer. The area of a mosaic piece in the middle layer is reduced and represented as a mosaic piece in the top layer. According to the scaling concept, reduction can decrease the original data size of a large number of locations; and as both phases are carried out only in the location server, the two-phase SRM can thus overcome the constraints of screen size, computing speed, and network bandwidth.

The zoom phase and mosaic phase are presented below with more details. An example to illustrate the zoom phase is shown in Figure 3. Assume that the original area is 20×20 m^2 and the screen area is 10×10 pixels^2. The original area is shown in Figure 3(b). The black points represent the real-time locations of moving objects. Figure 3(a) shows the reduction result when $AS = 1{:}1$. The screen area constraint causes only one fourth of the result to be visible and is marked by the blue dashed line in Figure 3(a). Thus, only four locations are included in the visible area.

Figure 3(c) shows the reduction result when $AS = 1{:}2$. The whole area is included in the visible area. However, the location is imprecise. The actual location of a point could be at any one within the 2×2 m^2. If two locations are within the same square, their coordinates are reduced to the same one in

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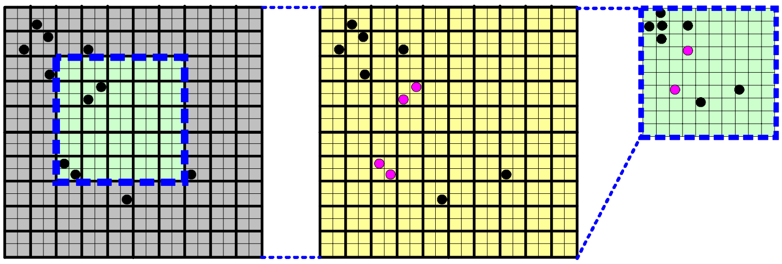
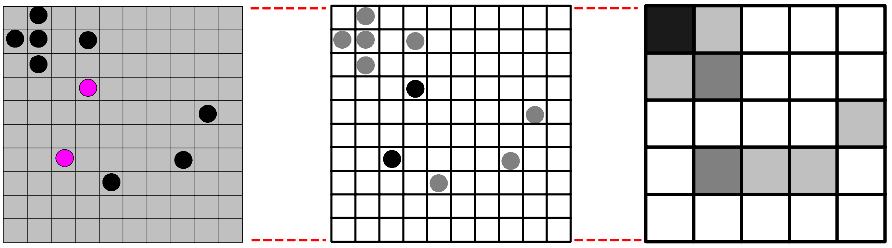


(a) (b) (c)

Figure 3. An example of the zoom phase: (a) $AS = 1{:}1$; (b) original monitoring area; (c) $AS = 1{:}2$.



(a) (b) (c)

Figure 4. An example of the mosaic phase: (a) the result of $AS = 1{:}2$; (b) $SS = 1$; (c) $SS = 1{:}2$.

the middle layer. In the figures shown above, the four pink points in Figure 3(b) are reduced to two pink points in Figure 3(c). This means that even though the whole area is visible, the data size is usually smaller than the original size.

The mosaic phase is illustrated by the diagram shown in Figure 4. The mosaic phase follows the zoom phase. The same reduction result in Figure 3(c) is shown in Figure 4(a). When *SS* is equal to one, there is no mosaic effect. The result is shown in Figure 4(b). It is the same as Figure 4(a) except for the gray levels. The two pink points represent two locations while the corresponding points are darker than the others. When $SS = 1{:}2$, the mosaic piece area is equal to 2×2 pixels^2. Thus, the locations in the same area of a mosaic piece are reduced and represented as a mosaic piece. The number of points in a mosaic piece area determines the gray level of the mosaic piece. The result is shown in Figure 4(c). Because there are three different numbers of locations in the mosaic piece areas, there are also three different gray levels, as shown in Figure 4(c). After the reduction of the mosaic phase, only one coordinate is needed for those locations in the same mosaic piece area. Hence, the data size can be reduced further. In addition, the display of a mosaic piece is the drawing of a square which is faster

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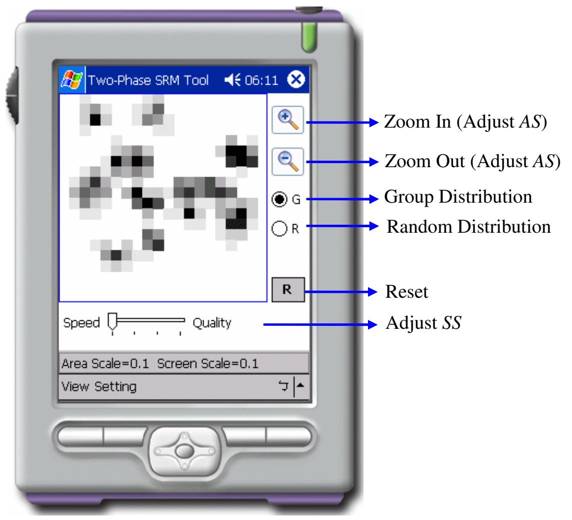

Figure 5. A screen shot of the simulation tool.

than the display of individual points on the screen. Using the mosaic phase not only reduces the data size but also shortens the display time.

Users can adjust the two scales, *AS* and *SS*, and focus solely on the interesting area. Only the locations in the visible area are reduced and transmitted to the mobile client. As there is no computing load on the mobile device, it addresses the constraints on screen size, computing speed, and network bandwidth.

3. SIMULATION

A simulation tool was utilized to illustrate and evaluate the performance of the two-phase SRM. The default original monitoring area is 2000×2000 m^2. The screen area of the mobile device is 200×200 pixels^2. The locations were generated, based on random or group distributions. The two distributions are approximations of people in an open area that are obtained by using a series of gaussians. The distribution is done by generating the locations in the monitoring area at random. A screen shot of the simulation tool is shown in Figure 5.

In Figure 5, the plus and minus icons are used to adjust the area scale. Two radio buttons are used to select the type of location distribution. The track bar is used to adjust the screen scale. There are four different screen scales on the track bar and these are, from left to right, 1, 0.7, 0.4, and 0.1. When $SS = 1$, there is no mosaic effect, i.e. the display quality is already the best. When $SS = 0.1$, the mosaic piece area is the largest from among the four different scales. Although the display quality is at

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(a) (b) (c)

Figure 6. The screen shots for the zoom phase under group distribution: (a) $AS = 0.1$ (1:10); (b) $AS = 0.2$ (1:5); (c) $AS = 1$ (1:1).

its worst when $SS = 0.1$, the display speed is at its fastest. Hence, the labels 'Speed' and 'Quality' are used on the track bar instead of the values of the SS.

A demonstration of the zoom phase is shown in Figure 6. There are three screen shots for the three different area scales under the group distribution. The screen scale is assigned with the value of 1, which means that there is no mosaic effect in the mosaic phase. When $AS = 0.1$, the entire original monitoring area is displayed on the screen, as shown in Figure 6(a). Conversely, the precise locations of the moving objects are displayed on the screen when $AS = 1$, as shown in Figure 6(c).

A demonstration of the mosaic phase is shown in Figure 7. The value of 0.1 is assigned to the area scale to allow the entire monitoring area to be shown on the screen. When $SS = 1$, there is no mosaic effect and the result is as shown in Figure 7(a). Conversely, the mosaic effect is obvious when $SS = 0.1$, as shown in Figure 7(c).

Similarly, the screen shots for the mosaic phase under random distribution are shown in Figure 8.

As an advanced illustration, the screen shots of the simulation tool with the background map and object information are shown in Figure 9. In Figure 9(a), the tool displays the correct part of the background map according to the AS. The tool can also display the object's information, e.g. its label, based on its identification. However, many locations can be reduced into the same pixel when the AS is small. If the labels of the objects in the same pixel are simultaneously displayed, the result would be similar to the screen shot shown in Figure 9(b), which can be confusing for the users. Such a problem can be resolved by displaying only parts of the object that are interesting for the users.

From these demonstrations, we can already understand the principles behind the two-phase SRM as well the operation of the monitoring service on a mobile device.

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(a) (b) (c)

Figure 7. Screen shots for the mosaic phase under group distribution: (a) $SS = 1$ (1:1); (b) $SS = 0.7$ (7:10); (c) $SS = 0.1$ (1:10).

(a) (b) (c)

Figure 8. Screen shots for the mosaic phase under random distribution: (a) $SS = 1$ (b) $SS = 0.4$ (c) $SS = 0.1$.

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(a) (b)

Figure 9. The screen shots of the simulation tool with the background map and object information: (a) $AS = 1$; (b) $AS = 0.7$.

4. EXPERIMENTAL STUDY

4.1. Experimental metrics

There are two ratios which have been defined for the performance evaluation of the two-phase SRM. The reduction ratio (*RRatio*) is the percentage of the final data size after the reduction by the two-phase SRM in relation to the original size. *RRatio* is influenced by the settings of *AS* and *SS*. On the other hand, only the data of the visible area are transmitted to the mobile devices to implement the monitoring service. The transmission ratio (*TRatio*) is defined as the percentage of the data size of the visible area when compared to the original data size. The computation for the *RRatio* or the *TRatio* does not include the size of the background maps or the information related to the moving objects as shown in Figure 9. The reason for this is that these data are fixed and transmitted only once and, therefore, are no longer necessary in the computation of the *RRatio* and *TRatio*.

Furthermore, the experiment on the bandwidth usage is not included in the metrics as it is related to the operations of the mobile clients for only a period of time. Mobile clients can adjust the settings of *AS* and *SS* when necessary. Not only is it difficult to simulate the behavior of the mobile clients, but a mix-up of various settings of the *AS* and *SS* can result. Thus, the performance of the two-phase SRM is not easily evaluated from such a mix-up situation.

Assume that the original monitoring area is a square whose width is denoted by W. Let the width of the display area in the mobile device be denoted by *SW*, the area scale denoted by *AS*, and the screen scale denoted by *SS*. $AS = 1$ and 0.5 when the scale is 1:1 and 1:2, respectively. *SS* also has the same values. One of the locations of the moving objects is denoted by L_i. The coordinates of L_i are denoted

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by (x_i, y_i). N bytes are used to store the coordinates on the screen while M bytes are used to store the identification of the moving object.

Initially, the original location L_i is reduced to L_i' after the two-phase reduction under AS and SS. The equation for L_i' is shown in Equation (1):

$$L_i' = (x_i', y_i') \quad \text{where } x_i' = \lfloor x_i \times AS \times SS \rfloor, \quad y_i' = \lfloor y_i \times AS \times SS \rfloor \tag{1}$$

The width of the original area W is reduced to W', as shown in Equation (2).

$$W' = \lfloor W \times AS \times SS \rfloor \tag{2}$$

The equation for computing the total bytes of the reduced area is as follows:

$$\begin{aligned} Count_{mn} &= \text{Number of } L_i' \quad \text{where } x_i' = m \text{ and } y_i' = n \\ B_{mn} &= \begin{cases} N + M \times Count_{mn} & \text{when } Count_{mn} \geq 1 \\ 0, & \text{otherwise} \end{cases} \\ Total_{(AS,SS)} &= \sum_{m=1}^{W'} \sum_{n=1}^{W'} B_{mn} \end{aligned} \tag{3}$$

In Equation (3), the notation $Count_{mn}$ represents the number of locations at the specific coordinates (m, n) on the screen. The notation B_{mn} represents the bytes for the locations at the coordinates (m, n). Thus, B_{mn} is equal to N bytes for the coordinates (m, n) plus the product of M and $Count_{mn}$ for the identification of all the moving objects. If $Count_{mn}$ is equal to zero, B_{mn} also is equal to zero. Then, all of B_{mn} is summed up and denoted as $Total_{(AS,SS)}$. This represents the total bytes under the scales of AS and SS.

After the $Total_{(AS,SS)}$ is computed, the notation $RRatio_{(AS,SS)}$ represents the reduction ratio under the scales of AS and SS. It is equal to the $Total_{(AS,SS)}$ divided by the $Total_{(1,1)}$, i.e. the original and largest value of $Total_{(AS,SS)}$. The equation of $RRatio_{(AS,SS)}$ is defined in Equation (4).

$$RRatio_{(AS,SS)} = \frac{Total_{(AS,SS)}}{Total_{(1,1)}} \tag{4}$$

The visible area on the screen of the mobile devices determines the transmission size. The transmission size of a crowded area may be several times that of a sparse area. Hence, three transmission ratios: *MaxTRatio*, *MinTRatio*, and *AvgTRatio*, are defined to take into account the variance on the transmission size. The equations are shown in Equation (5):

$$\begin{aligned} TRatio_{(AS,SS)}(m, n) &= \frac{\sum_{i=m}^{m+\lfloor SW \times SS \rfloor - 1} \sum_{j=n}^{n+\lfloor SW \times SS \rfloor - 1} B_{ij}}{Total_{(1,1)}} \\ MaxTRatio_{(AS,SS)} &= Maximum\ TRatio_{(AS,SS)}(m, n), \\ &\qquad 1 \leq m \leq W' - \lfloor SW \times SS \rfloor + 1, \quad 1 \leq n \leq W' - \lfloor SW \times SS \rfloor + 1 \\ MinTRatio_{(AS,SS)} &= Mininum\ TRatio_{(AS,SS)}(m, n), \\ &\qquad 1 \leq m \leq W' - \lfloor SW \times SS \rfloor + 1, \quad 1 \leq n \leq W' - \lfloor SW \times SS \rfloor + 1 \\ AvgTRatio_{(AS,SS)} &= \frac{\sum_{i=1}^{W' - \lfloor SW \times SS \rfloor + 1} \sum_{j=1}^{W' - \lfloor SW \times SS \rfloor + 1} TRatio_{(AS,SS)}(i, j)}{(W' - \lfloor SW \times SS \rfloor + 1)^2} \end{aligned} \tag{5}$$

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Table I. An example of *RRatio* and *TRatio* under various *AS* and *SS*.

	RRatio		*MinTRatio*		*AvgTRatio*		*MaxTRatio*	
SS	$AS = 1$	$AS = 0.5$	$AS = 1$	$AS = 0.5$	$AS = 1$	$AS = 0.5$	$AS = 1$	$AS = 0.5$
1	100%	90.9%	9.1%	90.9%	30.5%	90.9%	59.1%	90.9%
0.5	90.9%	63.6%	9.1%	63.6%	21.3%	63.6%	50%	63.6%

In Equation (5), $TRatio_{(AS,SS)}(m, n)$ represents the transmission ratio when the top left corner of the visible area is (m, n). $TRatio_{(AS,SS)}(m, n)$ is equal to the sum of B_{ij} divided by $Total_{(1,1)}$. $MaxTRatio_{(AS,SS)}$, $MinTRatio_{(AS,SS)}$, and $AvgTRatio_{(AS,SS)}$ represent the maximum, minimum, and average values of $TRatio_{(AS,SS)}(m, n)$, respectively.

For the examples shown in Figures 3 and 4, the width of the original area *W* is 20. The width of the screen *SW* is 10 and the scales *AS* and *SS* can be 1 or 0.5. The coordinates and the identifications, i.e. N and M, are assigned with two bytes. The values of *RRatio* and *TRatio* are listed in Table I.

In Table I, $RRatio_{(1,1)}$ is 100%, but $AvgTRatio_{(1,1)}$ is only 30.5%, i.e. one third of the original size is transmitted to the mobile client. $MaxTRatio_{(1,1)}$ and $MinTRatio_{(1,1)}$ are equal to 59.1 and 9.1%, respectively. This means that the difference between the transmission sizes of a crowded and a sparse area is very large. On the other hand, when *AS* and *SS* are both equal to 0.5, $RRatio_{(0.5,0.5)}$ is only 63.6%. This means that, even though the entire original area is shown on the screen, more than one-third of the data size can be reduced in order to lower the utilization of the network bandwidth.

4.2. Experimental design

Several experiments were designed to evaluate the performance of the two-phase SRM in terms of data size, display time, and server load. The *RRatio* and *TRatio* of the zoom and mosaic phases were evaluated separately. An experiment was also designed to evaluate the load of the location server. The values of the relevant parameters of the experiments are listed in Table II.

The values of the two parameters N and M were based on the screen width and the number of moving objects. Because the screen width is 200 pixels, one byte is enough for storing the x or y coordinates. Two bytes were assigned to N. M was also assigned with two bytes, enabling a maximum of 65 536 moving objects to be identified.

4.3. Experimental results of the zoom phase

The simulation generated ten sets of separate locations. The *RRatio* and *TRatio* under different scales were computed for each set of locations. In order to evaluate the zoom phase, the screen scale (*SS*) was set to 1. The results of *RRatio* in the zoom phase are shown in Figure 10.

In Figure 10, the x-axis represents the area scale from 0.1 to 1, while the y-axis represents the reduction ratio. The four curves represent the *RRatio* of 1000, 4000, 7000, and 10 000 locations with

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Table II. The values of experimental parameters.

Parameters	Setting
Original area	$2000 \times 2000\ \text{m}^2$
Screen width	200×200 pixels^2
Number of locations	1000, 4000, 7000, and 10 000
Location distribution	Random or group (the area of a group is a circle with 200 meters radius. There are 250 locations in a group.)
Area scale (*AS*)	0.1, 0.2, ..., and 1
Screen scale (*SS*)	0.1, 0.4, 0.7, and 1
N	Two bytes for storing a coordinate on the screen
M	Two bytes for storing the identification of a moving object
Mobile device	HP iPAQ h5545 with Pocket PC 2002 OS

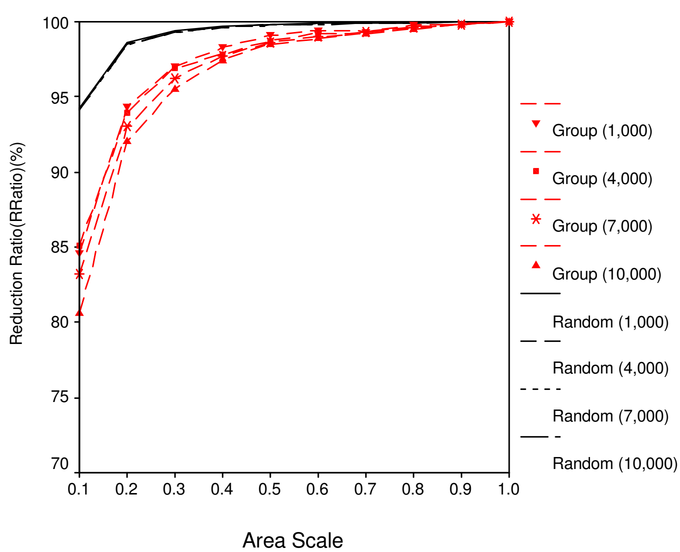

Figure 10. A comparison of *RRatio* under random or group distribution in the zoom phase.

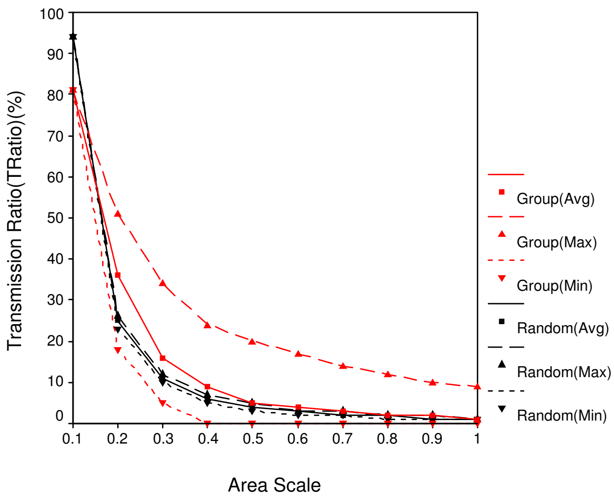

Figure 11. A comparison of *TRatio* with 10 000 locations under random or group distribution.

group and random distributions. In general, *RRatio* increased as the area scale increased. The *RRatio* of the group distribution was *ca*. 10–15% lower than that of the random distribution. This means that the two-phase SRM performed better when the locations were concentrated in several hot spots. The four curves resulting from the random distribution were almost identical. This means that *RRatio* was not influenced by the location size. Conversely, the more locations involved, the lower the *RRatio* under the group distribution. The smallest *RRatio* was 80.6% under a scale value of 0.1 and with 10 000 locations. Almost one-fifth of the location data was reduced by the two-phase SRM.

The results of the *TRatio* are shown in Figure 11. There are three curves representing the average, maximum, and minimum *TRatio*s under the random and group distributions with 10 000 locations. It was obvious that *TRatio* decreased rapidly as the area scale increased. In the case of the random distribution, the difference between *MinTRatio* and *MaxTRatio* was small. For the group distribution, *AvgTRatio* was close to the curve that resulted from the random distribution. However, *MaxTRatio* was *ca*. 5–13% higher than *AvgTRatio*. This means that even though the locations were concentrated on the hot spots, *TRatio* did not increase that much. The smallest values of *MaxTRatio*, *AvgTRatio*, and *MinTRatio* were 6.2, 1.2, and 0%, respectively. This illustrates that the network bandwidth constraint can be solved using the two-phase SRM based on the scale concept.

The influence of the location size on *AvgTRatio* was also tested. The results are shown in Figure 12. There is no explicit difference from among the curves resulting from random distribution. Conversely, *AvgTRatio* decreased as the location size decreased for the group distribution. This is because the decrease in location size caused the group distribution to become similar to that of the random distribution. Thus, the curve resulting from the group distribution with 1000 locations overlaps with the curves resulting from the random distribution.

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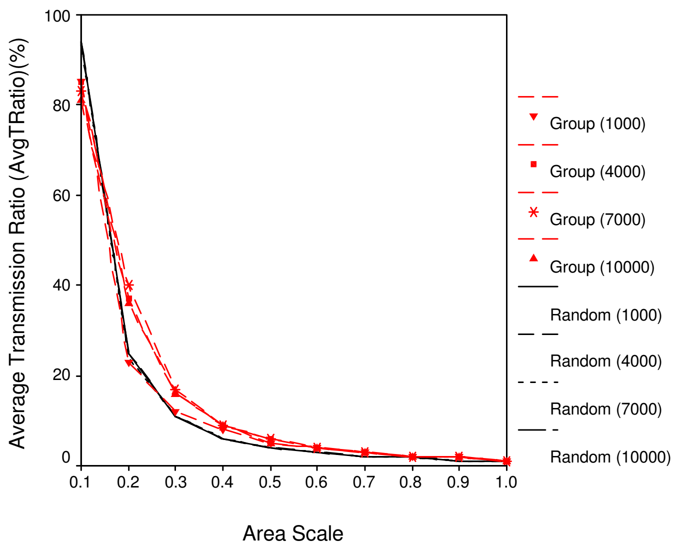

Figure 12. A comparison of *AvgTRatio* with different location sizes.

From the above-mentioned results, even though the smallest *RRatio* was 81%, *AvgTRatio* decreased rapidly to 1.2% as the area scale increased. This shows that the two-phase SRM can resolve the screen size and network bandwidth constraints and is therefore effective for monitoring a large number of objects on mobile devices.

4.4. Experimental results of the mosaic phase

The experimental results of *RRatio* in the mosaic phase are shown in Figure 13. The number of locations was 10 000 under random and group distributions.

In Figure 13, the x-axis represents the area scale from 0.1 to 0.6, and the y-axis represents the *RRatio*. There are four separate curves for group and random distributions. Each curve represents the *RRatio* under a specific *SS*. Based on these curves, *RRatio* increased as *AS* increased. *RRatio* for the group distribution was lower than that of the random distribution. The smallest *RRatio* was 52% when *AS* and *SS* were both 0.1. The difference in *RRatio* between the group and random distributions increased as *AS* increased. The largest difference was *ca*. 15% when $AS = 0.6$ and $SS = 1$.

There are two conclusions to drawn from the experimental results. Firstly, the *RRatio* for group distribution is smaller than that for random distribution. Secondly, the larger the mosaic effect, the smaller is the *RRatio*. This means that the mosaic phase can reduce the data size to almost half and thus, decrease the network transmission.

Another experiment was conducted to evaluate the *AvgTRatio*. The results are shown in Figure 14.

In Figure 14, the x-axis represents the area scale, and the y-axis represents the *AvgTRatio*. The results under the group and random distributions are depicted by the red and black curves. There are four

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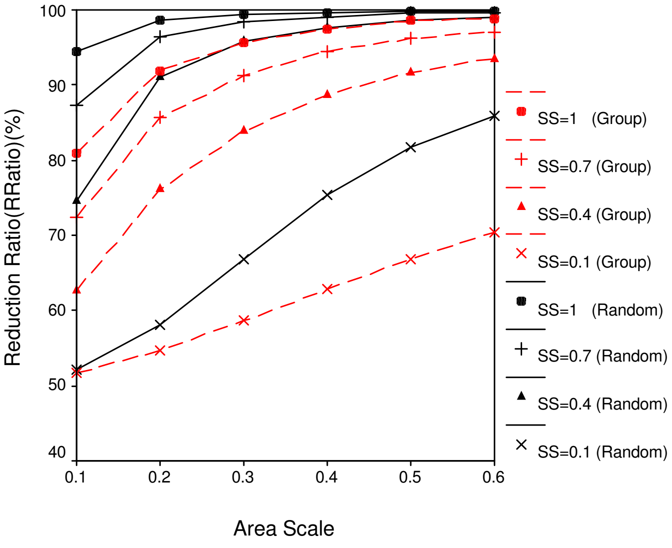

Figure 13. A comparison of *RRatio* under group and random distribution in the mosaic phase.

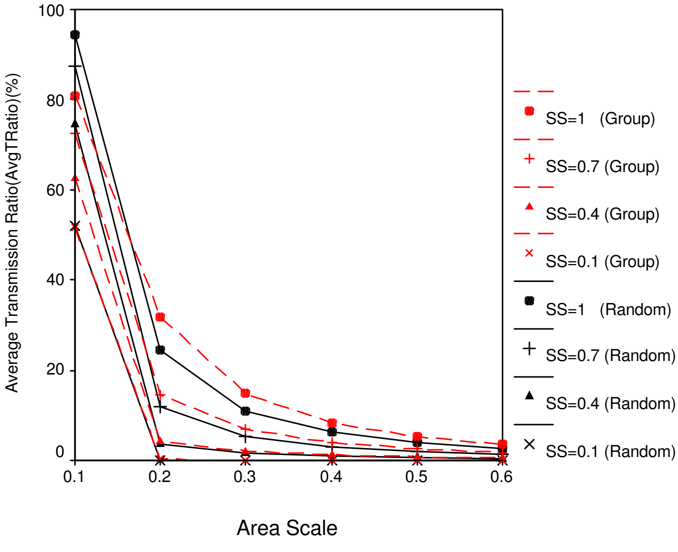

Figure 14. A comparison of *AvgTRatio* in the mosaic phase.

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Table III. The display time of various *AS* and *SS* on Pocket PC.

	Random distribution				Group distribution			
AS	$SS = 1$	$SS = 0.7$	$SS = 0.4$	$SS = 0.1$	$SS = 1$	$SS = 0.7$	$SS = 0.4$	$SS = 0.1$
0.1	14.3	4.2	1.4	0.7	10.16	2.23	0.91	0.58
0.2	4.1	2.6	1.3	0.7	2.88	1.28	0.56	0.33
0.3	2	1.4	0.9	0.6	1.59	0.79	0.46	0.29
0.4	1.1	0.8	0.7	0.5	1.01	0.6	0.38	0.26
0.5	0.7	0.6	0.5	0.4	0.76	0.47	0.32	0.23
0.6	0.5	0.4	0.4	0.3	0.55	0.36	0.28	0.21

(unit = s)

curves for the different *SS* values of 0.1, 0.4, 0.7, and 1. *AvgTRatio* decreased as the *AS* increased. This result was the same as that shown in Figure 11. However, the decrease in *SS* caused *AvgTRatio* to decrease further from 81 to 52%. *AvgTRatio* almost approached zero when $SS = 0.1$. This shows that *AvgTRatio* can be decreased dramatically by the mosaic phase.

The mosaic phase not only reduces the data size, but also shortens the display time of moving objects in mobile devices. The display times were measured on the mobile device HP iPAQ h5545, and are shown in Table III. In the table, the longest display time is 14.3 s when $SS = 1$ and $AS = 0.1$ under random distribution, i.e. the whole area is shown on the screen without any mosaic effect. The mosaic phase causes the display time to decrease rapidly as *SS* decreases. For the same *AS* and distribution, the display time can be shortened to 0.7 s when $SS = 0.1$. The result is similar for the group distribution. This shows that the display time can be shortened effectively by the mosaic phase. A short display time causes the locations to be updated more frequently.

Furthermore, the maximum reduction capacity, which is limited by the number of gray levels, was also considered. The maximum gray level of a mosaic piece is 255. According to the principle of the two-phase SRM, the gray level is determined by the number of locations in the area of a mosaic piece. The area of a mosaic piece is equal to $1/(AS^2 \times SS^2)$ m^2. It is equal to 100×100 m^2 when both *AS* and $SS = 0.1$. If the number of locations in the mosaic piece area is directly assigned with the gray level of the mosaic piece, the maximum reduction capacity is 255 locations in an area of 100×100 m^2. However, the gray level should be adjustable by the users in order to obtain a preferred reduction result. To illustrate the above scenario, a function is applied to enable the adjustment of the gray level. Three screen shots under the group distribution with 10 000 locations are shown in Figure 15. In Figure 15(a), the gray level of a mosaic piece is equal to the number of locations in the mosaic piece area. Many mosaic pieces are black, as the number of locations has exceeded 255. The reduction result can be lightened or darkened by clicking the 'L' or 'D' buttons as shown in Figure 15(b) and (c). The example illustrates that the limited gray level causing the maximum reduction capacity is 255 locations in an area of 100×100 m^2. Thus, the adjustment of the gray level of the reduction results can still accomplish the monitoring service without having to suffer the limitation due to reduction capacity.

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(a) (b) (c)

Figure 15. The screen shots of the simulation tool by adjusting the gray level of reduction result: (a) original; (b) lightened; (c) darkened.

4.5. Experimental results for the server load

According to the principle of the two-phase SRM, the computations are only on the server side. An experiment was designed to evaluate the computation time of the location server. The computation time was evaluated under the maximum load of the server, i.e. the whole area is processed by the server. In other words, both AS and $SS = 0.1$. A Pentium IV 3.0 GHz desktop computer with 512 MB of memory was used as a location server. Various numbers of subscribers, that is, mobile clients, requested the monitoring services from the location server. The number of subscribers was from 20 to 200, while the number of locations was from 5000 to 50 000. The computation was repeated 100 times for every set of subscribers and locations in order to obtain the precise computing time.

The experimental results as listed in Table IV show that the computing time increased as the number of subscribers increased. However, the computing time for 200 subscribers was only 0.31 ms. The computing time was almost the same, regardless of the number of locations was for the same number of subscribers. This shows that the two-phase SRM efficiently reduces the number of moving objects.

5. CONCLUSION AND FUTURE WORKS

LBSs are growing in popularity as the use of wireless networks and mobile devices are becoming more widespread. However, the storage, screen size, network bandwidth, and computing speed constraints are causing many of these services to require special designs in order to address these problems. Here, a two-phase SRM is proposed to solve the problems of monitoring a large number of moving objects on mobile devices. The experimental results show that the two-phase SRM not only overcomes, the screen

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Table IV. The computing time for various of subscribers and locations.

	Locations					
Subscriber	5000	10 000	20 000	30 000	40 000	50 000
20	0.05	0.04	0.05	0.05	0.05	0.04
40	0.08	0.08	0.07	0.08	0.08	0.08
60	0.11	0.1	0.11	0.11	0.1	0.11
80	0.14	0.13	0.13	0.13	0.13	0.13
100	0.16	0.17	0.17	0.16	0.16	0.17
120	0.20	0.19	0.20	0.19	0.19	0.19
140	0.23	0.22	0.22	0.22	0.22	0.21
160	0.25	0.25	0.25	0.25	0.24	0.25
180	0.28	0.3	0.28	0.28	0.28	0.28
200	0.31	0.31	0.32	0.31	0.31	0.31

(unit = ms)

size, computing speed, and network bandwidth constraints, but also efficiently shortens the display time of the locations. These results show that the two-phase SRM is practical and efficient when applied to the monitoring service on mobile devices.

There remain other issues that need to be addressed in the future. One example of such as issue is the incorporation of the two-phase SRM and the cache technique. The cache is a useful technique for lessening unnecessary network traffic and can decrease the network traffic beforehand. Another issue concerns the situation whereby a large number of mobile clients are subscribing to the monitoring service for different sets of moving objects. The two-phase SRM will have to be refined in order to overcome all the possible problems that may arise.

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REFERENCES

1. Ni LM, Liu Y, Lau YC, Patil AP. LANDMARC: Indoor location sensing using active RFID. *Proceedings of the 1st IEEE International Conference on Pervasive Computing and Communications (PerCom'03)*, Fort Worth, TX, 23–26 March 2003. IEEE Computer Society Press: Los Alamitos, CA, 2003. 407–415.
2. Kitasuka T, Nakanishi T, Fukuda A. Wireless LAN based indoor positioning system WiPS and its simulation. *Proceedings of the IEEE International Pacific Rim Conference on Communications, Computers, and Signal Processing (PACRIM'2003)*, Victoria, BC, 28–30 August 2003, vol. 1. IEEE Computer Society Press: Los Alamitos, CA, 2003; 272–275.
3. Ingram SJ, Harmer D, Qssnlan M. Ultra wideband indoor positioning systems and their use in emergencies. *Proceedings of the IEEE Position Location and Navigation Symposium (PLANS'2004)*, Monterey, CA, 26–29 April 2004. IEEE Computer Society Press: Los Alamitos, CA, 2004; 706–715.

4. Anastasi G *et al*. Experimenting an indoor bluetooth-based positioning service. *Proceedings of the 23rd IEEE International Conference on Distributed Computer Systems (ICDS'03)*, Providence, RI, 19–22 May 2003. IEEE Computer Society Press: Los Alamitos, CA, 2003; 480–483.
5. Banerjee S *et al*. Rover: Scalable location-aware computing. *IEEE Computer* 2002; **35**(10):46–53.
6. Lo SC, Chen LP. Adaptive region-based location management for PCS system. *IEEE Transactions on Vehicular Technology* 2002; **51**(4):667–676.
7. Lee DL, Xu J, Zheng B. Data management in location-dependent information services. *IEEE Pervasive Computing* 2002; **1**(3):65–72.
8. Bauer M, Becker C, Rothermel K. Location models from the perspective of context-aware applications and mobile *ad hoc* networks. *ACM Personal and Ubiquitous Computing* 2002; **6**(5–6):89–94.
9. Jin MH, Wu EHK, Horng JT. Location query based on moving behavior. *Proceedings of the 11th IEEE International Conference on Computers Communications and Networks (ICCN 2002)*, Miami, FL, 14–16 October 2002. IEEE Computer Society Press: Los Alamitos, CA, 2002; 268–273.
10. Roos T, Myllymaki P, Tirri H. A statistical modeling approach to location estimation. *IEEE Transactions on Mobile Computers* 2002; **1**(1):59–69.
11. Pandya D, Jain R, Lupu E. Indoor location estimation using multiple wireless technologies. *Proceedings of the 14th IEEE International Conference on Person, Indoor, and Mobile Radio Communications (PIMRC'2003)*, Beijing, China, 7–10 September 2003, vol. 3. IEEE Computer Society Press: Los Alamitos, CA, 2003; 2208–2212.
12. Harri S, Mena E, Illarramendi A. Dealing with continuous location-dependent queries: Just-in-time data refreshment. *Proceedings of the 1st IEEE International Conference on Pervasive Computing and Communications (PerCom'03)*, Fort Worth, TX, 23–26 March 2003. IEEE Computer Society Press: Los Alamitos, CA, 2003; 279–286.
13. Prabhakar S *et al*. Query indexing and velocity constrained indexing: scalable techniques for continuous queries on moving objects. *IEEE Transactions on Computers* 2002; **51**(10):1124–1140.