Performance Comparison of Location Areas and Reporting Centers under Individualized Mobility Models

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ABSTRACT
Location management deals with how to track mobile users within the cellular network. It consists of two basic operations: location update and paging. The total cost of location management is the sum of the location update cost and the paging cost. There are many location management schemes, Location Areas and Reporting Centers are two classical and popular location management schemes. To the best of our knowledge, no performance comparison between Reporting Centers and Location Areas has been reported in the literature. The paper compares the performance of the Location Areas scheme and the Reporting Centers scheme. The motivation for the study is that the location areas can be derived from a given set of reporting centers such that the location update cost difference between the Reporting Centers scheme and the Location Areas scheme is small whereas the paging cost in the Reporting Centers scheme is larger than that in the Location Areas scheme. Given a set of reporting centers, this paper shows how to derive the location areas from the reporting centers, and compares the performance of Location Areas and Reporting Centers schemes under various mobility models and incoming call arrival rates. Simulation results show that the Location Areas scheme greatly outperforms the Reporting Centers scheme in most cases although the Reporting Centers scheme performs a little bit better than the Location Areas scheme in some extreme cases.

Keywords
Cellular Networks, Location Management, Location Areas, Reporting Centers, Location Update, Paging, Performance Comparison

1. INTRODUCTION
In the past decade, cellular communications has experienced an explosive growth due to technological advances in cellular networks and cellular phone manufacturing. It is expected that it will experience even more growth in the next decade. In a cellular system, a service area is divided into smaller areas of hexagon shape, called cells. Each cell is served by a base station (BS). Through a base station controller (BSC), each base station is connected to a mobile switching center (MSC) that is, in turn, connected to the public switched telephone network (PSTN). A mobile station (MS) communicates with another terminal, either mobile or fixed, via the closest base station. Figure 1-1 illustrates a typical cellular network. For more detailed information, please refer to [4, 11].

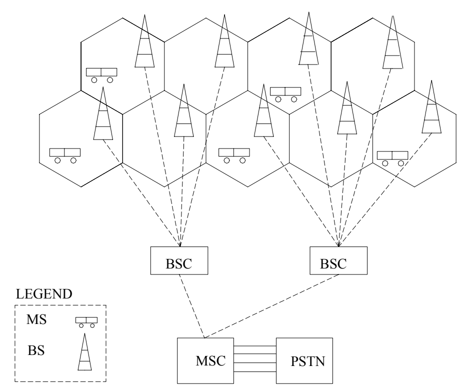

Figure 1-1 A typical cellular network.

When an incoming call arrives for a mobile station, the cellular network needs to find out the exact cell in which the mobile station is located so the incoming call can be routed to the corresponding base station. Location management deals with how to track mobile users within the cellular network. Location management consists of two basic operations: location update and paging. Each operation has a cost. The total cost of location management is the sum of location update cost and paging cost. The task of location management is to find a strategy that minimizes the total cost. A location update scheme can be classified as either static or dynamic [3,10]. In a static scheme, there is a predetermined set of cells at which a location update must be generated by a mobile station regardless of its mobility. Location Areas [9] and Reporting Centers [2,5] are two popular examples of the static scheme. In a dynamic scheme, a location update can be generated by a mobile station in any cell depending on its mobility. Examples of dynamic schemes include time-based [3,12], movement-based [1,3,7] and distance-based [3,6,8]. A location update scheme can also be classified as either global or individualized [3,10]. A location update scheme is global if all subscribers update their locations at the same set of cells, and a scheme is individualized if an individual subscriber is allowed to decide when and where to perform location update. There are a lot of other location management schemes proposed in the literature. Interested readers are referred to [13] for a survey on this topic.

Among location management schemes, Location Areas and Reporting Centers are two classical and popular schemes. In the Location Areas approach [9], the service coverage area is partitioned into location areas. Each location area (LA for short) consists of several contiguous cells. The base station of each cell broadcasts the identification of the location area to which the cell belongs. Therefore, a mobile station knows which location area it is in. A mobile station will update its location whenever it moves into a cell that belongs to a new location area. On a call arrival for a particular mobile station, the cellular system will page all cells within the LA reported by the mobile station at its last update. The key issue with the Location Areas scheme is how to define location areas such that the total location management cost is minimized. Figure 1-2 illustrates a simple service area with three location areas separated by solid lines. When a mobile station moves from cell *a* to cell *b*, it needs to report its new location area because cells *a* and *b* are in different location areas. After that, no update is needed if the mobile station moves to cell *d* or cell *e*. At that time, if an incoming call arrives for the mobile station, the cellular system will page cells *b*, *d* and *e*.

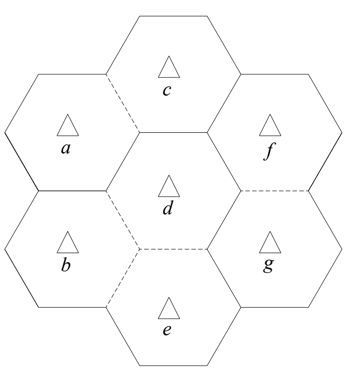

Figure 1-2 A service area with three location areas.

Reporting Centers is another popular location management scheme [2,5]. The Reporting Centers approach designates a subset of cells as reporting centers (also known as reporting cells). A reporting center (RC for short) periodically transmits a short message to identify its role. A mobile station can learn whether or not it is in a reporting cell by listening to the message. A mobile station will update its location when it enters a new reporting center. When an incoming call arrives for a mobile station, the cellular system will page all cells within the vicinity of the reporting center that was last reported by the mobile station. The vicinity of a reporting center is defined as the collection of all non-reporting cells that are reachable from the reporting cell without crossing another reporting cell plus the reporting center itself. The key issue of the Reporting Centers scheme is how to select a set of reporting cells to minimize the total location management cost. Figure 1-3 illustrates a simple service area with four reporting cells marked by solid triangles. If a mobile station moves from cell *c* to cell *d*, it needs to report its new location because cell *d* is a reporting cell that is different from the last known reporting cell *c*. After that, no location update is necessary if the mobile station moves to cell *f*, then back to cell *d*. At that time, if an incoming call arrives for the mobile station, the cellular system will page all cells within the vicinity of the last known reporting cell *d* that includes cells *d*, *a*, *f* and *g*.

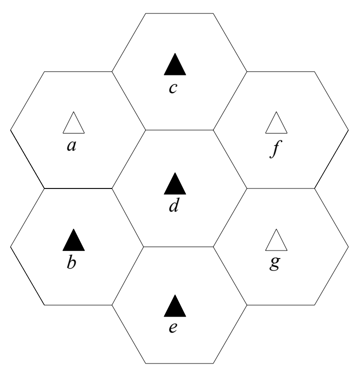

Figure 1-3 A service area with four reporting cells.

In [2], the authors have first proposed the idea of reporting centers. They have shown that for an arbitrary topology of the cellular network, find the optimal set of reporting centers is an NP-complete problem. For the case of unweighted vertices, they have presented an optimal solution for ring graphs and near optimal solutions for various types of grid graphs including the topology of hexagonal cellular network. For the case of weighted vertices, they have presented an optimal solution for tree graphs and a simple approximation algorithm for arbitrary graphs. In [5], the authors use the topology of hexagonal cellular network with weighted vertices. A procedure has been given to find an approximate solution to the reporting centers problem. They have shown that the Reporting Center scheme performs better than the Always-Update scheme and the Never-Update scheme.

Although Location Areas and Reporting Centers are two classical and popular location management schemes, to the best of our knowledge, the reporting Centers scheme has not been compared to the Location Areas. In this paper, we compare the performance of the Reporting Centers scheme and the Location Areas scheme under individualized mobility models by simulations. The remainder of the paper is organized as follows. Section 2 describes the motivation of the study. Section 3 compares the performance of Reporting Centers and Location Areas in one-dimensional network topology under random walk and Markov walk mobility models. In Section 4, we compare the performance of Reporting Centers and Location Areas in a two-dimensional network topology under the random walk mobility model. Section 5 summarizes the simulation results.

2. MOTIVATION

The motivation of the study is the observation that the location areas can be derived from a given set of reporting cells such that the location update cost difference between Reporting Centers and Location Areas is small whereas the paging cost in the Reporting Centers is far larger than that in the Location Areas. Let us consider a one-dimensional network topology as shown in Figure 2-1, where *b*, *d*, and *e* are assumed to be the reporting centers. We define the location area *A* as consisting of all non-reporting cells between *d* and *b* and the location area *B* as consisting of all non-reporting cells between *b* and *e*. The reporting cell *b* can belong to either LA *A* or LA *B*, which will be determined later based on the location update cost.

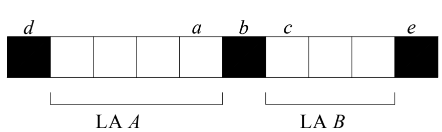

Figure 2-1 A one-dimensional network topology with reporting centers and location areas.

The total cost of location management is the sum of location update cost and paging cost. First we consider the paging cost. In the Reporting Centers scheme, the paging cost will be the number of cells in the vicinity of the reporting center. The vicinity of a reporting center is defined as the collection of all non-reporting cells that are reachable from the reporting cell without crossing another reporting cell plus the reporting center itself. In Figure 2-1, the vicinity of reporting cell *b* consists of 8 cells. The paging cost is 8 when a call arrives for a mobile station (MS for short) whose last reported cell is *b* in the Reporting Centers scheme. In the Location Areas scheme, the reporting center *b* will be assigned to either the left location area *A* or the right location area *B*. In either case, the paging cost in the Location Areas scheme is smaller than that in the Reporting Centers scheme because both LA A and LA B are smaller than the vicinity of *b*. In Figure 2-1, if the last reported location area by the MS is LA A, the paging cost for the MS is either 5 or 4 depending on whether *b* belongs to LA *A* or not. The above argument applies to any other reporting centers. Therefore the paging cost in the Reporting Centers scheme is larger than that in the Location Areas scheme.

Next we consider the location update cost. In the long run, the number of times a mobile station enters a cell is about the same as the number of times the MS leaves the cell. This is because an MS needs to enter a cell before existing it except the cell is the initial position of the MS, and an MS will eventually exit a cell after entering it unless the cell is the destination of the MS. Let $m_{i\to j}$ denote the number of times a MS moves from cell *i* to *j*, for cell *b* in Figure 2-1, we have:

$$m_{b\to a} + m_{b\to c} = m_{a\to b} + m_{c\to b} \quad (2\text{-}1)$$

In the Location Areas scheme, a user updates its location when it crosses a boundary between two location areas. In the Reporting Centers scheme, we assume a MS updates its location when it enters a reporting center. (Please note this is different from the actual rule. The actual rule specifies that a MS updates its location when it enters a *new* reporting cell. The actual rule will be used for simulations.) We will show that the location update cost in Reporting Centers is always larger than that in Location Areas by assigning the reporting cell to one of its neighboring location areas based on the location update cost.

Suppose reporting center *b* belongs to left location area *A* in Figure 2-1, the update cost in the Reporting Centers scheme is $m_{a\to b} + m_{c\to b}$, and the update cost in the Location Areas scheme is $m_{b\to c} + m_{c\to b}$. If the location update cost in Location Areas is smaller than that in Reporting Centers, Equation 2-2 will hold.

$$m_{b\to c} + m_{c\to b} < m_{a\to b} + m_{c\to b} \quad (2\text{-}2)$$

If Equation 2-2 does not hold, then

$$m_{b\to c} + m_{c\to b} > m_{a\to b} + m_{c\to b} \quad (2\text{-}3)$$

From Equation 2-3, we get

$$m_{b \to c} > m_{a \to b} \quad (2\text{-}4)$$

Subtracting Equation 2-4 from Equation 2-1, we get

$$m_{b \to a} < m_{c \to b} \quad (2\text{-}5)$$

Adding $m_{a \to b}$ to both sides, we get

$$m_{b \to a} + m_{a \to b} < m_{c \to b} + m_{a \to b} \quad (2\text{-}6)$$

The right side is exactly the location update cost in the Reporting Centers scheme, and the left side of Equation 2-6 is exactly the location update cost in the Location Areas scheme when *b* belongs to the right location area *B*. From Equations 2-2 and 2-6 we show the location update cost in the Location Areas scheme is always smaller than that in the Reporting Centers scheme by properly assigning the reporting cell to one of its neighboring location areas. Of course we have assumed a MS updates its location when it enters a reporting cell in the Reporting Centers scheme. Simulation results show that the location update cost difference between Reporting Centers and Location Areas is small if a MS updates its location when it enters a new reporting cell in the Reporting Centers scheme.

3. ONE-DIMENSIONAL NETWORK TOPOLOGY UNDER RANDOM WALK AND MARKOV WALK MOBILITY MODELS

The network topology can be either one-dimensional or two-dimensional. This section will consider one-dimensional network topology. We will compare the performance of the Reporting Centers scheme and the Location Areas scheme under the random walk and Markov walk mobility models by simulation.

3.1 One-Dimensional Network Topology

In a one-dimensional network topology, each cell has two neighboring cells. The one-dimensional network topology is used to model the service area in which the mobility of mobile stations is restricted to either forward or backward direction. Examples include highways and railroads. For convenience, we will consider a ring network topology (see Figure 3-2) in which the first and last cells are considered as neighboring cells.

3.2 Incoming Call Arrival Probability

The incoming call arrival probability is very important when evaluating the performance of location management schemes. We assume that the incoming call arrival to a MS follows a Poisson process. Therefore the interarrival times have independent exponential distributions with the density function $f(t) = \lambda e^{-\lambda t}$, where λ represents the call arrival rate. We will generate incoming calls using an exponential random number generator provided by the CSIM simulation software [14].

3.3 Mobility Models

We use the discrete random walk and Markov walk as the mobility models to compare the performance between the Location Areas scheme and the Reporting Centers scheme. In the random walk mobility model, it is assumed that time is slotted. If a subscriber is in cell *i* at the beginning of time slot *t*, at the beginning of time slot *t*+1, the probability that the subscriber remains in cell *i* is *p* (referred to as the stationary rate), and the probability that the subscriber moves to cell *i*+1 (or *i*-1) is equal to (1-*p*)/2.

In the Markov walk mobility model, three states have been assumed for a subscriber at the beginning of time slot *t*: the stationary state (*S*), the left-move state (*L*), and the right-move state (*R*). For the *S* state, the probability that the subscriber remains in *S* is *p*, and the probability that the subscriber moves to a neighboring cell is equal to (1-*p*)/2. For the *L* (or *R*) state, the probability of remaining in the same state is *q*, the probability of going to the opposite state is *v*, and the probability that the subscriber moves to *S* is 1-*q*-*v*. Figure 3-1 illustrates the state transitions.

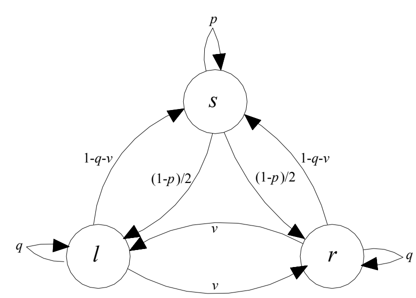

Figure 3-1 The state transitions of the Markov Walk.

3.4 Simulation Results

We will experiment with a ring topology with 16 cells. First, we will randomly generate reporting centers. Then we will derive location areas based on reporting centers. Specifically, all the non-reporting cells delimited by two reporting centers form a location area. A reporting center either belongs to one of its neighboring location areas or forms a LA by itself.

Figure 3-2 shows a ring topology with 16 cells, named from 1 to 16. Cells 3, 7, 10 and 15 are reporting cells, which are shown as filled squares in Figure 3-2. The rest cells are nonreporting cells. Based on the reporting cells, we will derive four location areas. Cells 16, 1 and 2 form LA *A*. Cells 4, 5 and 6 form LA *B*. Cells 8 and 9 form LA

C. Cells 11, 12, 13 and 14 form LA *D*. Reporting cell 3 can belong to either LA *A* or LA *B*, or form a LA by itself.

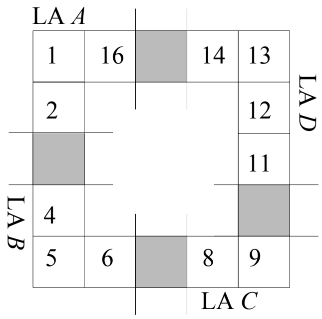

Figure 3-2 A ring network topology with reporting centers and location areas.

3.4.1 Simulation Results under the Random Walk Mobility Model

The simulation was first run under the random walk mobility model. In this model, the probability that the subscriber remains in the same cell is p (stationary rate), and the probability that the subscriber moves to a neighboring cell is equal to $(1-p)/2$. In this simulation, the range of p is from 0 to 1.0. (p=0 means the subscriber always moves, and p=1.0 means the subscriber does not move at all.) The incoming call arrival to the subscriber follows a Poisson process and is generated by an exponential random generator of the CSIM simulation software. The parameter to the generator is the mean of interarrival times. The mean of interarrival times is the reciprocal of the call rate. A simulation runs for 10000 time slots. In each time slot, the subscriber either moves forward or backward, or does not move based on p.

Whenever a mobile station performs a location update, the total location update cost will be incremented by one and whenever the system performs a paging operation, the total paging cost will be increased by the number of cells it has paged. The total location management cost is the sum of the total location update cost and the total paging cost. To make it more general, in this paper, the total location update cost and total paging cost are separately considered, but they are stacked together in different colors in our plots.

The output from a simulation consists of the total location update cost and the total paging cost. After running the simulation 100 times for a set of parameters, we average the numbers and plot them in figures. Figure 3-3 plots the location management costs of the Reporting Centers scheme and the Location Areas scheme under the random walk mobility model with different values of p, where the number of cells in this ring network is 16, and the number of reporting cells is 4. The call arrival rate is 0.1638. From Figure 3-3, we have found the stationary rate p doesn't greatly affect the performance difference when the call rate is fixed. The location update cost in the Reporting Centers scheme is smaller than that in the Location Areas scheme whereas the paging cost in the Reporting Centers scheme is larger than that in the Location Areas scheme. The total cost in the Reporting Centers scheme is larger than that in the Location Areas scheme. In summary, the Location Areas scheme performs better than the Reporting Centers schemes under the random walk mobility model with a fixed call rate.

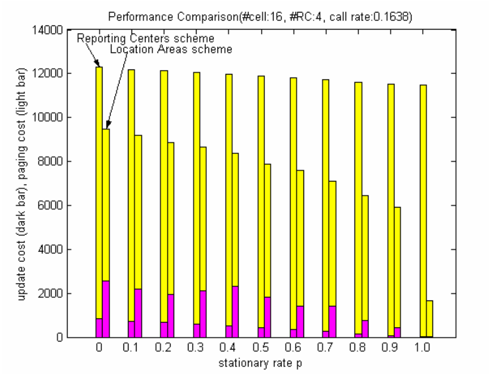

Figure 3-3 Total cost comparison of Location Areas and Reporting Centers schemes under the random walk mobility model with a fixed call rate and varying stationary rates.

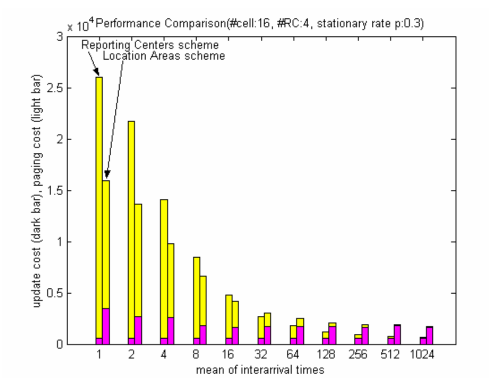

Figure 3-4 Total cost comparison of Location Areas and Reporting Centers schemes under the random walk mobility model with a fixed stationary rate and varying call rates.

Figure 3-4 presents the performance comparison between the Reporting Centers scheme and the Location Areas scheme under the random walk mobility model with a fixed stationary rate (p=0.3) and varying call rates. The figure shows that the location update cost in the Reporting Centers scheme is always smaller than that in the Location

Areas scheme whereas the paging cost in the Reporting Centers scheme is always larger than that in the Location Areas scheme. The simulation results show that when the mean of interarrival times is smaller than 32 (the call rate is larger than 0.0304), the Location Areas scheme greatly outperforms the Reporting Centers scheme; when the mean of interarrival times is equal to or larger than 32 (the call rate is equal to or smaller than 0.0304), the Reporting Centers scheme performs a little better than the Location Areas scheme.

Figure 3-5 shows the performance comparison between the Reporting Centers scheme and the Location Areas scheme under the random walk mobility model with a fixed stationary rate (*p*=0.3) and a fixed call rate (call rate is 0.1368). If the number of reporting cells is equal to the total number of cells in this network topology, the total cost in the Reporting Centers scheme is the same as the total cost in the Location Areas scheme because every cell is chosen to be a reporting cell. (This is the Always-Update scheme [3].) If there is no reporting cell in this network topology, the total cost in the Reporting Centers scheme is also the same as the total cost in the Location Areas scheme. (This is the Never-Update scheme [3].)

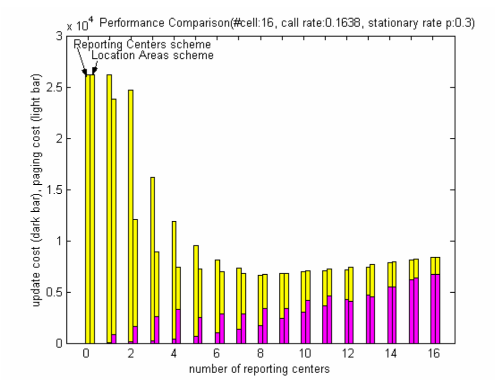

Figure 3-5 Total cost comparison of Location Areas and Reporting Centers schemes under the random walk mobility model with a fixed stationary rate and a fixed call rate.

When the number of reporting cells is equal to or smaller than 11, the update cost in the Reporting Centers scheme is smaller than the Location Areas scheme whereas the paging cost in the Reporting Centers scheme is larger than the Location Areas scheme. When the number of reporting cells is larger than 11, the paging cost in the Reporting Centers scheme is smaller than Location Areas scheme. Simulation results show when the number of reporting cells is smaller than 8, the Location Areas performs better than the Reporting Centers, otherwise Reporting Centers performs a little better than Location Areas.

3.4.2 Simulation Results under The Markov Walk Mobility Model

The performance comparison of Reporting Centers and Location Areas schemes was also done under the Markov walk mobility model by simulation. In the Markov walk mobility model, there are three parameters: the stationary state probability *p*, probability of remaining in the same state *q* and probability of going to the opposite state *v*. We consider two cases in this simulation. Case I assumes *p* = 0.1, *q* = 0.85 and *v* = 0.05. It is to simulate a subscriber with a destination in his/her mind. Case II assumes *p* = 0.4, *q* = 0.33 and *v* = 0.33. It is to simulate a subscriber with no destination.

Figure 3-6 presents the simulation results for Case I under varying call rates whereas Figure 3-7 presents the simulation results for Case II under varying call rates. In both simulations, the total number of cells of this ring network topology is 16, and the number of reporting cells is 4. From Figures 3-6 and 3-7, the update cost in the Reporting Centers scheme and the update and paging cost in the Location Areas scheme in Case I are always smaller than those in Case II under the same call rate, whereas the paging cost in the Reporting Centers scheme in Case I is about the same as that in Case II under the same call rate.

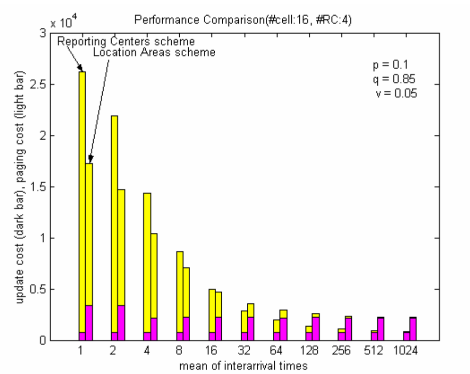

Figure 3-6 Total cost comparison of Location Areas and Reporting Centers schemes under the Markov walk mobility model with *p*=0.1, *q*=0.85 and *v*=0.05 (Case I).

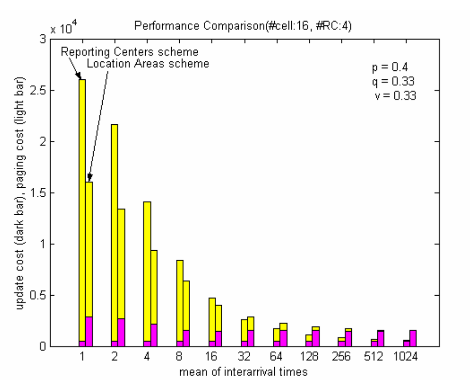

Figure 3-7 Total cost comparison of Location Areas and Reporting Centers schemes under the Markov walk mobility model with *p*=0.4, *q*=0.33 and *v*=0.33 (Case II).

The simulation results in both figures show that when the mean of interarrival times is smaller than 32 (the call rate is larger than 0.0304), the Location Areas scheme outperforms the Reporting Centers scheme; when the mean of interarrival times is equal to or larger than 32 (the call rate is equal to or smaller than 0.0304), the Reporting Centers scheme performs better than the Location Areas scheme.

Figure 3-8 presents the simulation results for Case I under varying numbers of reporting cells, whereas Figure 3-9 presents the simulation results for Case II under varying numbers of reporting cells. In both simulations, the call rate is 0.1638. These two simulations show that in the cases corresponding to Always-Update and Always-Searching, the total cost in the Reporting Centers scheme is the same as that in the Location Areas scheme.

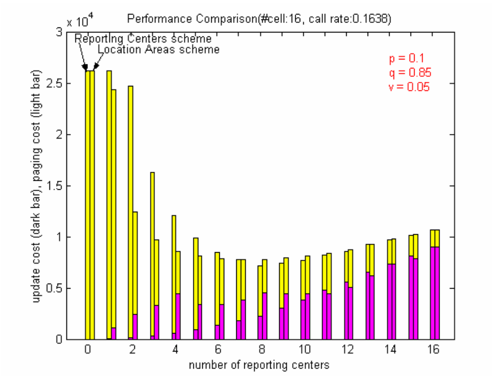

Figure 3-8 Total cost comparison of Location Areas and Reporting Centers schemes under a fixed call rate and the Markov walk mobility model with *p*=0.1, *q*=0.85 and *v*=0.05 (Case I).

Figure 3-8 (corresponding to Case I) shows that, if the number of reporting cells is smaller than 8, the Location Areas scheme performs better than the Reporting Centers scheme. Otherwise, the Reporting Centers scheme performs a little better than the Location Areas scheme.

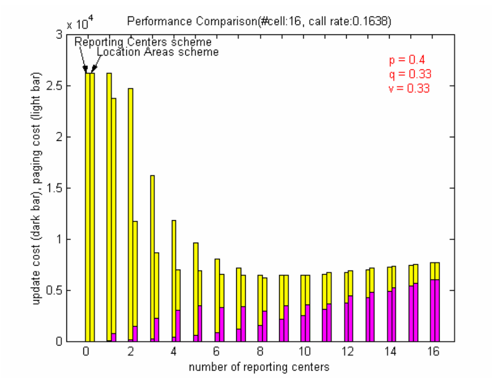

Figure 3-9 Total cost comparison of Location Areas and Reporting Centers schemes under a fixed call rate and the Markov walk mobility model with *p*=0.4, *q*=0.33 and *v*=0.33 (Case II).

Figure 3-9 (corresponding to Case II) shows that, if the number of reporting cells is smaller than 11, the Location Areas scheme performs better than the Reporting Centers scheme. Otherwise the Reporting Centers scheme performs a little better than the Location Areas scheme.

4. TWO-DIMENSIONAL NETWORK TOPOLOGY UNDER THE RANDOM WALK MOBILITY MODEL

In this section, we will compare the performance of the Reporting Centers scheme and the Location Areas scheme in a two-dimensional cellular network. The random walk will be used as the mobility model.

4.1 Two-Dimensional Network Topology

A two-dimensional network topology is used to model a more general service area where mobile stations can move in any directions. Figure 4-1 shows a two-dimensional cellular network with 19 cells, where a cell is represented by a hexagon. In such a network, each cell has 6 neighboring cells.

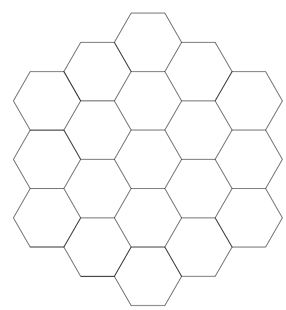

Figure 4-1 A two-dimensional network topology.

4.2 Rationale for Selection of Reporting Cells

In a two-dimensional cellular network, we assume the reporting cells are connected and divide the whole service area into several regions. Specifically, we will use a two-dimensional network with 19 cells. We select seven of them as reporting cells marked by black solid triangles in Figure 4-2. Those reporting cells are connected and divide the whole service area into three regions. Next we will explain the rationale for the selection of reporting cells.

First, both Reporting Centers and Location Areas have two extremely cases: Always-Update and Never-Update. The performance difference between Reporting Centers and Location Areas is very small when only a few cells are reporting cells or most cells are reporting cells. This behavior has been demonstrated in Figures 3-5, 3-8, and 3-9 for the one-dimensional network. The two-dimensional network behaves similarly.

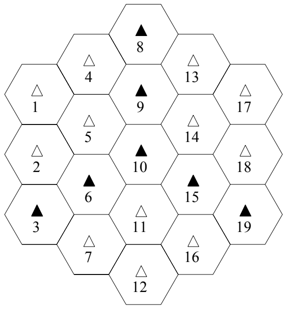

Figure 4-2 A two-dimensional network with 3 regions divided by reporting cells.

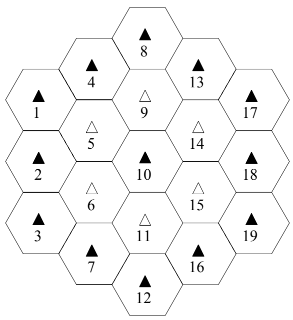

Figure 4-3 A two-dimensional network with an isolated reporting cell.

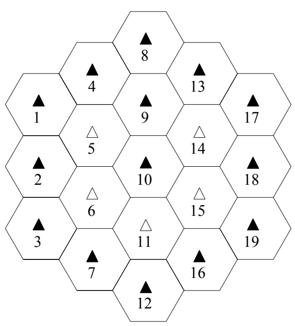

Figure 4-4 A two-dimensional network with hanging reporting cells.

Next, let us consider an isolated reporting center in a two-dimensional network, as illustrated in Figure 4-3, where cell 10 is an isolated reporting center. In this case, the vicinity of the reporting center 10 consists of its six neighboring cells and itself. If we let the vicinity of cell 10 be a location area, the paging cost in the Location Areas scheme is the same as that in the Reporting Centers scheme, whereas the update cost in the Location Areas scheme is a little bit smaller than that in the Reporting Centers scheme because a mobile station does not need to update its location at cell 10 in the Location Area scheme. Therefore it is not very meaningful to have an isolated reporting center. For the same reason, it is not meaningful to have hanging reporting centers as shown in Figure 4-4, where cell 10 is a hanging reporting center.

Because it is not very meaningful to have isolated or hanging reporting cells, in the following discussion, we assume the reporting cells are connected and divide the whole service area into several regions as shown in Figure 4-2. We will let a region bounded by reporting cells be a location area. A reporting cell can belong to one of its neighbor location areas or form a location area by itself. In such a network, we can classify all reporting cells into two categories. A reporting cell in Category I has two neighboring regions, and a reporting cell in Category II has more than two neighboring regions. For example, reporting cell 10 in Figure 4-2 has three neighboring regions whereas the others have only two. It is obvious that the paging cost in the Reporting Centers scheme is larger than that in the Location Areas. Next we will show the location update difference between Reporting Centers and Location Areas for a reporting cell in Category I.

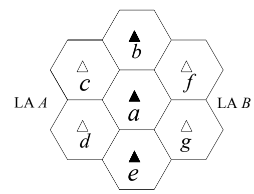

Figure 4-5 A two-dimensional network topology with reporting centers and location areas.

Without loss of generality, let us consider the reporting cell *a* in Figure 4-5. Cell *a* has two neighboring regions. Let those two regions be location area *A* and location area *B*. Let $m_{i \to j}$ denote the number of times a MS moves from cell *i* to *j*. We assume that the number of times a mobile station enters a cell is about the same as the number of times it leaves the cell in the long run. We have the following Equation for cell *a*:

$$m_{a\to b}+m_{a\to c}+m_{a\to d}+m_{a\to e}+m_{a\to f}+m_{a\to g} = m_{b\to a}+m_{c\to a}+m_{d\to a}+m_{e\to a}+m_{f\to a}+m_{g\to a} \quad (4\text{-}1)$$

Next consider the location update difference. In the Location Areas scheme, when a mobile station crosses the boundary between two location areas, it updates its location. In the Reporting Centers scheme, we assume, when a mobile station enters a reporting center, it updates its location. (Again this is different from the actual rule, and we will use the actual rule for simulation.) We let the regions divided by reporting cells be location areas. A reporting center can belong to either one of its neighboring location areas. Because *b* and *e* are *a*'s neighboring reporting centers, we have 4 cases to consider as shown in Table 4-1.

Table 4-1 Four cases concerning reporting cells *b* and *e*

Case #	Reporting cell *b*	Reporting cell *e*
Case 1	LA *A*	LA *A*
Case 2	LA *A*	LA *B*
Case 3	LA *B*	LA *A*
Case 4	LA *B*	LA *B*

We will consider Case 1, where reporting cells *b* and *e* belong to the same location area *A*. The location update cost in the Reporting Centers scheme is $m_{b\to a}+m_{c\to a}+m_{d\to a}+m_{e\to a}+m_{f\to a}+m_{g\to a}$. The location update cost in the Location Areas scheme is $m_{b\to a}+m_{a\to b}+m_{c\to a}+m_{a\to c}+m_{d\to a}+m_{a\to d}+m_{e\to a}+m_{a\to e}$, if *a* belongs to location area *B*. If the location update cost in the Location Areas scheme is smaller than that in the Reporting Centers scheme, Equation 4-2 holds.

$$m_{b\to a}+m_{a\to b}+m_{c\to a}+m_{a\to c}+m_{d\to a}+m_{a\to d}+m_{e\to a}+m_{a\to e} < m_{b\to a}+m_{c\to a}+m_{d\to a}+m_{e\to a}+m_{f\to a}+m_{g\to a} \quad (4\text{-}2)$$

If Equation 4-2 does not hold, then

$$m_{b\to a}+m_{a\to b}+m_{c\to a}+m_{a\to c}+m_{d\to a}+m_{a\to d}+m_{e\to a}+m_{a\to e} > m_{b\to a}+m_{c\to a}+m_{d\to a}+m_{e\to a}+m_{f\to a}+m_{g\to a} \quad (4\text{-}3)$$

In this case, we assign the reporting center *b* to the left location area *A*. We will show the location update cost in the Location Areas scheme is also smaller than that in the Reporting Centers scheme. From Equation 4-3, we get

$$m_{a\to b}+m_{a\to c}+m_{a\to d}+m_{a\to e} > m_{f\to a}+m_{g\to a} \quad (4\text{-}4)$$

Subtracting Equation 4-4 from Equation 4-1, we get

$$m_{a\to f}+m_{a\to g} < m_{b\to a}+m_{c\to a}+m_{d\to a}+m_{e\to a} \quad (4\text{-}5)$$

Adding $m_{f\to a}+m_{g\to a}$ to both sides, we get

$$m_{a\to f}+m_{f\to a}+m_{a\to g}+m_{g\to a} < m_{b\to a}+m_{c\to a}+m_{d\to a}+m_{e\to a}+m_{f\to a}+m_{g\to a} \quad (4\text{-}6)$$

The right side of Equation 4-6 is the location update cost in the Reporting Centers scheme, and the left side is the location update cost in the Location Areas scheme when cell *b* belong to LA *A*. From Equations 4-2 and 4-6, we can conclude that the location update cost in the Reporting Centers scheme is larger than that in the Location Areas scheme for Case 1. For the other three cases, the results are the same as for Case 1. Therefore it is not very meaningful to assume a lot of reporting cells in Category I. We only need to worry about the performance difference around a reporting cell in Category II.

4.3 Incoming Call Arrival Probability

We assume that the incoming call arrival to a MS follows a Poisson process. As in Section 3.2, the interarrival times have independent exponential distributions with the density function $f(t)=\lambda e^{-\lambda t}$, where λ represents the call arrival rate.

4.4 Mobility Model

We use the discrete random walk as the mobility model for the performance comparison in the two-dimensional network. Assume a subscriber is in cell *i* at the beginning of time slot *t*. At the beginning of time slot *t*+1, the probability that the subscriber remains in the same cell *i* is *p* (stationary rate), and the probability that the subscriber moves to each neighboring cell is equal to (1-*p*)/6.

4.5 Simulation Results

Based on the discussion in Section 4.2, we assume the reporting centers are connected, and divide the whole service area into several regions. We will define the regions divided by the reporting centers as location areas. A reporting center can either belong to a neighboring location area or form a location area by itself.

We will use a two-dimensional network with 19 cells named from 1 to 19 as shown in Figure 4-2. Assume cells 3, 6, 8, 9, 10, 15 and 19 are reporting centers that are marked by solid black triangles in Figure 4-2. The other cells are non-reporting cells. Those reporting centers divide the service area into 3 regions. Three location areas can be obtained from those three regions. Cells 1, 2, 4 and 5 form LA *A*. Cells 7, 11, 12 and 16 form LA *B*. Cells 13, 14, 17 and 18 forms LA *C*. Each reporting cell either belongs to a neighboring location area or forms a location area by itself.

In Figure 4-2, each reporting center has a set of cells as its vicinity. The vicinity of a reporting center is defined as the collection of all non-reporting cells that are reachable from the reporting cell without crossing another reporting cell. The vicinity for each cell is summarized in Table 4-2.

Table 4-2 Reporting cells and their vicinity cells

Reporting cell	Vicinity cells
3	1,2,3,4,5,7,11,12,16
6	1,2,4,5,6,7,11,12,16
8	1,2,4,5,8,13,14,17,18
9	1,2,4,5,9,13,14,17,18
10	1,2,4,5,7,10,11,12,13,14,16,17,18
15	7,11,12,13,14,15,16,17,18
19	7,11,12,13,14,16,17,18,19

The simulation has been run under the random walk mobility model. The probability that a subscriber remains in the same cell is *p* (stationary rate), and the probability that the subscriber moves to a neighboring cell is equally (1-*p*)/6. In this simulation, the range of *p* is from 0 to 1.0 (*p*=0 means the subscriber always moves, and *p*=1.0 means the subscriber does not move). The incoming call arrival to the subscriber follows a Poisson process. We will generate the incoming calls using an exponential random number generator of the CSIM simulation software. A simulation runs for 10000 time slots. The output from the simulation consists of the total location update cost and the total paging cost. We run the simulation for 100 times, and the average costs are shown in the next three figures.

Figure 4-6 plots the location management costs of the Reporting Centers scheme and the Location Areas scheme under the random walk mobility model with a fixed call rate. The number of cells in this two-dimensional network is 19, the number of reporting cells is 7 (at cells 3, 6, 8, 9, 10, 15 and 19 in Figure 4-2), and the call rate is 0.1638.

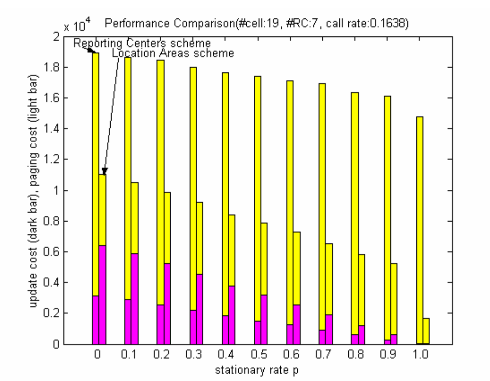

Figure 4-6 Total cost comparison of Location Areas and Reporting Centers schemes in a two-dimensional network under the random walk mobility model with a fixed call rate.

From Figure 4-6, we have found stationary rate *p* didn't affect the performance difference. The location update cost in the Reporting Centers scheme is smaller than that in the Location Areas scheme whereas the paging cost in the Reporting Centers scheme is larger than that in the Location Areas scheme. The total cost in the Reporting Centers scheme is larger than that in the Location Areas scheme. The Location Areas scheme performs better than the Reporting Center scheme under the random walk mobility model with a fixed call rate.

Figure 4-7 presents the simulation results for a fixed stationary rate *p* (*p*= 0.3) and varying call rates under the random walk mobility model. *p*=0.3 means the probability that the subscriber remains in the same cell is larger than the probability that the subscriber moves to a neighboring cell. The figure shows that when the mean of interarrival times is smaller than 32, the location update cost in the Reporting Centers scheme is smaller than that in the Location Areas scheme. Otherwise the location update cost in the Reporting Centers scheme is larger than that in the Location Areas scheme. The paging cost in the Reporting Centers scheme is always larger than that in the Location Areas scheme regardless of the call rate. The simulation results show the Location Areas scheme outperforms the Reporting Centers scheme no matter what the call rate is.

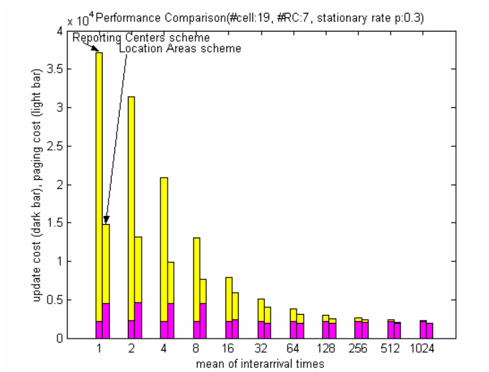

Figure 4-7 Total cost comparison of Location Areas and Reporting Centers schemes in a two-dimensional network under the random walk mobility model with p=0.3.

Figure 4-8 presents simulation results for a fixed stationary rate (*p*=0.1) and varying call rates under random walk mobility model. *p*=0.1 means the probability that the subscriber remains in the same cell is smaller than the probability that the subscriber moves to a neighboring cell. Figure 4-8 shows the Location Areas scheme outperforms the Reporting Centers scheme regardless of the call rate.

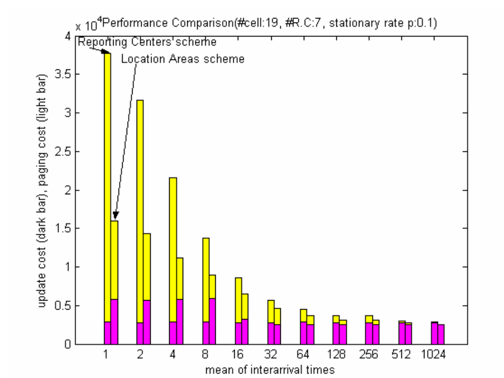

Figure 4-8 Total cost comparison of Location Areas and Reporting Centers schemes in a two-dimensional network under the random walk mobility model with *p*=0.1.

5. SUMMARY

Location Areas and Reporting Centers are two classical and popular location management schemes. In the Location Areas scheme, the service area is partitioned into location areas. A mobile station updates its location whenever it moves into a cell that belongs to a new location area. On a call arrival for a mobile station, the cellular system will page all cells within the location area that was last reported by the mobile station. In the Reporting Centers scheme, a set of cells has been selected as reporting cells. A mobile station needs to update its location whenever it moves into a new reporting cell. When an incoming call arrives for a mobile station, the cellular system will page all the cells within the vicinity of the reporting center that was last reported by the mobile station. The total cost of Location Areas and Reporting Centers is the sum of their corresponding location update cost and paging cost. The paper compares the performance of the Location Areas scheme and the Reporting Centers scheme under different individualized mobility models and different network topologies by simulation.

In a one-dimensional cellular network under the random walk and Markov walk mobility models, simulation results show that if more than 50% of cells are reporting, the Reporting Centers scheme performs a little better than the Location Areas scheme; otherwise, the Location Areas scheme performs better than the Reporting Centers scheme. Simulation results also show that when the call arrival rate is large, the Location Areas scheme performs a lot better than the Reporting Centers scheme under the random walk and Markov walk mobility models.

In a two-dimensional cellular network, simulation results show the Location Areas scheme outperforms the Reporting Centers scheme when the reporting cells are connected and divide the whole service area into several regions regardless of the call arrival rate under the random walk mobility model.

The final conclusion of this study is that in most cases the Location Areas scheme performs much better than the Reporting Centers scheme although the Reporting Centers scheme performs a little bit better than the Location Areas scheme in some extreme cases.

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