AN ENHANCED ADAPTIVE LOCATION UPDATE SCHEME FOR NEXT GENERATION PCS NETWORKS

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Abstract-

Locating users as they move from one place to another in a cellular network is a key issue that allows unrestricted mobility, yet poses several challenging constraints to the network designers. In this paper, an enhanced adaptive location update scheme is proposed to decrease the total cost of the location management process. The proposed scheme relies on the deployment of a direction based location update scheme along with a simple prediction line paging technique to decrease the paging cost. The proposed protocol is implemented over both random walk and random waypoint mobility pattern. Results obtained proved a reduction in the overall cost up to 47% compared to the direction based location update scheme without prediction. Further, the accuracy of the prediction technique for users with varying speed is increased by issuing a location update message periodically. The slight increase in the update cost is compensated by the savings in the paging cost. This enhancement is implemented over two set of experiments with different cost coefficients. Both produced a reduction in the location management overall cost up to 26% compared to the proposed protocol without the enhancement.

Keywords: Location management, prediction technique, location updates, line paging, cellular networks

1. Introduction

The rapid technological advances in wireless networks and cellular communication have led to the emergence of the mobile computing paradigm, where information is accessible anywhere and at any time. This new paradigm enables almost unrestricted mobility to the users which poses new set of constraints and new kind of challenges that need to be considered in the design of network protocols and information services.

The two main key issues that affect network protocols are mainly mobility and wireless links characteristics. Since mobility became the norm rather than the exception, a user's location information is an additional parameter that needs to be taken into consideration in protocol design. A cost effective technique should be deployed to locate a certain user as well as efficient data structures and algorithms to manage this fast changing data.

A location management algorithm usually involves two main activities: location update and location paging. The location update is the process that is established by the mobile user to specify its location to the wired network. The paging process is the one in which the network is searching for the exact location of the mobile user for call delivery. Both paging and update consume scarce resources like wireless network bandwidth and mobile equipment power, and each have a significant cost associated with it. The total cost for locating mobile user is the cost of the update process performed by the mobile user added to the paging cost established by the network to search for the user. A tradeoff between updating the user's location information as it varies and searching for the user whenever needed has to be maintained. This problem is aggreviated in the third and fourth generation wireless networks where the cell size is expected to shrink and the user population is increasing exponentially.

There exist two main approaches for the adjustment of the number of update and paging processes performed. The first approach focuses on decreasing the number of update messages performed by the user without a great increase in the number of the paging processes. This can be accomplished by requiring from the users to send an update message only when it is necessary. On the other hand, the aim of the second approach is to decrease the paging cost incurred by the network without increasing the update messages. This can be achieved if an intelligent paging technique is deployed that will avoid paging unnecessary cells. A survey of both approaches is presented in [1, 2].

In this paper, we propose an adaptive location update scheme that aims at reducing the overall cost of the location management process by applying a two phase enhancement to the direction based location management scheme proposed in [3]. In this scheme, an update message in sent to the network with the current user location whenever a change in the moving direction of the user is detected. On call arrival, the user is paged for call delivery starting from the last reported cell. The proposed enhancement basically targets the paging cost by deploying a simple prediction technique that will allow for the intelligent paging of cells and hence minimizes the paging cost and at the same time reduces the paging delay. In the proposed protocol, the update message sent to the network includes the user's average speed in addition to its current location. On call arrival, a simple prediction technique is then applied to predict the cell that the mobile user probably moves to, then the paging process starts from that cell and then moving up and down through the user's moving direction line. The direction line of movement for the user is established from the mobility information reported by the user in the last update message. The proposed protocol is implemented over both random walk and random waypoint mobility pattern. Results obtained proved a reduction in the overall cost up to 47% compared to the direction based location update scheme without prediction, assuming users are moving within their average speed reported in their update message. This approach is highly recommended for mobility patterns that applies the trip concept with nearly constant speed.

The second phase of the enhancement aims at adapting to the users moving with varying velocity in order to increase the accuracy of the prediction technique. The same update method is implemented where an update message is sent to the system with the mobile user's location and speed whenever a change in direction is detected. In addition, inspection points are set during the user trip to minimize the deviation between the predicted cell and the actual cell. At each inspection point, the user compares between the paging cost incurred if the predicted cell is used, and the update cost incurred if an update message is sent at that moment. If the paging cost exceeds the update cost, due to deviation between predicted and actual location, an update message is initiated. Otherwise, no action is performed

The inspection points, which are specified according to the study of the user's movement and call history, are useful in enhancing the accuracy of the prediction of the user's location performed in the paging process. On call arrival, the same predictive line paging technique used in the first phase was used to search for the user. This protocol showed a reduction in the total cost of the location management process for users moving with a random waypoint mobility pattern with random acceleration compared to the first phase of enhancement.

The paper is organized as follows. Section 2 describes the system model. Section 3 presents the previous work in the location management track of study. The proposed scheme is introduced in section 4 and its simulation model is presented in section 5. The analysis and results are discussed in section 6. Finally section 7 concludes the paper.

2. System model

We consider a PCS system that is built upon cellular architecture. The service area covered by the wireless network is divided into a collection of cells, each serviced by a base station (BS). A BS is a central host machine equipped with a wireless interface that serves all mobile hosts within its cell. Several BSs are usually wired to a base station controller (BSC), and a number of BSCs are further connected to a mobile switching center (MSC) which acts as the gateway for service area to the wired Network. Mobile users (MH) establish a call through this path with a wireless uplink channel to the wired network; also receive calls the same way back with a wireless downlink channel from the wired network. Database systems are used to store the location of the moving users for call delivery.

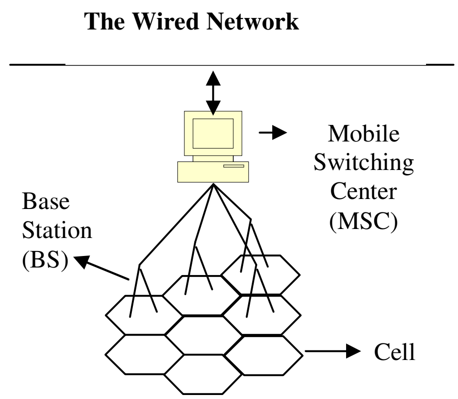

FIGURE1. PERSONAL COMMUNICATION SYSTEM

3. Related Work

Location management algorithms can be classified into static and dynamic algorithms. In the static algorithms, the update operation is minimized according to the network topology. The network area is divided into location areas (LAs) and the user updates its location upon each entry of a new LA [4]. This approach suffers some inefficiency especially for users that are located around LA boundaries and cross these boundaries back and forth frequently. Moreover, LA sizes are fixed for all users without considering their individual mobility and call arrival patterns. Adaptive location areas [5, 6] and overlapping location areas [7] were proposed to reduce the system cost

Dynamic location updates are developed to repair the inefficiency in the static algorithms. The update operation is initiated according to the user's movement pattern and the frequency of its incoming calls. The three most commonly used schemes are: Time based [8], Movement based [9], and Distance based [10] algorithms. They are based on the idea of sending location updates whenever a certain threshold is exceeded. The performance of the three algorithms is compared in [11] and it has been shown that the distance-based location update has the lowest cost.

A variation of the distance-based scheme is presented in [12]. *Adaptive distance based* update algorithms were proposed for supporting arbitrary cell topologies and general distribution of cell residence time. Direction based location management update scheme is introduced in [3] where an update message is sent only in changing of mobile user moving direction. The update scheme is applied with line paging providing reduction in location management cost compared to distance based. A variation of this technique was introduced in [13] where the selection of the threshold is an adaptive process that depends on the periodic change of transition directions.

Prediction methods took place in the studies of the location management problem. Predictive distance based location management was introduce to predict user future location based on his mobility pattern and only updates when the predicted location is away from the actual location with certain threshold[12, 13].

Selective location Update scheme is introduced in [14] that skip location updates in certain LAs. Based on user mobility model and call generation pattern it determines whether or not user should update in LA. This leads to minimize the overall location management cost for a user with a specific mobility pattern and even with moderately high call arrival rate. By the increase in the mobile users this system will need a large amount of repository to memories the update and the non-update areas for each mobile user register in the network.

Other studies perform the update operation based on a prerecorded user profile to determine the most likely LAs to the user to visit [15]. It suggested that the network maintains a profile for each user, which includes a sequential list of the most likely LAs that the user is located at different time periods. This list is sorted from the most to the least likely LA where a user can be found. When a call arrives, the LAs on the list are being paged sequentially. As long as the mobile terminal moves between LAs within the list, no location update is necessary. Location update is performed only when the mobile terminal moves to a new LA which is not on the list. The list may be derived from the user's movement history.

An enhancement to this scheme was introduced in [16]. A categorization of users performed, it treats every user either as Frequent Profile Changer FPC or Less-Frequent Profile Changer LFPC depending on its profile for last period of time. It applies the appropriate location update and paging schemes for each category.

LeZi-update described in [17] works as an add-on module to any update scheme. The LeZi update algorithm can be considered to be a *path-based* update scheme in which the *movement history* rather than the current location is sent in an update message. The responsibility of generating the movement history of a mobile still lies with the primary update scheme. The network database maintains the movement history in a compact form that can be considered as a user profile. Upon a call arrival, selective paging based on the information provided by this profile is used to locate the mobile terminal. However, a real update message is not sent immediately. The LeZi-update algorithm captures the update message and tries to process it in chunks, meaning that it delays the actual update for some sampled symbols. When it finally triggers an actual update, it reports in an encoded form the whole sequence of movements *(User Profile)* since the last Update.

In [18] moving location area concept is introduced in which a group of users with near mobility patterns share the same update operation. This scheme is applied for users moving in the same path according to geographical restrictions, like users moving in high ways.

To reduce the paging cost, paging unnecessary cells should be avoided. The *velocity paging scheme* [19] aims to reduce the paging cost by decreasing the size of the paging area. It introduces the *velocity class* concept, in which users are grouped according to their velocity observed at the location update instance. It generates a velocity class index at each LA or cell, in which the next cell or group of cells is stored according to the velocity class of a user assumed to update at this cell or LA. When a call arrives, the paging area is dynamically generated based on the user's last registration time and the velocity class index. The velocity paging scheme can be deployed on top of other location update algorithms.

Location update and paging strategies for hierarchical macrocell/microcell cellular network can be found in [20, 21, 22].

4. Proposed Algorithm

In Direction Based Location Management Scheme proposed in [3] a mobile user performs location update only when the user moving direction changes. Three moving directions were used as shown in figure 2. The directions A-D, B-E, F-C represent North-South, Northern East- Southern West, and Northern West-Southern East directions respectively. At the entry of a new cell the user checks if its moving direction has been changed from the last updated direction, if a change in direction is detected the mobile user sends and update message with its new location and moving direction. To establish a call to that mobile user the system performs a line paging technique starting from the last updated cell going up and down over the line of the last updated moving direction until the user is found. This scheme is implemented to users moving with a random walk mobility pattern and it showed an improvement in location management performance over the distance based location update strategy [3].

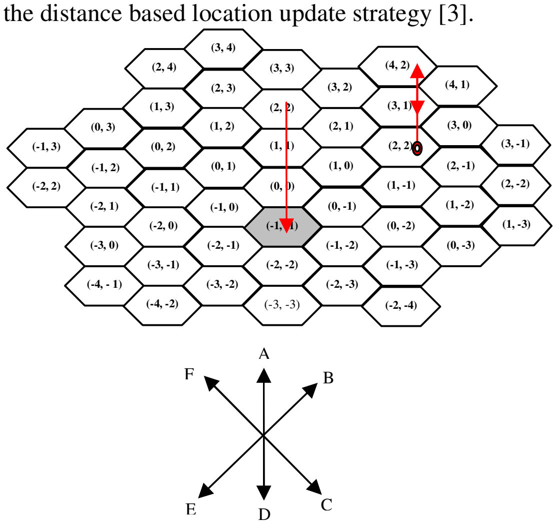

FIGURE2. A SAMPLE OF THE WIRELESS NETWORK, AND THE MOVING DIRECTIONS

This paper presents a two-phase enhancement to the Direction Based Location management scheme in order to decrease the total cost for mobile users' tracking. The enhancement phases exploit the predictability of user mobility patterns in wireless PCS networks. A mobile's future location is predicted by the network, based on the information gathered from the mobile's last update message. When a call is made, the network line pages the destination mobile starting from the predicted location.

4.1 Phase-1

Our aim is to decrease the paging overhead by combining an enhanced direction location update mechanism along with predictive line paging. The prediction of the user movement is based on the mobile user's mobility information that can be reported in its update messages. The same cell identification mechanism used in [3] was used, assuming six moving directions {A, B, C, D, E, F} as shown in Figure 2. Once a change in direction from the last updated direction of movement is detected by the mobile user upon its entering a new cell, an update message is sent to the system including the mobile user's new direction of movement. On call arrival to the mobile user, a prediction for the cell that the user may reside in is performed based on user mobility information included in the update message and with the assumption of an average velocity of the mobile user Vav. Then line paging takes place starting from the predicted cell then up and down in the moving line of direction until the user is found. The two main activities in the algorithm can be described as follows:

A. Location updates:

Assuming that the last direction reported in the last update message for the user is know, when a change in moving direction is detected, the mobile user makes an update message to the network. The update message includes the user new direction D_u and time of update T_u.

B. Paging:

On call arrival the system calculates the user expected cell by using the call arrival time T_c and the last update message time T_u, the difference between these two time instances is denoted as ΔT.

$$\Delta T = T_u - T_c \qquad (1)$$

Using ΔT along with the assumed average velocity Vav, the distance traveled by the mobile user, d, is calculated as follows:

$$d = Vav * \Delta T \qquad (2)$$

Knowing the cell size, then the number of cells crossed by the mobile user is:

$$\text{No. of cells crossed} = d / \text{Cell size} \qquad (3)$$

Knowing the mobile user's direction of movement Du from the last update message, and calculating the number of cells crossed, the expected cell can be easily identified. Starting from the expected cell, the line paging scheme is applied to page the network for the user in the line of moving direction of the user. Line paging pages the cells only in the moving direction up and down the expected cell until the user is found.

To illustrate the scheme assume the last update message was at time to = 0 including the following: cell (2, 2), moving direction Du = D, and average speed of 5 m/sec. Assuming the cell size is 5 meters and a call arrives at tc = 3. Applying (1), then $\Delta T = 3$. Then by substituting ΔT in (2), then d = 3 * 5 = 15 meters. Thus the number of cells crossed by mobile user is 15/5 = 3 cells in the direction D. Therefore, the cell in which the user is expected to be is (-1, 1). Thus the paging process starts paging the cell (-1, 1). If mobile user is not found, then paging (0, 0) and (-2, -2). If also mobile user is not found then paging (1, 1) and (-3, -3) and so on until the user is found. If mobile user is not found then the system will page the entire network area.

4.2 Phase-2

Users do tend to move with acceleration, thus an average velocity for prediction will not results in an accurate predicted locations for users moving with a changing velocities. So an adaptation to the prediction technique used in the predictive direction based location update scheme is proposed to enhance the prediction accuracy. The prediction accuracy can be improved by the phase-2 proposal. The same direction update technique used in phase-1 is implemented. Also inspection points in time are developed to decide whether to make an additional update message or not. This decision is based upon the comparison between the cost of an update message made at the inspection point and the paging cost from the predicted location of the moving user. The inspection points are determined according to the history of movements and calls delivered to the mobile user in a sampling period. The same cell identification code and directions used in phase-1 is implemented in this proposal. The Adaptive Direction Based Location management technique scenario is as follows.

4.2.1 Sampling Period:

A sampling Period for a user that first registers to the system is taken to observe the number of cells crossed by the user and the number of calls that need to be delivered to that user. The mobile user sets a counter that increment upon each cell entry. Another counter is set upon each call arrived to that user. At the end of the sampling period the mobile user can calculate the mobility to call ratio of it that will be used as its inspection interval.

Inspection Interval = Number of Moves / Number of Calls (4)

The inspection interval is a point in time at which the mobile user compares the cost of the update operation and the paging cost that will be done at this point of time to decide whether to send an update message of its location to the system or not. This operation will be explained in details in the next section.

4.2.2 Location Updates:

Location update message is sent by the mobile user in two cases:

First: At each cell entry, assuming that the last direction reported in the last update message is known, the mobile user checks for a change in direction from the last reported moving direction. If a change in direction is detected an update message with the new direction, location, speed and time is reported to the network.

Second: When an inspection point in time is reached the mobile user calculates the paging cost from the predicted cell to the current cell:

$$\text{Paging Cost} = Cp * \text{No.Of.Cells} \qquad (5)$$

Where Cp denotes the cost of paging one cell and No.Of.Cells denotes the number of cells that could have been paged applying a line paging technique starting from the predicted cell up and down over the line of direction of the last reported message until the current cell is reached. A comparison between the Update Cost and the Paging Cost is performed, where the update cost is the cost of sending one update message to the system Cu. If the update cost is less than the paging cost an update message is sent, otherwise no actions are to be taken from the mobile user side.

4.2.3 Paging:

On call arrival the system calculates the user expected cell. It calculates ΔT, the time between the call arrival time Tc and the last update message time $T_{u,}$ the same way used in phase-1 using (1). Using ΔT along with the last reported velocity of the user Vu, the distance traveled by the mobile user d is calculated:

$$d = \Delta T * Vu \qquad (6)$$

Also the number of cells crossed by the mobile user is calculated using (3) in phase-1. Then the same line paging technique used in phase-1 is applied to search for the mobile user's location starting from the expected cell, paging in the moving direction line up and down until the user is found.

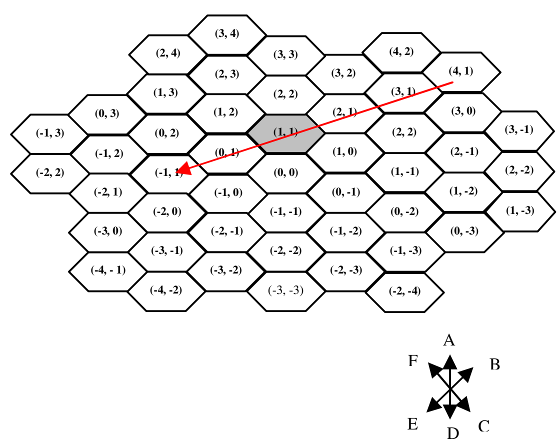

FIGURE 3.EXAMPLE OF ADAPTIVE DIRECTION LOCATION MANAGEMENT SCHEME

Consider the example in Figure 3, assuming that the sampling period proposed an inspection interval every 3 cells moved by the user, Cu = 0.5 and Cp=1. The last update message was at time to = 0 including the following: cell (4, 1), moving direction Du = E, and velocity = 5 m/sec. Assuming the cell size is 5 meters and a call arrives at Tc =3. Then the user changes its velocity in cell (3, 1) to be 10 m/sec.

At cell (1, 1) the inspection interval is reached and the current time Tcurr= 2sec. The update cost is equal to Cu = 0.5. To calculate Paging cost, (1) is applied first to calculate the time the user took from the last update message. So $\Delta T = 2$. Then by substituting ΔT in (6), then the distance traveled by the user d = 2 *5 = 10 meters. Thus, applying (3), the number of cells expected to be crossed by the mobile user is 10/5 = 2 cells in direction E. Therefore, the cell in which the user is expected to be is (2, 1). To reach the actual cell the user currently in, the system has to page cells (2, 1), (3, 1) and (1, 1). Applying (5), then Paging Cost = 1 * 3 = 3.Comparing the paging cost with update cost then the system will send an update message including the following: Tu = 2, cell (1, 1), moving direction Du = E, and velocity = 10 m/sec. At time Tc =3 a call arrived to the user. The same prediction technique is applied, using equations (1), (6) and (3) then expected cell for the user is (-1, 1). Thus the system has to page only the cell (-1, 1) to find the user for call delivery.

5. Simulation model

The proposed algorithms were implemented to calculate the cost per unit of time for mobile users with different mobility to call ratios. The implementation was constructed as follows:

- **Network modeling**: Using the same cell identification coding system used in [3], our coverage area consists of 14*14 hexagonal cells, thus each having six neighbors. Each cell is identified by x and y axis starting from the center cell of the entire network as the cell with x = 0 and y = 0.

- **Call modeling:** Calls arrive for mobile users according to Poisson distribution with mean λc = 1 per unit of time.

- **Mobility modeling:** The simulation model implements the users cell residence time with Poisson distribution with mean λr.

For the first phase, the simulation model implements the user movements through cells according to both complete random mobility model and random waypoint mobility model introduced in [23] with and average velocity Vav=1 and cost coefficients for sending an update message Cu =0.5 and for paging one cell Cp = 1.

For the second phase only the random waypoint mobility model is implemented. The system runs two sets of experiments for different values of the cost coefficients for sending an update message Cu and paging one cell Cp. The first experiment sets Cu=1 and Cp = 1. The second experiment sets Cu=0.5 and Cp= 1.

- **Performance measurements:** The system calculates the cost per unit of time for the moving users as values for their mobility to call ratio varies from 0 to 10.

- **Simulation results:** Each point on the curve is an average of 20 runs for the simulation model with confidence interval of 90%.

6. Analysis and results

6.1 Phase-1

Predicted Distance location management scheme was implemented over users moving with waypoint mobility pattern. Figure 4 shows that Predictive Direction location update scheme reduces location management total cost up to 47% compared to the Direction Location management scheme. This reduction is due to the nature of the mobility pattern in which the mobile users travels into a series of predicted small trips.

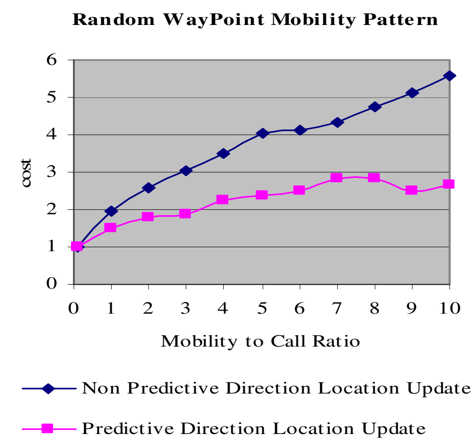

FIGURE 4. COMPARISON OF TOTAL COST FOR RANDOM WAYPOINT MOBILITY PATTERN

Figure 5 shows Predicted Distance location Management scheme implemented over users with complete random walk mobility model and produces the same total cost for low values for mobility to call ratios and a slight increase in total cost for higher values of mobility to call ratios up to 11%.

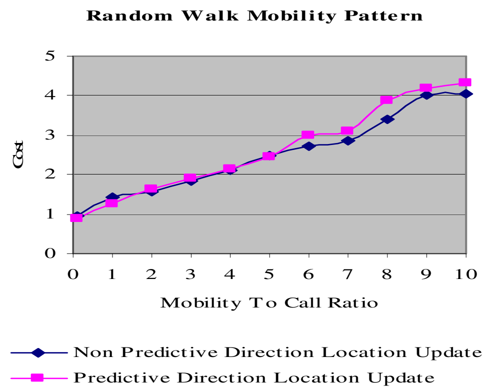

FIGURE 5. COMPARISON OF TOTAL COST FOR RANDOM WALK MOBILITY PATTERN

Studies for mobility patterns showed that random walk mobility patterns are not reflecting the real mobile users' movements [24]. A random waypoint mobility pattern is introduced in [23], in which users tend to move in a series of trips; each trip is traveled by the mobile user in a straight way to a certain destination in mind.

6.2 Phase-2

The performance of the proposed algorithm is compared to the Direction Based Update scheme proposed in [3] and the Predictive Direction Based Update technique; Phase-1. For the Predictive Direction Based Update scheme implementation the update message contains the user's velocity to be used in the prediction of the expected cell instead of using an average velocity. The waypoint mobility pattern implements movements of the users in the three protocols. Figure 6 shows the first experiment that uses equal cost coefficient for both sending an update message and paging one cell. It can be seen that Adaptive Predictive Direction location update scheme showed reduction in location management total cost than the Direction Based Location Management scheme up to 38%. Also a reduction in total cost than the Predictive Direction Based Location Management scheme is obtained up to 25%. This reduction is due to the inspection points that reduce the uncertainty in the prediction for the mobile user movements.

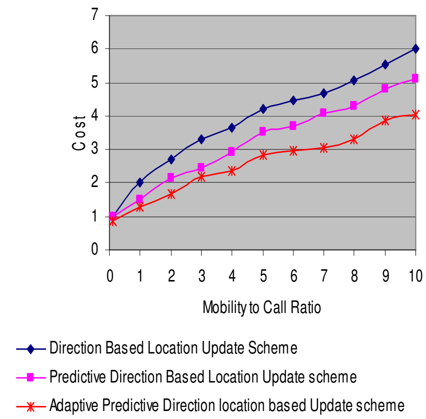

FIGURE 6. COMPARISON OF TOTAL COST USING CU=CP=1

In Figure 7, the results of the second experiment that uses cost coefficient for sending an update message half the cost coefficient for paging one cell can be shown. The Adaptive Predictive Direction location update scheme showed reduction in location management total cost than the Direction Based Location Management scheme up to 44%. A reduction in total cost is shown than the Predictive Direction Based Location Management scheme 26%.

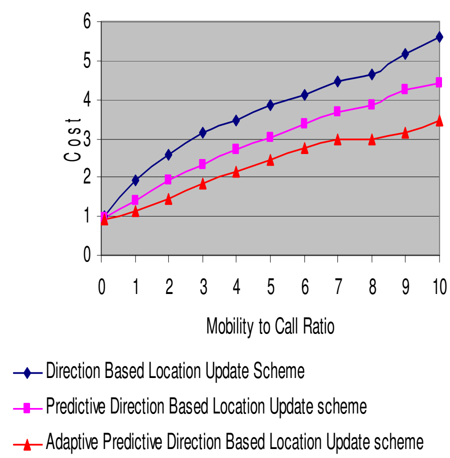

FIGURE 7.COMPARISON OF TOTAL COST USING CU=0.5 AND CP=1

7. Results and conclusion

Location management plays an important role in the next generation PCS systems. It can ensure almost unrestricted user mobility allowing them to move freely while being able to send/receive calls. In this paper, we propose a 2-phase enhancement for the Direction based Location Management update scheme introduced in [3] in order to reduce the total location update and paging cost.

The proposed protocol combines an enhanced direction location update technique with predictive line-paging to locate mobile terminals. The scheme is applied for both random walk and random waypoint mobility patterns; the later consists of a series of trips.

The simulation results show that the proposed scheme can reduce the location management cost by up to 47% compared to the Direction Based Location update scheme with line paging for users moving with random waypoint mobility pattern, while a slight increase in the cost of up to 11% has been noticed for users moving with complete random walk mobility pattern and high mobility to call ratio.

An Adaptive Predictive Direction Location Management scheme is proposed next, which is useful to increase the accuracy of the prediction technique used to predict the user location for call arrival delivery. The proposed update technique is used along with predictive line paging to search the mobile terminals. The proposed enhancement is applied to users moving with random waypoint mobility pattern. The simulation is experimented with different sets of cost coefficients; the first experiment sets the cost of sending an update message equal to the cost of paging cells, which showed a reduction in the total location management cost up to 25% compared to the Predictive Direction Location Management approach. Also the other experiment, which sets the cost of sending an update message half of the cost of paging one cell, showed a reduction in the total location management cost up to 26% compared to the Predictive Direction Location Management approach.

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