A Dynamic Location Management Scheme based on individual metrics and coordinates

Bjorn Landfeldt* and Natalie Kolodziej**
*School of Information Technologies
University of Sydney
NSW, 2006, Australia
bjornl@it.usyd.edu.au

**Telstra PTY/LTD
Level 7, 400 George Street
NSW, 2000 Australia
Natalie.Kolodziej@team.telstra.com

Abstract

Location management in cellular networks have been in focus for the research community for a number of years. The current static method of determining location or paging areas has been shown to be sub-optimal and costly for operators. Therefore, much research has been focussed on dynamic schemes, which show great promise in cost optimisation. However, the research has still been focussed on aggregation of user behaviour and location area determination based on the aggregate.

In this paper, we present another solution and argue that per-user behaviour based schemes will perform even better than the aggregate schemes. We present an analytically based proposal, which delegates the responsibility of performing individual updates to the terminals, making the scheme easy to deploy in current cellular systems. In addition, we simulate the relative cost savings obtained compared with the currently used static schemes. The results indicate that our proposed method can cut the cost of location management significantly and free up valuable spectrum for user data.

1. Introduction

Location management is a fundamental issue in cellular networks. There have been a number of schemes proposed for locating users in mobile networks, each attempting to make the process of tracking and locating users efficient and of minimal cost. Essentially, these schemes consist of two basic procedures, location update (or registration) and paging. Current schemes involve a combination of these two methods [1], with an ultimate goal to balance the registration and paging operations in order to minimise the cost of mobile terminal location tracking.

The issue will also become increasingly important as cellular networks evolve and become integrated with Wireless Local Area Networks such as IEEE 802.11. Currently, such integration is widely considered as the most likely scenario for future generation wireless networks. As the number of base stations increase, the burden of location management increases and the resources utilised for this purpose consequently increase as well. Thus, it is essential to be prepared for this scenario with efficient location management schemes in place.

In this paper, we build on the knowledge gained from previous research and propose a novel method for locating terminals in cellular networks. Our proposal has the advantage of being efficient while at the same time being easy to deploy in current cellular infrastructure. We combine a simple mathematical cost function with a coordinate system and distribute the decision of when to make handovers to terminals in order to facilitate this. We also compare the cost of location management using our proposed scheme with the currently in cellular systems used static scheme, through a simulation study. The results show that our scheme consistently outperforms the current scheme and can drastically save on location management cost.

2. Background and previous work

Various strategies have been proposed for both location updating and paging operations. The most widely used are the static schemes implemented in current cellular networks since they are the easiest to implement[2,3,4].

Dynamic schemes are more complex and typically require more infrastructure support. However, they show much better performance in terms of cost optimisation. Therefore, recent research has been focussed on this area.

2.1. Dynamic Location Update Strategies

Dynamic update strategies account for the dynamic behaviour of the user, as each user decides when and where to update its location, resulting in a lower location management cost. Thus, updates may be generated in any cell, and the mobility and call arrival patterns of each user are considered. Three dynamic location update strategies are examined in [5, 3, 6] and [7].

2.1.1. Time-based strategy

In this location update strategy, an MT performs location updates periodically, at a constant time interval of $\Delta\mathbf{T}$. This strategy is effective as each MT needs only an interval clock to keep track of the time that has passed since its last Location Update, LU, and the value of $\boldsymbol{T}$ may be adjusted for each user In [6], it was found that the signalling load within the network may be reduced using this strategy, as the network will know the MT is turned off (or 'detached') if it does not receive a period location update from the MT, thereby not performing unnecessary paging operations. However, using this strategy suggests that users with low movement rates will still perform location updates periodically, thereby generating unnecessary network traffic [3] if they have only moved to surrounding cells, or in the worst case, if they have not moved at all. However, [10] found that this time-based strategy method of location updating performed better than the location area method.

2.1.2. *Movement-based strategy*

This strategy involves an MT performing a location update after a certain number of movements across cell boundaries. The predefined number of movements *M* is referred to as the *movement threshold* [5] and the value of *M* may be adjusted for each user. This scheme therefore limits the radius of an MT's location since the last location update to *M* cells. Hence upon call arrival, the paging operation can be limited to those surrounding cells within radius *M*. This reduces paging area, thereby conserving network resources.

2.1.3. *Distance-based strategy*

In distance-based LU strategies, an MT performs a LU when it has moved a distance *D* from the cell where it performed the last location update. *D* is a predefined distance, and is referred to as the *distance threshold* [5]. Using this strategy, location updates may only be performed in the cells at radius *D* from the last LU cell, thus limiting the paging operation in a similar way to the movement-based strategy discussed above. Distance-based location update strategies are essentially the most difficult to implement [4]. This is because the mobile terminal needs to retain information about the starting location in order to calculate the distance *D*. Since user mobility patterns generally fit the Markovian random-walk model [8], the user may move in any direction from the starting location, and the calculated distance *D* would need to adjust as required.

The dynamic location area strategy proposed in [13] dynamically determines the size of a mobile terminal's location area according to the terminal's incoming call arrival rate and mobility. The analytical results presented indicate that when call arrival rates are dependent on individual users or time, this strategy is an improvement over static location update strategies. [9] introduced a distance based dynamic location management scheme using local VLR clusters. The scheme is based on the IS-41 architecture, which allows it to easily interface with existing networks. It was found that the proposed scheme performed significantly better than IS-41 for typical call mobility ratio (CMR) values.

2.2. Summary

A large body of work has been done previously in the area of location management and it is impossible to provide information about all proposals in this paper. Thus, we summarise the commonalities of the previous research and detail how our proposal is different as such:

Current research has focussed on determining location areas (LA) depending on the aggregated behaviour of users, and therefore the network has determined the optimum location areas based on user input. Both static and dynamic schemes have been proposed. However, there are two problems with the approach of determining common location areas based on aggregated user behaviour. Firstly, aggregation of data can never become optimal since individual terminals will behave different to the generalised behaviour. Secondly, it is suggested in [5] that excessive location updates may be performed by terminals that are located around LA boundaries, especially if the mobile user is making frequent movements back and forth between the two LA. This results in a large overhead expense and an inefficient use of network resources. Several strategies have been proposed to reduce this 'ping-pong' effect, including the two location area (TLA) scheme [11] and the virtual layer scheme (VLS) [12]. Although these strategies may assist in reducing the ping-pong update effect over the boundary between two LA's, they are not effective in 'corner' situations. A corner is the intersection of three LA's and movement around a corner is known as the 'generalised ping-pong effect'.

In the following section, we detail our proposed scheme which determines a *unique LA for each terminal* taking the individual call arrival rate and movement patters into account. In doing so it optimises the cost saving to a degree not feasible with common LA schemes. In addition, our approach does not require vast changes to the current cellular network infrastructure.

3. Our proposed scheme

The proposed scheme has two major components, a cost function which is used to determine the location area size for each individual terminal and a coordinate system which enables terminals to take responsibility for triggering location updates instead of the network. In this section we detail these components and also show how they can be integrated into existing infrastructure with a small impact.

In our initial research we have chosen to follow previous research by making some assumptions about the network. Firstly, there is a difference in cost between location updates and paging messages set to a factor of 10:1 as in [3,13,15] among others. This is a somewhat arbitrary value, which is system dependent. Secondly, we assume that the network consist of an infinite hexagonal mesh. Even though this assumption does not hold true in real networks, it follows on previous research and allows us to benchmark. We intend to investigate the effects on performance by other network layouts in later research studies. Thirdly, we assume that user movement is random which has been shown to be a good approximation in [14].

3.1. Cost function

Taking the above assumptions into account, since movement is random and we cannot predict any direction we can assume a paging area shape of a hexagon with radius r. Thus, the number of cells in a paging area can be describes as a function of the radius as: $1+\sum_{1}^{r} 6r$ cells, (0.1)

The paging operation is carried out each time an incoming call is received. When this occurs, paging messages of size ς_p bytes are sent to each cell within the current paging area. Thus, the paging cost can be given by:

*Paging Cost = # incoming calls per hour * paging message size * # cells in paging area*

$$C_{PAGING} = \lambda.\varsigma_P.N_C \qquad (0.2)$$

where the cost is measured in bytes per hour.

The total cost of location updating is the product of the number of location updates and the size of each location update message. The size of each location update message, measured in bytes, will be given by ς_{LU} As discussed earlier, $\varsigma_{LU}:\varsigma_P$ is approximated as 10:1 due to among other things the need to set up a signalling channel for location updates.

It is now necessary to calculate the number of location updates given a user's movement rate. The movement rate, μ, is defined as the number of handoffs made per hour. If we divide this movement rate by the average number of handoffs made before exiting from a location area, we will have the average number of location updates performed per hour. We refer to the average number of handoffs as the *probability* that the user will make a certain number of moves before moving out of a location area.

Thus, the cost of location updating can be given by:

*Location Update Cost = Movement Rate / Probability for current radius * LU message size*

$$C_{LU} = \frac{\mu}{P_{LA}}.\varsigma_{LU} \qquad (0.3)$$

where the cost is measured in bytes per hour.

As the proposed location management scheme contains a combination of both location updating and paging to locate and track users, the total cost of location management is comprised of the sum of the costs of these components. We can represent this as:

Total Cost = Location Updating Cost + Paging Cost

$$C_{TOTAL} = C_{LU} + C_{PAGING} \qquad (0.4)$$

Substituting C_{LU} and C_{PAGING} with the formulae derived in (0.2) and (0.3), we obtain:

$$C_{TOTAL} = \frac{\mu}{P_{LA}}.\varsigma_{LU} + \lambda.\varsigma_P.N_C \qquad (0.5)$$

3.2. Coordinate system

Since our method is based on input from each mobile terminal and each terminal gets assigned individual location areas based on their movement and call arrival rate history, the system needs a way of telling the terminal of it's location area. Once the terminal knows the location area, it can monitor when the LA boundary is crossed itself and not burden the network with such monitoring. In order for the terminal to easily identify LA boundary crossings, base stations can be placed in a coordinate system, which identifies their geographic location in the network. The coordinate system used should reflect the layout of the network taking into account cells shapes and network boundaries.

In our experiments we have assumed an infinite mesh of hexagonal cells and therefore, the coordinate system used is a simple Cartesian system as shown in figure 1.

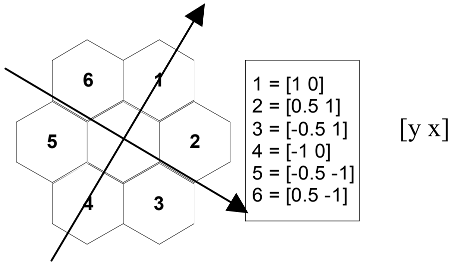

Figure 1 . Coordinate system for use in a hexagonal mesh

Beginning from the centre cell each neighbouring cell is given a relative coordinate in two dimensions. It is then very simple for a terminal to determine the distance from any given cell from the initial cell using a simple vector operation:

$$r = [y \;\; x]_{current} - \;\; [y \;\; x]_{centre} \qquad (0.6)$$

3.3. Movement pattern

A number of ways of modelling user movement have been proposed in the literature. The fluid flow model [15] has been used to describe user movement in cellular networks. However, this model aggregates user movements and is therefore not suitable for our purposes. The random walk model assumes an equal probability of movement from a given cell to any of its neighbours. It has been indicated in [16] that this model is a good approximation in densely populated areas and being a simple model and applicable to an infinite mesh, we have used it in our experiments. A third proposal is the Markovian movement model [8], which combines random properties with a net directional component through the assignment of different probabilities in different directions. This model has the advantage of being able to capture directional movements such as users travelling along highways.

In our assumed hexagonal cell layout and with the random walk movement pattern applied, the location area will take on a hexagonal shape of radius δ. Thus, when the network determines the size of the new LA, it simply notifies the terminal of the radius to the LA boundary. Hence, the terminal detects a LA boundary crossing by analysing if condition (0.7) is true or false:

$$abs\left([x \;\; y]_{current} - \;\; [x \;\; y]_{centre}\right) \le \delta \qquad (0.7)$$

3.4. System integration

A nice feature of the proposed scheme is that it does not require major changes to existing cellular infrastructure to be deployed. The cost function is very simple to calculate which means that the node, which calculates the location areas in the network is a small function. The terminals need to be able to perform additional functions compared with the current static scheme. In addition they need to keep track of movement and call arrival and also the coordinate of the current cell. Fortunately, the information needed is already present at terminals. Cell IDs are available by passively listening to the control channel, movement history is derived from the cell IDs and call arrival history can be passively logged. It is possible to implement the revised signalling function in terminal hardware but other possibilities are for example, using the program portion of the SIM card.

4. Experiments

We have carried out a number of simulations to verify our model and to quantify the relative cost savings compared with the current static method. However, before the cost simulations we needed to determine the parameters to go into the cost model.

Since we assume an infinite hexagonal mesh and a random walk movement for terminals, we need to define the average number of moves a terminal makes before crossing the LA boundary. We have therefore simulated random walk movements in LAs with a radius r, $1 \leq r \leq 10$ where the probability of a terminal moving to a neighbouring cell is 1/6 for all cells. Our results are shown in, and based on 3 simulations of 1 million trials each for every radius using Matlab.

Table 1. Average moves before crossing LA boundary

Radius	Paging area size	Average moves
0	1	1
1	7	3.33
2	19	8.05
3	37	14.75
4	61	23.5
5	91	34.25
6	127	47.0
7	169	61.8
8	217	78.5
9	271	97.2
10	331	117.8

4.1. Minimum cost simulations

Taking the average number of movements into account, we found the least cost location area for different combinations of μ and λ. We expected to find that very mobile terminals would benefit from increased location area sizes and that terminals with high incoming call arrival rates would benefit from decreased location area sizes which is indeed true. Figure 2 shows the cost function for different combinations of μ and λ.

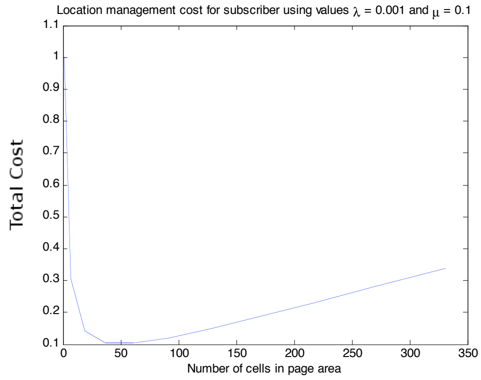

Figure 2a, μ = 0.1 and λ = 0.001

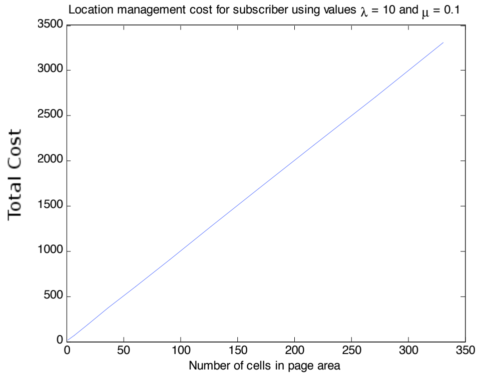

Figure 2b, μ = 0.1 and λ = 10

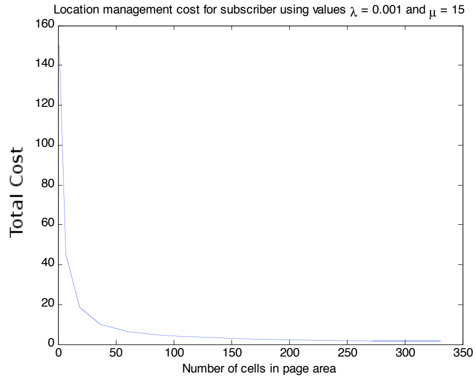

Figure 2c, μ = 15 and λ = 0.001

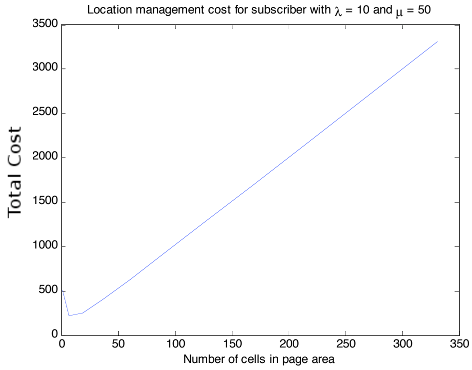

Figure 2d, μ = 50 and λ = 10

As can be seen from the figure, in the extreme case, where terminal mobility is high and incoming call rates are low the least cost LA is as large as possible (never update) whereas in the other extreme when terminal mobility is low and incoming call rates are high, the least cost paging area is the smallest possible (always update). In-between the two extremes the least cost area has a local minimum.

By simulating all combinations of $0 \leq \lambda \leq 10$ and $0 \leq \mu \leq 50$ we identified the following relationship between μ and λ resulting in the least cost LA in the case of infinite hexagonal mesh and random walk:

$$N_C = \frac{7\mu}{\lambda} \tag{0.8}$$

and applying the following conditions:

```
if 0 < $N_c$ ≤ 6 then Paging Area = 1
else if 6 < $N_c$ ≤ 48 then Paging Area = 7
else if 48 < $N_c$ ≤ 342 then Paging Area = 19
else if 342 < $N_c$ ≤ 680 then Paging Area = 37
else if 680 < $N_c$ ≤ 1610 then Paging Area = 61.
```

It should be noted that these results are not determined by mathematical modelling since the exact formulation for this case is not relevant to real cellular networks. Our main aim with these simulations are to show that our method works well in the same scenarios as previous work to justify and inspire future research as detailed in section 5.

4.2. Comparison with static schemes

In order to quantify the relative advantage of using a per-user based scheme to using a static scheme we have made a direct comparison between the two.

We have used the Stanford University Mobile Activity TRAces (SUMATRA), which aim to provide a common benchmark for researchers in the wireless community, enabling a direct exchange of performance results and thus avoiding inaccuracies. SUMATRA is a trace generator that encompasses several calling and mobility models, and is well validated against real calling and mobility trace data [17].

The SUMATRA values for the average movement and call arrival rates within the network are 0.3 moves per hour and 2 calls per hour. Therefore, $\mu = 0.3$ and $\lambda = 2$.

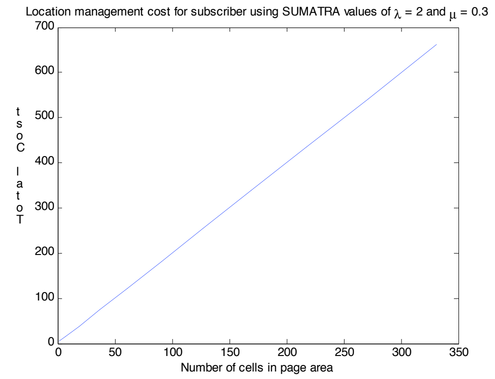

Figure 4, Location management cost for SUMATRA values

Simulating the location management cost using these values yields the results shown in Figure 4. The graph shows that the minimum cost occurs when the paging radius is 0 i.e. the paging area is 1 cell for these values.

In order to benchmark our dynamic scheme with the static scheme, we therefore use the lowest cost possible for the average user when using the static scheme, i.e. LA = 1 cell. Therefore, the location management cost plots shown below are actually a *best-case* scenario for the current model, as any deviation from the average would result in a higher cost.

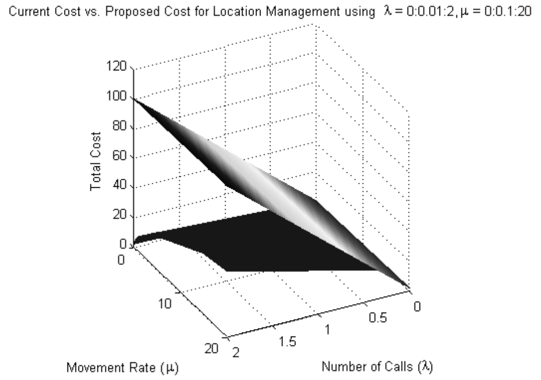

Figure 5a, C = 10

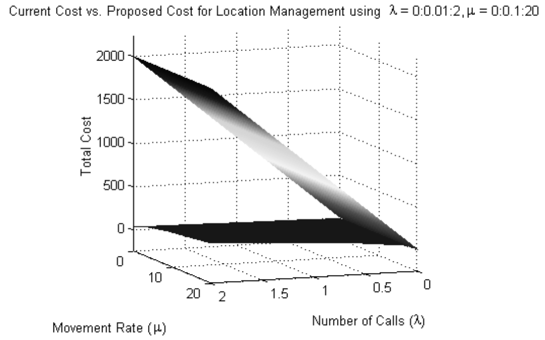

Figure 5b, C = 5

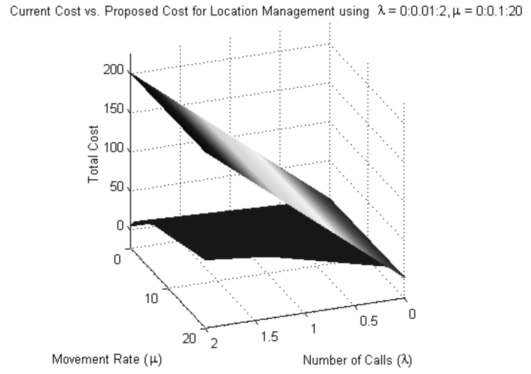

Figure 5c, C = 100

4.2.1. Results

We simulated the location management cost using different c, μ and λ. In order to summarise our results and to highlight the advantage of using our per–terminal based scheme we show 3 dimensional plots of the total cost when $0 \leq \mu \leq 20$ and $0 \leq \lambda \leq 2$. Figure 5 shows the cost when c = 10, when c = 5 as in [18] and also when c = 100. The solid black plane represents our proposed method and the shaded grey plane the static method. The figures show that our proposed method outperforms the static scheme in all cases apart from when all terminals conform to the average norm in which case the performance is equal. In addition, we also find that our scheme outperforms the static scheme regardless of the value of c. Thus, we can conclude that our scheme is applicable to all forms of networks and that there always will be a cost saving of varying size.

5. Conclusions and future research

In this paper we have presented a novel method for location management in cellular networks using individual per-terminal information for optimising the management cost. Our method has the additional advantage that it is relatively easy to deploy in that it relies on a relatively low complexity cost function, which does not require excessive computations in the network coupled with input parameters that are already known to the terminals.

Our experimental results show that the scheme outperforms the currently used static scheme in all scenarios. In addition, using different values for the cost relationship between location updates and paging messages, we have shown that our scheme is applicable to different kinds of networks with different costs.

We have followed previous research and presented results for an assumed hexagonal mesh as a network model. However, real networks differ significantly from this model. Therefore, in our future research, we will revise our scheme to take real network topologies into account. In addition, we will determine the real cost ratio between location updates and paging messages in different cellular network types and also include other movement models such as the Markovian model into our experiments.

References

[1] D. G. Jeong and W. S. Jeon, “Effective Location Management Strategy Based on User Mobility Classes”, IEEE Global Telecommunications Conference, Vol. 3, pp. 1426–1430, 1998.

[2] F. Galliano et al, “Cellular Network Optimisation Based on Mobile Location”, Cello Consortium, Document ID: CELLO-WP5-MTCI-D09-005-Apr, August 2001.

[3] R. Subrata and A. Y. Zomaya, “Location Management in Mobile Computing”, Computer Systems and Applications, ACS/IEEE International Conference 2001, pp. 287–289, June 2001.

[4] B. Furht and M. Ilyas, “Wireless Internet Handbook – Technologies, Standards and Applications”, Chapter 15, CRC Press, 2003.

[5] I. F. Akyildiz, J. McNair, J. S. M. Ho, H. Uzunalioglu, W. Wang, “Mobility Management in Next-Generation Wireless Systems”, Proceedings of the IEEE, Vol. 87, No. 8, pp. 1347 – 1384, August 1999.

[6] H. Levy and Z. Naor, “Minimising the Wireless Cost of Tracking Mobile Users: An Adaptive Threshold Scheme”, Proceedings IEEE Conference on Computer Communications, Seventeenth Annual Joint Conference of the IEEE Computer and Communication Societies, 1998.

[7] A. Bar-Noy, I. Kessler and M. Sidi, “Mobile users: To update or not to update?”, Wireless Networks, Vol. 1, No. 2, 175–186, 1995.

[8] S. Tabbane, “Location Management Methods for Third-Generation Mobile Systems”, IEEE Communications Magazine, August 1997.

[9] J. H. Zhang and J. W. Mark, “A Local VLR Cluster Approach to Location Management for PCS Networks”, Wireless Communications and Networking Conference, IEEE, Vol. 1, pp. 311–315, September 1999.

[10] C. Rose, “Minimising the Average Cost of Paging and Registration: A Timer-based Method”, Wireless Networks, Vol. 2, pp. 109–116, 1996.

[11] Y. B. Lin, “Reducing Location Update Cost in a PCS Network”, IEEE/ACM Transactions on Networking, Vol. 5, No. 1, pp. 25–33, February 1997.

[12] D. Chung, H. Choo and H. Y. Youn, “Reduction of Location Update Traffic Using Virtual Layer in PCS”, Proceedings of the 30th Annual International Conference on Parallel Processing, Valencia, Spain, pp. 331–338, September 2001.

[13] H. Xie, S. Tabbane and D. J. Goodman, “Dynamic Location Area Management and Performance Analysis”, Proceedings of the 43rd IEEE Vehicular Tech. Conf., pp. 536–539, 1993.

[14] I.R. Chen, T.M. Chen and C. Lee, “Analysis and comparison of location strategies for reducing registration cost in PCS networks”, Wireless Personal Communications, Vol. 12, No. 2, pp. 117–136, 2000.

[15] N.A. Bar and I. Kessler, “Tracking Mobile Users in Wireless Communication Networks”, IEEE Transactions on Information Theory, Vol. 39, pp. 1877–86, 1993.

[16] J. Chan, B. Landfeldt, A. Seneviratne and P.Sookavatana, “Integrating Mobility Prediction and Resource Pre-allocation into a Home-Proxy Based Wireless Internet Framework”, IEEE ICON 2000, September 2000.

[17] Stanford University Mobile Activity TRAces (SUMATRA) http://www-db.stanford.edu/sumatra

[18] T. Kunz, A. A. Siddiqi and J. Scourias, “The Peril of Evaluating Location Management Proposals through Simulations”, Wireless Networks, Vol. 7, Issue 6, pp. 635–643, November 2001.