

Performance of a Distributed Location Management Scheme for Wireless Networks

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Abstract- Location management schemes continue to be a topic of major research. Especially with the upcoming 3G, 4G and wireless LAN technologies, which will bring better services to the mobile users, it is anticipated that the mobile user population would continue to increase. Location management schemes comprise of location update and paging procedures. Efforts to introduce an efficient location update scheme results in increased costs in paging and vice-versa. In this work we propose a simple Base Station controller based Location Area and paging control, which optimizes the total location management costs and is very simple to implement. This scheme has been evaluated using a mobility model, which has features to study location update rates. These results are compared with some of the more popular dynamic Location Area schemes. Preliminary comparison results show that the proposed scheme is optimal, when considering network architecture and total costs.

I. INTRODUCTION

Work on 3G networks and its deployment is progressing steadily while 4G is emerging with its broadband and high bit rate capabilities. With IP undisputedly being accepted as the core network, this will make available numerous Internet applications and resources to the mobile users. Number of mobile users and their demands on various Internet services and applications will also grow. Efficient location management schemes have been a major area of study in mobile networks. With this developing scenario with IP as core network, it will become more important to have optimal location management schemes, which will perform location management functions fast with reduced complexity, reduced signaling traffic and associated costs. The focus of this work is to study such a location management scheme.

Location registration (or update) and *terminal locating* (or paging) are the two basic operations performed under location management. The two-level database strategy, based on Home Location Register (HLR) and the Visitor Location Register (VLR), used in current cellular networks continue to be the base for newly proposed location management strategies. A Mobile Terminal (MT) initiates a location update message to the network when it crosses a pre-defined Location Area (LA) boundary. A number of LA schemes, static and dynamic have been proposed and analyzed. The static LA schemes, have the problem of frequent location updates made by users roaming on the LA boundary. The overlapped LA concept proposed in [5] resolves this problem to a certain extent. LA scheme which are per-user and mobility pattern based [1-4, 6, 11] are

another solution to avoid frequent location update at an LA boundary.

All the above-cited schemes, have been evaluated for their efficiency. However one finds in the analysis, the dependency of the total signaling costs on the network architecture is not taken into account. In other words, a per-user based LA which is efficient for a given scenario can result in more signaling traffic if the LA spans a number of BSCs (Base Station Controller) or VLR coverage areas. The fact that there could be quite a number of mobile users, who fall in this category can result in heavy signaling traffic. Besides, it well known that when estimating signaling costs, there is a trade-off between the location update costs and paging costs ie schemes for reducing location updates costs invariably lead to increased paging costs and vice-versa

In this work we propose a BSC (or Cell Site Switch - CSS in UMTS – Universal Mobile telecommunication Systems) coverage area as the LA. This will overcome problems encountered due to the effect of the network architecture. If the BSC is also used as the local handoff control point and is involved in distributed paging, then the scheme becomes highly efficient in terms of signaling traffic and associated costs and with very low implementation complexity. The *BSC based LA scheme, will thus optimize the total costs*, ie combined costs for location updating and locating. By distributing the paging control to the BSC level, intelligent (or sequence) paging algorithms [9] can be easily implemented. The only requirement for the above implementation is that the BSC should support a macro-cell coverage as an umbrella for the micro-cells under the BTS (Base Transceiver Station). This is not uncommon.

We introduced a mobility model in [9] which can be used to study the location update rates. This model was modified to help conduct a comparative study between the proposed BSC based LA scheme and other more popular scheme like the movement-based and the distance-based LA schemes [2]. Due to space limitations cases pertaining to inter-VLR spanning of the coverage are not handled here. If this scenario were also included, then the BSC based LA scheme would be far superior.

This paper is organized as follows. Section II provides a brief insight into the network architecture used in our earlier work. Section III discusses location update procedures for different LA approaches and Section IV deals with paging procedures for these approaches. In

section V, mobility models for the different approaches are discussed. Section VI presents the analysis of the different approaches and the location management costs. Section VII discusses on the comparative performances of the different approaches. Conclusions follow in Section VIII.

II. BACKGROUND

Fig. 1 illustrates the signaling network architecture for a BSC based LA location management proposed by the author in [8]. The MSC/VLR is shown collocated.

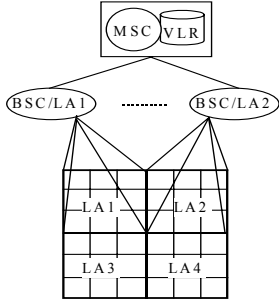


Fig. 1 Network Architecture

As this study involves taking into consideration the network architecture while estimating the signaling costs, the following scenarios need to be addressed

* Movement of MT within LA that is Intra VLR

* Movement of MT within LA that is Inter-VLR, in which case HLR and VLR updates will be initiated.

The first scenario will be applied to the different location management schemes. The study on the second scenario is not included here. The location update costs and paging costs will be calculated separately and then the overall signaling costs estimated.

III. LOCATION UPDATE

In the information flow diagrams given below, standard terminology and descriptive message names have been used hence no detailed explanation is provided. The information flows provided for dynamic LA schemes are applicable for both movement-based and distance-based schemes.

A. Intra VLR- Dynamic LA update:

Fig 2 shows the simplified information flow for intra VLR location update based on a dynamic LA approach. Because the LA is assigned dynamically, it could be covered by different BSCs. Hence 2 scenarios, which could effect signaling are

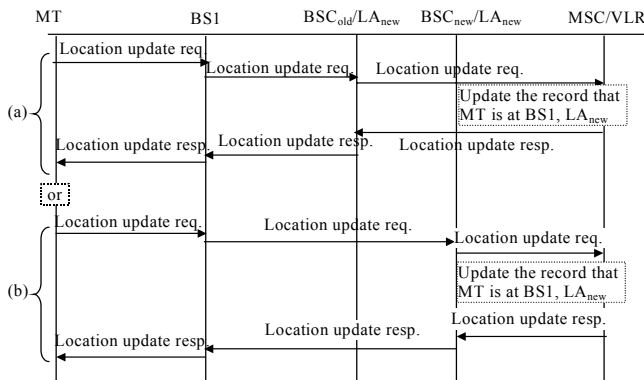


Fig. 2 Information Flows for dynamic LA based update (intra VLR movement)

- (a) Part of old LA and new LA under the same BSC
- (b) Old LA and new LA are under different BSC

Information flows marked (a) refers to case (a). Information flow marked (b) refers to case (b). BSC_{old}/LA_{new} identifies the case, where the user has moved into a new LA from the old LA, but is still under the coverage of the old BSC. BSC_{new}/LA_{new} identifies the case when the user moves into a new LA, he also moves into a new BSC.

The MSC/VLR in the case of dynamic LA needs to record the MT's last contacted BS and a list of probable BSs in the new LA for intelligent or sequential paging. The MSC/VLR can also just record all of BSs in the new LA for blanket paging. This is essential in the dynamic LA schemes as the paging control is at the VLR. Determining and maintaining a list of probable BSs can consume considerable processing-time and requires geographical knowledge of BSs.

B. Intra VLR -BSC based LA update:

The information flow for the BSC based LA update is shown in Fig. 3. In this scheme only a simple pointer update at MSC/VLR is required to track the roaming MT. If an intelligent paging algorithm were to be applied then the BSC/LA simply records the last contacted BS of the MT.

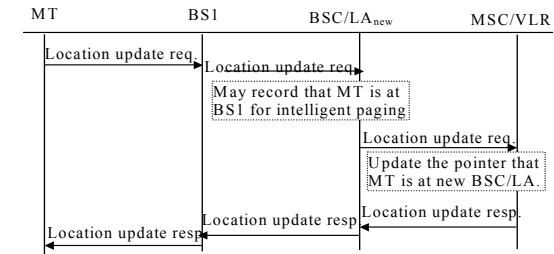


Fig. 3 Information flows for BSC -LA update (intra VLR movement)

IV. PAGING PROCEDURES

A. LA within the same VLR- Dynamic LA paging

Fig. 4 shows the paging procedure for dynamic LA approach when the LA is under one VLR. Though under the same VLR the LA could be under different BSCs coverage (as shown in right hand side of Fig. 4, where the LA is covered by three different BSCs, therefore the paging control point must be at VLR. When an incoming call arrives at MSC/VLR, the VLR will initiate a blanket paging procedure to page all of the BSs within the LA as given by the set of signals marked 'b'. VLR may also apply the intelligent or sequential paging algorithms by paging the last contacted BS or the most likely BSs first and then the other BSs on no response from the first paging - shown by the set of signals marked 'a'. The appropriate response flow in either case is indicated. The MSC/VLR needs to record the MT's last contacted BS and a list of probable BSs for paging in the new LA for intelligent or sequential paging algorithm, or just record all of BSs in the new LA for blanket paging.

B. BSC based LA paging procedure

Fig. 5 illustrates the paging procedure for the BSC based LA approach. Unlike the dynamic LA paging mechanisms

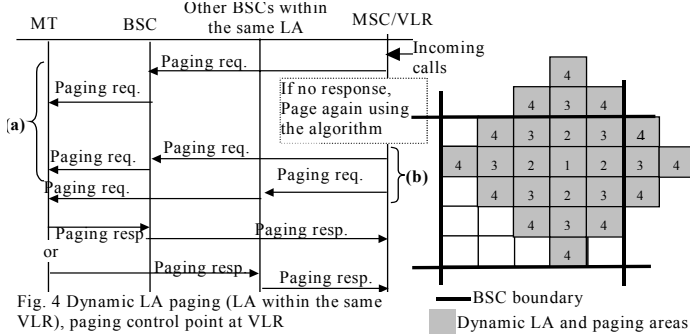


Fig. 4 Dynamic LA paging (LA within the same VLR), paging control point at VLR

in this case the paging control point is located at the BSC level and the BSC will record the MT's last contacted BS after a LA update or a call setup. The MSC/VLR works as a simple pointer during the paging procedure.

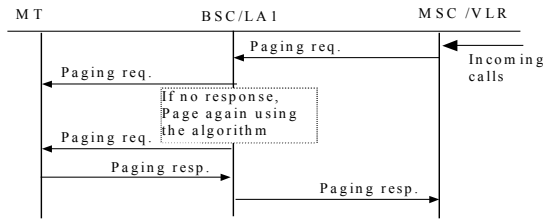


Fig. 5 BSC based LA paging procedure,

V. THE MOBILITY MODEL

Using the mobility model introduced in [9] we intend to compare the performances of the proposed BSC/LA based scheme with two dynamic LA based schemes namely the movement-based and distance-based LA schemes.

In Fig. 6 the LA configurations for square-shaped cells for the different Location management mechanisms with coverage area of approximately 25 cells is shown. The numbers within the cells indicate states in the Markov chain analysis. Identical numbers repeated in different cells indicate cells with symmetrical movement property. State aggregation of states belonging to same states will be performed in the random walk model.

Fig. 6A shows six aggregate classes for the BSC-based approach. Fig. 6B and 6C shows 3 aggregate classes with

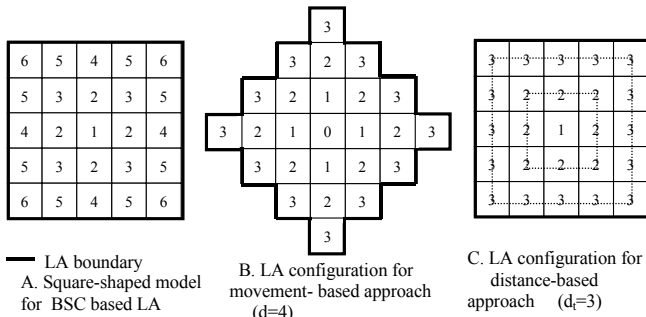


Fig. 6 LA configurations for different approaches

a movement threshold value $d=4$ for the movement-based scheme and movement threshold $d_t=3$ for the distance-based scheme respectively. The distance-based and movement-based mechanisms were studied with respect to

the Call-to-Mobility Ratio (CMR) in [2]. We have instead used a parameter called Movements Per Call (MPC), which carries similar information as CMR, but is its inverse. The MPC reflects the number of movements made by the MT between two calls.

Hence if we consider an example of a user who makes 20 steps (crosses 20 cells) between two call arrivals.

1. Average number of location update for proposed BSC based scheme is 3.8 [9].
2. Average number of location updates for movement based approach is 5 (i.e. $20/4$)
3. For the distance-based approach, average number of location updates was estimated applying the mobility model of [9]. This is explained briefly below

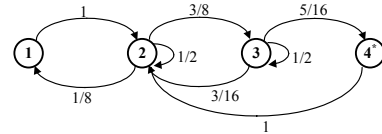


Fig. 7 State Transition Diagram for distance based mobility

Fig. 7 gives the state transition diagram for a mobile user moving in a distance-based scheme. 4^* is the cell (not shown) in the adjacent LA, when the user moves out of the boundary shown in Fig 6.C. The transition probability matrix for this mobility is given below, from which the probability that the user goes into the adjacent LAs namely state 4^* can be determined. This will give the location update rate. The values for average number of location updates in each of the three cases for different values of MPC is given in table 1

$$P = [p_{ij}] = \begin{matrix} & \begin{matrix} 1 & 2 & 3 & 4^* \end{matrix} \\ \begin{matrix} 1 \\ 2 \\ 3 \\ 4^* \end{matrix} & \begin{bmatrix} 1 & 0 & 1 & 0 & 0 \\ 2 & 1/8 & 1/2 & 3/8 & 0 \\ 3 & 0 & 3/16 & 1/2 & 5/16 \\ 4^* & 0 & 1 & 0 & 0 \end{bmatrix} \end{matrix}$$

TABLE 1

Number of location updates for various MPC values

MPC	1	2	3	4	5	6	7
Movement	0	0	0	1	1	1	1
Distance	0	0	0.115	0.123	0.234	0.345	0.456
BSC	0.192	0.32	0.448	0.608	0.8	1.0	1.2
MPC	8	9	10	11	12	13	14
Movement	2	2	2	2	3	3	3
Distance	0.567	0.678	0.789	0.900	1.012	1.123	1.234
BSC	1.4	1.6	1.8	2.0	2.2	2.4	2.6
MPC	15	16	17	18	19	20	
Movement	3	4	4	4	4	5	
Distance	1.345	1.456	1.567	1.678	1.789	1.900	
BSC	2.8	3.0	3.2	3.4	3.6	3.8	

From the table entries, for low values of MPC, the proposed approach is not so good, but gets comparatively better with increasing values of MPC. However the aim of this work is to provide a scheme which will optimize the combined signaling costs for location updating and locating. This will be shown in subsequent sections when the architecture and the paging costs are taken into account and one finds that the BSC based approach is superior.

Though the distance- based approach is good, it is very complex to implement and gets costly when considering the total signaling costs.

VI. LOCATION MANAGEMENT COST CALCULATIONS

The signaling and database processing costs are assumed as given in Table 2.

TABLE 2.
Signaling and database processing cost

MT – BSC	a
BSC – MSC/VLR	b
Database processing cost	DB
Pointer update cost	P

A. Location Update Cost

From section III and using the parameters defined in Table 2, we can estimate the cost for the different location update procedures as shown in Table 3. The costs for both the dynamic approaches will be the same.

TABLE 3.
Location update cost

Dynamic LA (intra VLR)	$2a+2b+DB$
BSC based LA (intra VLR)	$2a+2b+P$

For paging costs estimation, we have adopted the “shortest distance first” intelligent paging algorithm as explained in [9].

B. Paging Costs- Movement Based LA within one VLR

The movement-based dynamic LA would have 4 paging areas (loops) for the case $d = 4$, inline with the cell

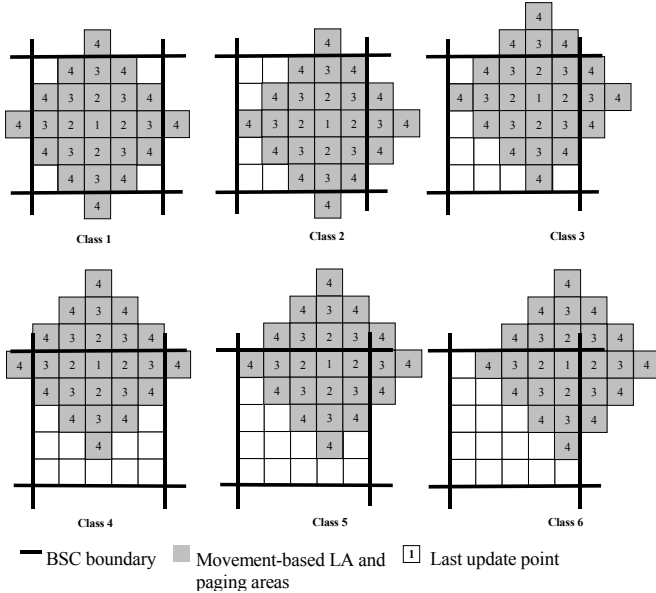


Fig. 8 Movement-based paging based on the last update position

numbering shown in fig 6B. The paging starts from the last contacted BS, cell numbered 0 and then extends to areas with cell clusters numbered 1, 2 and 3.

The Fig. 8 shows the overlaps of the LA or paging area on the actual BSC coverage areas for the movement-based scheme. Thick lines indicate a BSC coverage area. There are six relative positions that the paging areas can take with respect to the BSC coverage area and accordingly there

will be six different classes of paging costs associated with this scheme.

Let m be the number of movements after the last update. S is the paging class and depends on where the last update was initiated. l is the paging loop and starts from a value 1, for cell 0 and increases. ρ_l^m is the probability that the MT has made m movements after the last update and will be in the paging loop l .

TABLE 5.
 ρ_l^m , Probabilities of MT being in loop l after m steps

	$l=1$	2	3	4
$m=0$	1	0	0	0
1	0	1	0	0
2	0.25	0	0.75	0
3	0	0.5625	0	0.4375

Using the cost notations provided in table 2, paging costs for the movement based LA scheme can be estimated. For $S=1$, ρ_l^m as provided from table 5, the paging costs against various values of m are noted

m paging cost

0 $\{b+a\}_1$ - (subscript relates to loop number)

1 $\{b+a\}_1 + \{b+4a\}_2$,

2 $\rho_1^2 \{b+a\}_1 + (1-\rho_1^2) \{b+4a\}_2 + \rho_3^2 \{b+8a\}_3$

3 $\{b+a\}_1 + \rho_2^3 \{b+4a\}_2 + (1-\rho_2^3) \{b+8a\}_3 + \rho_4^3 \{5b+12a\}_4$.

Similar costs can be evaluated for $S=2, 3, 4, 5$ and 6 (they have not been provided here).

The average paging cost can be calculated by

$$\sum_{i=1}^c C_i * N_i / N_t \quad (1)$$

where $c = \max\{S\}$, C_i is the paging cost for class i , N_i is the number of cells in class i , and N_t is the total number of cells in one BSC.

C. Paging Cost -Distance based LA –within one VLR

Fig. 6C shows the paging loops associated with the distance base LA scheme, where the distance threshold $d_t = 3$. To estimate the paging costs we have to know the probability of the MT being in a cell belonging to any loop. The same mobility model with minor variations can be used to help estimate this. Fig. 9 shows the state transition diagram to be used for estimating the steady state probability of finding the mobile is a particular cell in the LA. From this state transition diagram, the state transition matrix can be obtained and is given as Q.

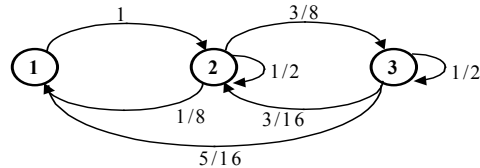


Fig. 9 State transition diagram

In Q, we are interested in the values of q_l^m -the probability that when MT has made m movements after the leaving cell 1, the MT is in the paging area l . The values for q_l^m as calculated are given in table 6. From this table it can be

seen that the probability of the MT being in loop1, loop2 or loop3 stabilizes after 8 steps and these entries give the steady state probability of finding the MT in any loop l .

$$Q = [q_{i,j}] = \begin{matrix} & \begin{matrix} 1 & 2 & 3 \end{matrix} \\ \begin{matrix} 1 \\ 2 \\ 3 \end{matrix} & \begin{bmatrix} 0 & 1 & 0 \\ 1/8 & 1/2 & 3/8 \\ 5/16 & 3/6 & 1/2 \end{bmatrix} \end{matrix}$$

TABLE 6.

q_l^m , Probabilities of MT being in loop l , after m movements

m	$l=1$	2	3
4	0.1729	0.4727	0.3545
5	0.1699	0.4756	0.3545
6	0.1702	0.4742	0.3556
7	0.1704	0.4740	0.3556
$m \geq 8$	0.1704	0.4741	0.3556

Following the approach used for the movement based case, it can be determined that there are six different classes of paging cost for distance-based LA ($d_i=3$). The costs for different paging classes is given in Table 7, where q_l^m is taken from table 6 for $m \geq 8$

TABLE 7.

Paging cost for Distance based LA within 1 VLR

S	Paging cost for different classes
1	$q_1^m \{b+a\}_1 + q_2^m (\{b+a\}_1 + \{b+8a\}_2) + q_3^m (\{b+a\}_1 + \{b+8a\}_2 + \{b+16a\}_3)$
2	$q_1^m \{b+a\}_1 + q_2^m (\{b+a\}_1 + \{b+8a\}_2) + q_3^m (\{b+a\}_1 + \{b+8a\}_2 + \{2b+16a\}_3)$
3	$q_1^m \{b+a\}_1 + q_2^m (\{b+a\}_1 + \{b+8a\}_2) + q_3^m (\{b+a\}_1 + \{b+8a\}_2 + \{4b+16a\}_3)$
4	$q_1^m \{b+a\}_1 + q_2^m (\{b+a\}_1 + \{2b+8a\}_2) + q_3^m (\{b+a\}_1 + \{2b+8a\}_2 + \{2b+16a\}_3)$
5	$q_1^m \{b+a\}_1 + q_2^m (\{b+a\}_1 + \{2b+8a\}_2) + q_3^m (\{2b+8a\}_2 + \{b+8a\}_2 + \{4b+16a\}_3)$
6	$q_1^m \{b+a\}_1 + q_2^m (\{b+a\}_1 + \{4b+8a\}_2) + q_3^m (\{b+a\}_1 + \{4b+8a\}_2 + \{4b+16a\}_3)$

Equation 1 is used to calculate the total average paging costs.

D. Proposed BSC based LA Paging

From fig 6A for the proposed BSC based LA approach the paging sequence would start from cell numbered 1 and go on to cells numbered 2 in the second sequence, cells numbered 3 in the third sequence and so on. The steady state probability of the MT being in a paging loop 1, 2, 3, 4, 5, and 6 is respectively 0.04, 0.16, 0.32, 0.32 and 0.16. The paging cost thus calculated will be

$$0.04*a + 0.16*4a + 0.32*8a + 0.32*8a + 0.16*4a.$$

VII EXAMPLES AND PERFORMANCE COMPARISONS

In this section, numerical examples are provided to evaluate the performance of the different LA schemes, but is restricted to only the intra-VLR case. For performance evaluation we have considered the configurations discussed in the previous sections. We then study the effect of the signaling network element cost by changing certain parameter values, which are explained below.

Case 1: $a=1, b=1, DB=2, P=1$

Sequence paging algorithm is used. Fig. 10 is a plot of the total location management costs for all three cases. The BSC based LA approach has the best performance (lowest cost) for most MPC values. The results for the movement-based LA approach shows that though the LA update cost is a uniformly increasing with the increased number of movements within two calls, the paging cost follows a saw

tooth pattern, which we see superimposed on the LA update cost. The saw tooth pattern for paging cost is because after a location update the paging cost drops and increases based on the movement of the user. The distance based approach has a slightly higher average cost than the BSC LA based approach, but when the number of movements between calls is very high, it seems to converge with the BSC based approach, but at higher MPC values the distance based approach would be better.

Case 2: $a=3, b=1, DB=2, P=1$

Fig. 11 shows that the location update cost for movement-based approach is lower than other approaches for some MPC values. The reason is that after the location update for the movement-based approach, the paging cost is reduced significantly; therefore the total cost is lower at location update points. The reason that the distance-based approach is not as good as BSC based approach is that the BSC based approach has more paging loops and will have longer paging delay though it shows lower total costs. But the dynamic LA based schemes will also have delays, especially if the LA is spanning BSCs and VLRs. Hence on an average one has to bear in mind that the delays and costs associated with the BSC LA based schemes will not be worse than the dynamic LA schemes.

Case 3: $a=1, b=1, DB=2, P=1$

No sequence paging involved and only blanket paging algorithm (paging all of the cells within a LA at the same time) is used. Fig. 12 and Fig. 13 show that the distance-based approach has the best performance for the MPC values greater than 4, because there is less location updates for distance-based approach under higher MPC values. The proposed BSC based LA approach always perform better than movement-based LA approach due to less location updates and as only one BSC is involved during the paging procedures.



Fig 20. BSC based LA macro-cell paging procedure

Case 4: Macro-cell paging in BSC-based scheme

As mentioned earlier, the advantage of this scheme is the control at the BSC. If macro-cell paging were used instead of sequential paging in each cell, then the cost of paging reduces considerably. In graph 14, we have shown the case where macro-cell paging was used, and even with the paging cost made 10 times (a^*) that for micro-cell cost (a), the overall costs have reduced considerably.

VIII. CONCLUSION

In this paper, we have introduced a location management scheme called BSC based LA location management. The proposed scheme is similar to the conventional scheme

adopted in current networks. The major difference is that we have made the size of the LA equals to the BSC coverage area, and also distributed the paging control to the BSC level. Unlike the dynamic LA approaches, the proposed scheme is easier to implement for the micro-cell/macro-cell overlaid approach and hierarchical location database architecture. Performance results show that the BSC based LA scheme is better whether one applies sequential paging or blanket paging. We did not show the performances comparisons for the cases for a LA under several VLRs in this paper due to the limited space. If we take such a situation into account, the performance of the proposed BSC based LA would be far better than the dynamic LA approaches because only one VLR is involved for the BSC based approach.

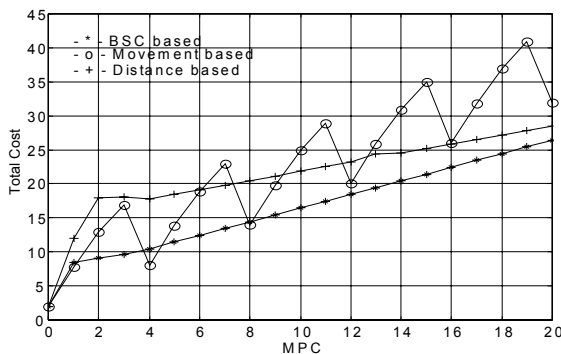


Fig. 10. Performance comparison with $a = 1$, $b = 1$, and intelligent (or sequential) paging

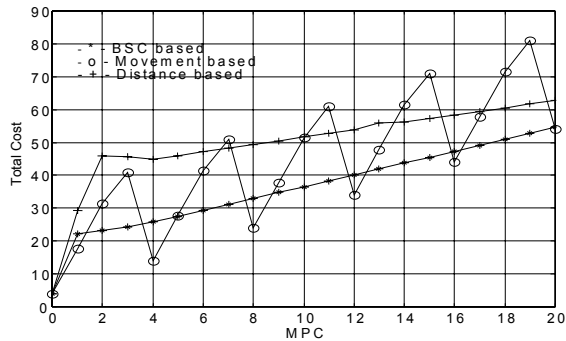


Fig. 11. Performance comparison with $a = 3$, $b = 1$, and sequential paging

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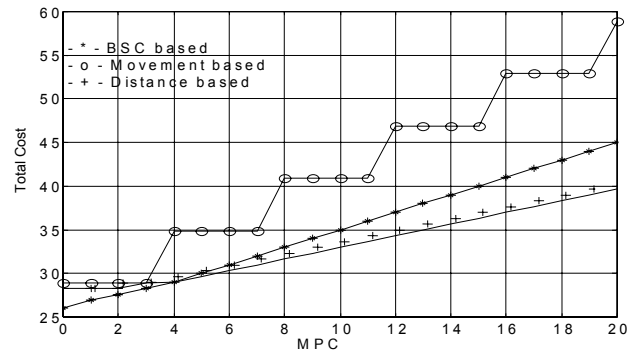


Fig. 12. Performance comparison with $a = 1$, $b = 1$, and blanket paging

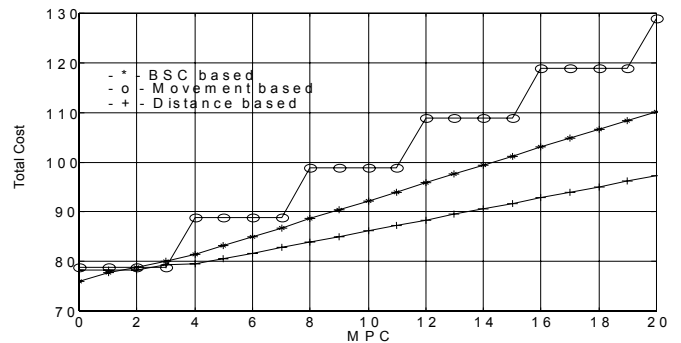


Fig. 13. Performance comparison with $a = 3$, $b = 1$, and blanket paging

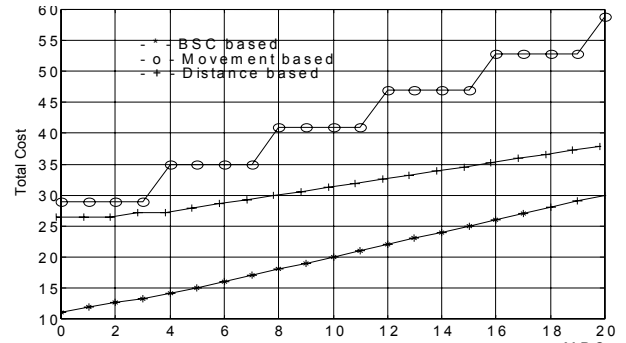


Fig.14. Performance comparison with $a = 1$, $a^* \text{ MPC} = 10$, $b = 1$, and macro-cell paging

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