ARTICLE IN PRESS
COMPUTER SCIENCE REVIEW ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Available online at www.sciencedirect.com
ScienceDirect
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Survey

Location management in mobile network: A survey

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HIGHLIGHTS

- Different types of location management schemes for mobile network are discussed.
- The location management cost in terms of message is calculated for these schemes.
- Comparative analysis is performed between the methods based on cost.
- Future scopes of location management are also explored.

ARTICLE INFO

Article history:
Received 27 July 2015
Received in revised form
13 December 2015
Accepted 21 December 2015

Keywords:
Location update
Paging
Cost
Macrocell
Femtocell

ABSTRACT

Location management is an important area of mobile computing. Location management in mobile network deals with location registration and tracking of mobile terminals. The location registration process is called location update and the searching process is called paging. Various types of location management methods exist such as mobility based location management, data replication based location management, signal attenuation based location tracking, time, zone and distance based location update etc. In this paper, existing location management schemes are discussed and compared with respect to their cost consumption in terms of bytes. Finally the key issues are addressed in the context of location management for future generation mobile network.

Contents

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http://dx.doi.org/10.1016/j.cosrev.2015.12.001
1574-0137/

Please cite this article in press as: A. Mukherjee, D. De, Location management in mobile network: A survey, Computer Science Review (2016), http://dx.doi.org/10.1016/j.cosrev.2015.12.001

1. Introduction

In a Personal Communication Services (PCS) network, the service area is partitioned into several location areas [1–5]. Each location area (LA) consists of several base stations. The coverage area of a base station (BS) is known as cell. The location information of mobile terminals (MTs) is maintained in databases of two types: Home Location Register (HLR) and Visitor Location Register (VLR). The process of tracking the location of a MT is referred as location management [6–10]. Location management is composed of two main processes: location registration and paging [11–14]. In this paper we have discussed on various kinds of location management schemes with their advantages and disadvantages to minimize the location registration as well as paging cost. The cost is measured in terms of messages or bytes. The registration process by reporting its own up-to-date location by the MT is called location update [15–19]. Whenever a MT enters into a LA, a location update is performed [20–24]. To deliver an incoming call to a MT, the current location of that MT is required. Location update [25–29] is performed using one of the following three methods:

a. Send location update on every cell update: Every time a MT moves into a different cell area, a location update is performed. This scheme has the following advantage and disadvantage:
   - Advantage: No paging requirement,
   - Disadvantage: Excessive signaling traffic load.
b. Page every cell in the network: Every time an incoming call is to be routed to a MT, all cells of the network are paged to identify the cell owning the MT. It has the following advantage and disadvantage:
   - Advantage: No location update requirement,
   - Disadvantage: Excessive signaling traffic load.
c. Subdivide network into paging sub-regions: Every time a MT moves to a new paging sub-region, it informs the identity of that sub-region to the network. When an incoming call arrives for that MT, only the cells of the current sub-region are searched to identify the cell owning the MT. It has the following requirements:
   - Requires paging procedure with reduced traffic load,
   - Requires location updating procedure with reduced traffic load.

At arriving of an incoming call, the network searches the called MT; this process of searching is referred as paging. Paging processes are of various types as shown in Table 1.

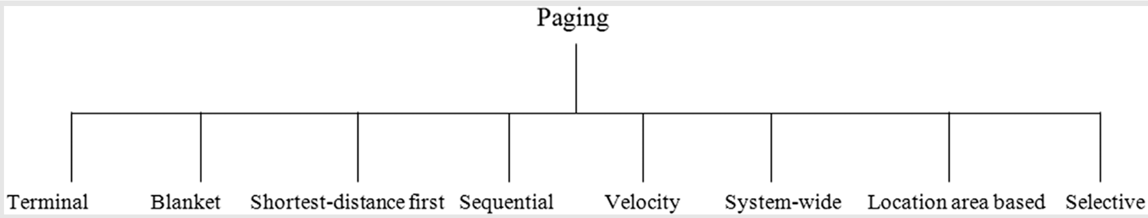
a. Terminal paging: In terminal paging, the exact location of a particular MT is determined for a terminated call; the system needs to determine the set of cells, where the MT may have entered [11]. The paging process gets finished as soon as that MT replies before timeout. Else another group of cells are selected for the next paging cycle.
b. Blanket paging: In this case, all the cells within the current LA of the MT are searched simultaneously when a call arrives for it.
c. Shortest-distance first paging: In this case, the MT is searched in a shortest-distance first order starting from the last-updated cell. The distance is the number of cells traveled from the last updated location.
d. Sequential paging based on user's location probability: In this case, the location probability distribution of the MT is used to predict the current location of that MT.
e. Velocity paging: In this case, the users are clustered into several velocity classes on the basis of their velocity at the instant of location update. When a call arrives for a MT, the paging area is generated dynamically based on the last location update time of the MT and the velocity class index.
f. System wide paging: System wide paging simply pages all the cells in the system looking for a particular MT. It is the simplest paging method, but the most expensive one. This method has been abandoned in current cellular systems because of high cost [6].
g. Location area based paging: In this scheme, all the cells in the current LA of the MT are searched. This method requires the location area registration method to cooperate with it. This scheme has been adapted by several cellular phone network implementations for its acceptable delay at field test [6].
h. Selective paging: This paging process consists of iterative steps. In each step, a subset of cells is selected for paging according to a predetermined criterion (e.g. distance). The paging process terminates as soon as the MT is found [6].

For better prediction of user movement pattern, two kinds of information are recorded in the profile of the user:

(i) Long term: It contains slow changing information of the user and it is concerned of only the long periods of time such as weeks, months.
(ii) Short/medium term: It contains information about the recent behavior of the user in terms of day or hour.

We have already discussed that each LA contains a number of cells. Cells are categorized into four types based on the amount of coverage area [30]:

Table 1 – Classification of paging.



(i) Macrocell: It contains a high power cellular BS to provide coverage to each and every part of a large area (1–10 km).
(ii) Microcell: It contains a BS to serve a number of users in its coverage area in the range of 200 m–1 km.
(iii) Picocell: It contains a low power BS having coverage area of 50–200 m.
(iv) Femtocell: It contains a very low power BS to provide coverage in a small area (10–20 m).

Due to large size the quality of service (QoS) is poor especially in indoor environment in macrocell. To deal with such situation, microcells and picocells are developed. Femtocell is a recent development in the field of mobile communications to provide cost-effective connectivity in the future broadband wireless networks [30–32]. Femtocell improves indoor voice coverage and data performance for all the subscribers residing under it [33–36]. Femtocell resembles a wireless router. Because of its small size it is able to afford low power consumption but improved QoS [37–40]. Femtocells (10 m) are low-power wireless access points operating in licensed spectrum to connect standard MTs to a mobile operator's network using residential DSL or cable broadband connections [41–46].

In this paper, we have discussed on different types of location registration and paging strategies based on mobility, data replication, signal attenuation etc. The organization of this paper is as follows: Section 2 presents the existing location management schemes with comparative analysis; in Section 3 the future scopes of location management are discussed; in Section 4 the conclusion is drawn.

2. Location management strategies

2.1. *Location management for traditional GSM network*

A location management method is proposed in [1], where the Signaling System Number 7(SS7) traffic load is associated with the mobility of the MT and the Pan-European standard Global System for Mobile Communications (GSM) is used. Call setups, inter-Mobile Switching Center (MSC) handovers and location updates are the important activities to generate SS7 traffic in GSM [1]. The frequency of originations and terminations of calls, handovers and location updates per hour are determined by considering the SS7 bytes generated per transaction with the total traffic load offered to the SS7 network. In traditional GSM when a new MT comes into a new LA, the VLR copies all relevant information for this MT from the HLR [13]. In GSM, the location update cost measured in terms of messages/ bytes. This cost includes the cost of accessing databases at HLR, the new VLR and the old VLR, the cost for message transmission through the fixed and wireless network links [13]. Four messages are used for sending request and receiving acknowledgment, from the old VLR and new VLR for registration and deregistration purpose. If C_h and C_v are the cost of accessing the HLR and VLR, C_f is the message sending cost through the fixed network and C_w is the message sending cost through the wireless network, then the location update cost is given by [13],

$$Cost_{lu\_gsm} = 2C_v + C_h + 4(C_f + C_w). \quad (1)$$

In paging, two messages are required for sending request and receiving acknowledgment for tracking the MT to deliver a call by accessing the VLR and HLR. Thus the paging cost is calculated as [13],

$$Cost_{pg\_gsm} = C_v + C_h + 2(C_f + C_w). \quad (2)$$

If λ_c is the call arrival rate and λ_m is the movement rate of the MT, the total location management cost is given by [13],

$$Cost_{lm\_gsm} = \lambda_m Cost_{lu\_gsm} + \lambda_c Cost_{pg\_gsm}. \quad (3)$$

In traditional GSM, the search is performed at the VLR of the caller MT. If the caller MT is not tracked in the local VLR, the HLR containing the current address of that MT is searched. Hence the paging cost gets increased. On the other hand, as location update cost includes both HLR and VLR access cost, it is also increased.

2.2. *Multi-layer location update scheme*

To distribute the location updating signal traffic over all cells and avoid short-term switching instability, a multilayer location update method (MULTI) is proposed in [2]. It consists of two methods:

(i) MULTI-Grouping (MULTI-G): The MTs are divided into several groups and each group is assigned to one or more layers in this scheme. The cells which the MT access for updating location, are different from group to group. The location updating signal traffic is distributed over all cells.
(ii) MULTI-Switching layer (MULTI-S): MTs of each group have several area layers. When a MT updates location, it switches layer, i.e. it updates to a different layer. MULTI-S yields location updating activity hysteresis, so that short term switching instability can be avoided.

Please cite this article in press as: A. Mukherjee, D. De, Location management in mobile network: A survey, Computer Science Review (2016), http://dx.doi.org/10.1016/j.cosrev.2015.12.001

2.3. Timer, zone and distance based location registration scheme

Timer, zone and distance based location registration methods are proposed in [3]. According to the timer based registration method, the average registration rate per cell is given by [3],

$$\lambda_{reg} = \frac{N_{mt}}{T_{rg}} \tag{4}$$

where N_{mt} is the number of MTs per cell and T_{rg} is the registration time interval of a MT. The difficulties of the timer method is paging should be done in an area proportionate to the maximum vehicle velocity [3].

According to the distance method, location of a MT is updated whenever it moves more than a specific distance from the last updated cell. The specified distance for location registration is given by [3],

$$d \le \sqrt{(\Delta lat)^2 + (\Delta long)^2} \tag{5}$$

where $\Delta lat = new\_lat - reg\_lat$ and $\Delta long = (new\_lat - reg\_lat)\cos(\pi/180 reg\_lat)$, the latitude of the current location is new_lat and the latitude of the last updated location is reg_lat. The cosine factor compensates for the merging lines of longitude as the latitude increases. In the zone method [3], every cell in a system is assigned to a specific zone. The MT contains a list of recently visited zones. Whenever a MT enters a new zone, the MT registers and adds the zone to the list. Another distance based location management scheme is proposed in [47]. In this method, the MT user movement pattern is predicted based on Markov Chain model. In this scheme the number of paging area visited by the MT is predicted along with the residence time in the paging area.

2.4. Classical strategy for location management

In Classical Strategy (CS) of location management, the number of cells contained in a LA is assumed based on the MT user behavior [4]. Three cases can occur in location update:

(a) Location updating occurs within the same LA: Let the probability of this case be β_1 and the number of message required at interface (int) be $Nl_{case1}(\text{int})$.
(b) Location updating between two VLRs using temporary mobile subscriber identity: Let the probability of this case be β_2 and the number of message required at interface (int) be $Nl_{case2}(\text{int})$.
(c) Location updating between two VLRs using international mobile subscriber identity: Let the probability of this case be β_3 and the number of message required at interface (int) be $Nl_{case3}(\text{int})$.

According to CS, the location update cost in CS is given by [4],

$$Cost_{lu\_cs} = \frac{8v}{\pi R\sqrt{N}}[\beta_1 Nl_{case1}(\text{int}) + \beta_2 Nl_{case2}(\text{int}) + \beta_3 Nl_{case3}(\text{int})] \tag{6}$$

where the cost is measured in terms of messages, v is the average speed of the MT, N is the number of cells per LA and R is the radius of a cell. In CS, the system always knows in which LA the MT is currently located; when an incoming call arrives for the called MT, the system pages it over the current LA [4]. Here two cases are possible:

(a) Successful paging: Let λ_{t1} be the number of successful paging requests and $Np_{cost1}(\text{int})$ be the number of message generated at interface (int) by a successful paging.
(b) Unsuccessful paging: Let λ_{t2} be the number of unsuccessful paging requests and $Np_{cost2}(\text{int})$ be the number of message generated at interface (int) by an unsuccessful paging.

Thus the paging cost in terms of messages is given by [4],

$$Cost_{pg\_cs} = N[\lambda_{t1} Np_{\cos t1}(\text{int}) + \lambda_{t2} Np_{\cos t2}(\text{int})]. \tag{7}$$

The total cost of location management is the sum of location update and paging cost, given as [4],

$$Cost_{lm\_cs} = Cost_{lu\_cs} + Cost_{pg\_cs}. \tag{8}$$

According to CS, whenever a MT crosses the border of a LA, the location registration takes place at VLR as well as at HLR to track the MT quickly when a call arrives for it. This in turn can cause very high traffic if a MT receiving few calls or no call at all, frequently changes the LA.

2.5. Signal attenuation based location tracking method

Based on the differences of downlink signal attenuations, a location tracking technique is proposed in [8]. Another scheme for location prediction is proposed in [9] based on advanced propagation models. Another distributed location management strategy is proposed in [23], where consecutively numbered location information databases are arranged into a weighted sliding-frame. However this scheme results in generation of redundant information; moreover the searching of location information is based on randomly selected initial location area IDs which is a time consuming process. A three-dimensional location estimation scheme is proposed in [24] based on the number of beacon packets which are periodically transmitted by power controlled MTs [24].

2.6. Mobility and replication based location management

Most of the location management schemes for today's mobile network are classified into two categories:

- Mobility based location management
- Replication based location management.

2.6.1. Mobility based location management

Alternative strategy for location tracking:

To reduce the traffic due to mobility management in CS, an 'Alternative Strategy' (AS) for location management is proposed in [4] based on the movement pattern of the MT user. In AS, a profile is maintained for each MT to record most probable mobility pattern of the corresponding user and the location of the MT is updated when it crosses the border of a zone instead of a LA. Each zone is composed of a number of LAs. When the subscriber moves away from the recorded zone during the corresponding time interval, a voluntary location registration of the MT takes place to enable the system to track the MT.

Three cases are considered for location update in AS:

- Case 1: Location updating within the same LA.
- Case 2: Location updating between two VLRs using temporary mobile subscriber identity.
- Case 3: Location updating between two VLRs using international mobile subscriber identity.

If α_i is the probability of presence of the MT at LA a_i, then the probability of a location update due to the crossing of a zone is $(1 - \sum_{i=1}^{k} \alpha_i)$ as observed in [4], where k is the number of LAs in a zone and $1 \le i \le k$. The location update cost in AS is given by [4],

$$Cost_{lu\_as} = \left(1 - \sum_{i=1}^{k} \alpha_i\right) \frac{8v}{\pi R \sqrt{N}} [\beta_1 Nl_{case1}(\text{int}) + \beta_2 Nl_{case2}(\text{int}) + \beta_3 Nl_{case3}(\text{int})] \tag{9}$$

where the cost is measured in terms of messages, v is the average speed of the MT, N is the number of cells per LA, R is the radius of a cell, β_1 is the probability of occurrence of case 1 and $Nl_{case1}(\text{int})$ is the number of message generated at interface (int) in case 1, β_2 is probability of occurrence of case 2 and $Nl_{case2}(\text{int})$ is the number of message generated at interface (int) in case 2, β_3 is probability of occurrence of case 3 and $Nl_{case3}(\text{int})$ is the number of message generated at interface (int) in case 3. As instead of LA, a zone is considered for location update, small amount of traffic is generated.

In AS [4], the system has to page a MT over the last updated zone to track it; hence a number of LAs contained in that zone are required to be searched until the MT is found. Here two cases are possible [4]: successful paging and unsuccessful paging. If λ_{t1} and λ_{t2} are the number of successful and unsuccessful paging request respectively and $Np_{cost1}(\text{int})$ and $Np_{cost2}(\text{int})$ are the number of message generated at interface (int) by a successful and unsuccessful paging respectively, the paging cost in AS is given by [4],

$$Cost_{pg\_as} = \left[\sum_{i=1}^{k} \alpha_i \left[\sum_{i=1}^{k} \{\alpha_i(\lambda_{t1} Np_{\cos t1}(\text{int}) + \lambda_{t2} Np_{\cos t2}(\text{int})) + (1-\alpha_i) Np_{\cos t2}(\text{int}) \times (\lambda_{t1} + \lambda_{t2})\} \left[1 - \sum_{j=0}^{i-1} \alpha_j \left(1 - \frac{\lambda_{t2}}{\lambda_{t1} + \lambda_{t2}}\right)\right]\right] + \left[1 - \sum_{i=1}^{k} \alpha_i\right] [\lambda_{t1} Np_{\cos t1}(\text{int}) + \lambda_{t2} Np_{\cos t2}(\text{int})]\right] N \tag{10}$$

where cost is measured in terms of messages.

The total cost of location management in AS is given as [4],

$$Cost_{lm\_as} = Cost_{lu\_as} + Cost_{pg\_as}. \tag{11}$$

AS [4] is user's long-term movement pattern based location management method as the zone is considered. Thus the shortcoming of AS is that the location information of the MT is obtained only if it generates a call or after it was paged. As a result, a huge increase occurs in paging cost and paging delay.

Intelligent location management scheme:

By overcoming the difficulties of AS, an intelligent location management method is proposed in [5] on the basis of the short term movement pattern of the MT user. But it has introduced overhead in storage by maintaining paging records for each MT which increases the processing time of the paging records. In [28,29] intelligent location management schemes are proposed for PCS network.

Cell counter and cache based location update scheme:

In this method, a MT updates its current location whenever it is switched on. To track the number of cells visited by the MT, it initializes a counter to zero [6]. Whenever the MT visits a new cell, it updates the cell ID in its cache and increments the value of the counter by 1. When the value of the counter reaches the movement threshold, the MT updates its current location to the new VLR along with the contents of the cache. Then it sets the counter to zero and clears the cache. If N_{sub} is the number of subscribers in the network, $cell[x]$ is the average number of cells visited per hour, M is the movement threshold, P_{re} is the probability of revisiting a cell and C_{reg} is the unit location registration cost, then the location management cost in terms of bytes is given by [6],

$$Cost_{lu\_6} = N_{sub} \left\{(1 - P_{re}) \frac{cell[x]}{M}\right\} C_{reg}. \tag{12}$$

To track a user, selective paging is performed in [6]. When a call arrives for a MT, the VLR is checked to identify the current LA of the MT. Then depending on the mobility information, the visited cells are searched. If the MT is not found in these cells, location area paging is done. If N_{cache} is the number of cells whose IDs are maintained in cache, P_{hit} is the probability of finding the MT in these cells and N_{area} is the number of cells in that LA, then the paging cost in terms of bytes is given by [6],

$$Cost_{pg\_6} = call\{P_{hit} N_{cache} + (1 - P_{hit}) N_{area}\} C_{page} \tag{13}$$

where C_{page} is the unit paging cost and $call$ is the number of call attempts per unit time. Hence the total cost of location management is given by [6],

$$Cost_{lm\_6} = Cost_{lu\_6} + Cost_{pg\_6}. \tag{14}$$

If a MT frequently moves from one cell to another, the location update cost is increased as well as high traffic is generated. On the other hand, the probability of successful paging is reduced; hence paging cost is also increased. A modified version of this location management scheme [6] is proposed in [7], where the received signal strength (RSS) of the MT is also considered [7]. In this method [7], the MTs unable to accept a call due to low RSS are not paged to reduce the resource wastage as well as to minimize the paging cost. Another cache based location management method is proposed in [48].

Regular movement pattern based location registration method:

Considering the regular movement pattern of the MT user, another location registration scheme is proposed in [10], where the location update is done at the HLR when the MT crosses a block instead of crossing a cell. A block means a collection of MSCs considered according to the regular movement pattern of the MT user. To reduce the location update cost, a three level architecture is introduced in [10] by maintaining a block register (BR) between the block and the HLR.

Low traffic location management scheme:

To deal with high traffic, another location management scheme is proposed in [15], where three dimensional cell based histogram is used to realize mobile location probability pattern based on time segments in a day, days in a week and cell locations. In this method [15] optimal paging zone partitioning is used for location tracking. A proxy server based scheme is proposed for location management in IP2 architecture to deal with large multimedia traffics generated in fourth generation (4G) mobile network [16]. During paging, signaling messages are transmitted to all MTs within the LA to efficiently utilize the shared resources of the network [16]. An analytical model for movement of MTs with multiple interfaces is proposed for multiple wireless access network (MWAN) in [17]. Another mobility management method based on probabilistic paging is proposed in [18].

Dynamic location management scheme:

Based on Brownian motion and Gauss Markov model, a location management strategy is developed in [19] for characterizing the locations and velocities of nodes in dynamic network. A dynamic periodic location area update scheme is developed in [20], where the location update interval is dynamically adjusted based on the call traffic and normal location area update rate. But this method is not sufficient to predict users' movement pattern for proper resource utilization. A distributed real time location monitoring system is designed in [21] to promote the location monitoring task into an optimal coordination of server-side processing and client-side processing. An ant system based location management method is proposed in [25]. An integrated framework is developed for location management for 4G wireless networks in [26]. Dynamic location-update area for per-user distance-based scheme in PCS network is presented in [27]. Based on location probability models, a location tracking strategy is proposed in [29] to reduce the signaling cost involved in location tracking under delay bounds. Another movement based location management scheme is proposed in [49], where the cost calculation is performed based on Markov Chain model. Another dynamic location management scheme is proposed in our previous work [11] based on the proposed schemes of [4,6,7].

RSS based three-dimensional movement prediction and dynamic location management scheme:

An extension of the proposed scheme of [11] is introduced in [12]. In [12] we have proposed a cost effective and dynamic location management scheme, Debashis–Anwesha Strategy (DAS) along with three dimensional movement prediction of the user. In the location update method of DAS, a dynamic LA list is maintained in the profile of individual user. It is a list of location area IDs (LAIDs) with probabilities of visiting them by the MT in decreasing order. This list is updated when a LA update takes place. Each LAID points to a cell list containing the cell IDs with the probabilities of visiting them by the MT in decreasing order as shown in Fig. 1.

This list is updated when a cell update or LA update takes place or a call arrives for the MT. A cache is maintained to hold the recently visited cell IDs by the MT in the current LA. The mean velocity of MTs, the cell updating rate, the probability of locating a MT within a particular LA, and the

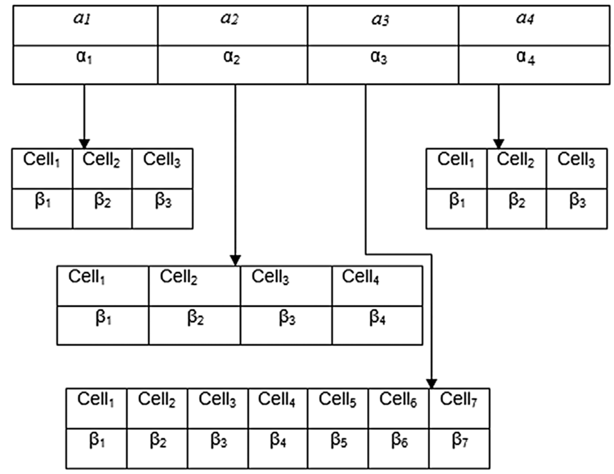


Fig. 1 – LA list and cell lists maintained in the profile of MT user [12].

number of cell updates performed due to call arrival are considered to calculate the location update cost in DAS [12]. It is assumed that different LAs contain different number of cells of different size to depict the real world network scenario. If N_i is the number of cells in LA a_i and R_i is one side length of a hexagonal cell in a_i, then the perimeter length of a LA is given by [12],

$$L_i = 4R_i\sqrt{3N_i}. \tag{15}$$

As surface area of a hexagonal cell is $\frac{3\sqrt{3}}{2}R_i^2$, the surface of LA a_i is given by [12],

$$S_i = \frac{3\sqrt{3}}{2}R_i^2 N_i. \tag{16}$$

If v_i is the mean velocity of MTs currently contained in a_i, the number of LA border crossings is calculated as [12],

$$Z_{ni} = \frac{v_i L_i}{\pi S_i} = \frac{v_i(4R_i\sqrt{3N_i})}{\pi\left(\frac{3\sqrt{3}}{2}R_i^2 N_i\right)} = \frac{1}{3}\frac{8v_i}{\pi R_i\sqrt{N_i}}. \tag{17}$$

In DAS [12], the location update takes place at VLR. The HLR is updated once in a day.

Four cases are considered to calculate the location update cost:

(a) **LAID update cost at VLR considering message transmission and database access when the MT changes LA**: It is calculated as $[((\frac{1}{3}\frac{8v_i}{\pi R_i\sqrt{N_i}} \times Nl_{\cos t1}) + (k + NC_i))(1-\alpha_i)]$, where Nl_{cost1} is the number of message generated by a LA update at VLR, NC_i is the number of cells contained in the current LA, α_i is the probability of locating MT at a_i, where $1 \le i \le k$ and k is the total number of LAs in the network.

(b) **Cell ID update cost at VLR considering message transmission and database access at a fixed time interval**: It is calculated as $[((C_{upi} \times Nl_{\cos t2}) + N_i)\alpha_i(1 - \frac{1}{N_i})]$, where Nl_{cost2} is the number of message generated by a cell update at VLR and C_{upi} is the cell updating rate at a fixed time interval (t_f) in a_i.

(c) **LAID and Cell ID update cost at HLR considering message transmission and database access**: It is calculated as $[\frac{1}{24} \times (Nl_{\cos t3} + (k + NC_i))]$, where Nl_{cost3} is the number of message generated by a location update at HLR.

(d) **Cell ID update cost at VLR considering database access due to call arrival**: It is calculated as $(CA_{upi} \times N_i)$, where CA_{upi} is the number of cell updates performed due to call arrival in LA a_i.

According to DAS [12], the location update cost is given by,

$$\begin{aligned} Cost_{lu\_das} = \frac{1}{k}\Bigg[\sum_{i=1}^{k}\Bigg[\Bigg[\Bigg\{\Bigg(\Bigg(\frac{1}{3}\frac{8.v_i}{\pi.R_i.\sqrt{N_i}} \times Nl_{\cos t1}\Bigg) \\ + (k + NC_i)\Bigg)(1-\alpha_i)\Bigg\} \\ + \Bigg\{((C_{upi} \times Nl_{\cos t2}) + N_i)\alpha_i\left(1 - \frac{1}{N_i}\right)\Bigg\}\Bigg] \\ + \left[\frac{1}{24} \times (Nl_{\cos t3} + (k + NC_i))\right] \\ + (CA_{upi} \times N_i)\Bigg]\Bigg] \end{aligned} \quad (18)$$

where the cost is measured in terms of messages.

A selective paging scheme is proposed in [12], where RSS [7] is considered to reduce the paging cost. In the paging method [12], the MT is searched within the cell IDs stored in the cache of the last updated LA. If the MT is not found within these cells, rests of the cells within that LA are searched. If the MT is found, the call is delivered and its current cell ID is updated at VLR and stored in the cache. After that the cell list is rearranged according to the probability of visiting each cell by that MT. If the MT is not found, a call failure message is generated.

Three possibilities are considered to calculate the paging cost in DAS [12]:

- **Fully successful paging**: In this case, the MT is traced within the cells (N_{csi}) whose IDs are maintained in the cache in the current LA. Let Ph_1 be the probability of this case and Np_{cost1} be the number of message generated by a fully successful paging.
- **Partially successful paging**: In this case, the MT is not found within the cells whose IDs are maintained in the cache but it is traced within the rests of the cells in the current LA. Let Ph_2 be the probability of this case and Np_{cost2} be the number of message generated by a partially successful paging.
- **Unsuccessful paging**: In this case, the MT is not tracked and a call failure message is generated. Let Np_{cost3} be the number of message generated by an unsuccessful paging. The probability of this case is given as $(1 - (Ph_1 + Ph_2))$.

If CA is the total number of call attempts per unit time, the paging cost is determined as [12],

$$\begin{aligned} Cost_{pg\_das} = CA[\{(Ph_1 \times N_{csi})Np_{\cos t1}\} \\ + \{(Ph_2 \times N_i)Np_{\cos t2}\} \\ + \{\{(1 - (Ph_1 + Ph_2)) \times N_i\}Np_{\cos t3}\}]. \end{aligned} \quad (19)$$

By maintaining the mobility information in the LA list and cache as well as considering the RSS, the system can track the user at low cost as observed in [12]. The total location management cost in DAS is given by [12],

$$Cost_{lm\_das} = Cost_{lu\_das} + Cost_{pg\_das}. \quad (20)$$

Three-dimensional location of a MT at each time instant is also predicted in DAS [12] by using the Inclination angle, the Azimuth angle measured using angle indicator and the Euclidean distance calculated based on the received power of that MT at that particular time. Generating relation matrix and relation graph from these visited location points, the route followed by the MT in a cell is predicted in DAS [12].

Table 2 – Parameter values assumed.

Parameters	Value
Number of cells in a LA	3/4/7
Radius of a cell	2–3 km
Mean velocity of MT	30 km/h
Call attempts per MT per hour	5–20

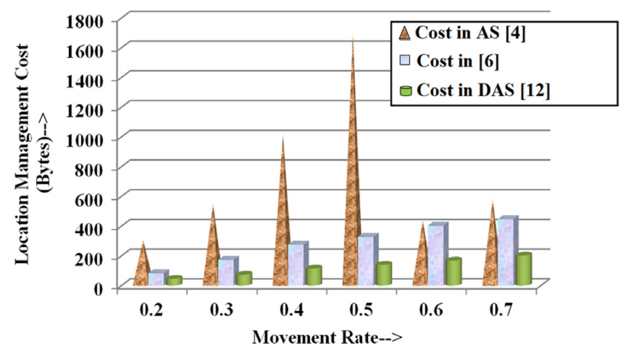


Fig. 2 – Comparison of location management cost between [4], [6], and [12].

We have calculated the location management cost in [4,6,12] and compared to select the optimum one with respect to the movement rate (MR). The MR is defined as the ratio of number of cells visited by a MT and the number cells contained in a LA. The MR is calculated as [12],

$$MR = \frac{NC_i}{N_i} \quad (21)$$

where N_i is the number of cells in the current LA a_i and NC_i is the number of cells visited by the user within a_i. The assumed parameter values are given in Table 2.

The total location management cost in [4,6,12] are calculated in terms of messages and converted into bytes. Then the results are presented in Fig. 2.

The paging cost is higher but location update cost is lower when the MR is low. At the medium MR, both of the location update and paging cost are high; hence the total location management cost is increased. With the increase in MR, the location update cost is increased but the paging cost is decreased as the last updated location of the MT is easily predicted. Hence there exists a tradeoff between the location update and paging cost. From Fig. 2, it is demonstrated that the location management costs in [4,6,12] are approximately >200 and ≤1600 bytes, ≤400 bytes and <200 bytes respectively. Hence it is observed that the scheme of [6] is 42%–73% cost effective than [4], and DAS [12] is 75%–88% cost effective than [4]. It is also observed that using DAS [12], 46%–58% of location management cost can be reduced than [6]. Hence it is demonstrated that, DAS [12] is more cost effective than both the schemes of [4,6]. In DAS paging cost is reduced as selective paging is performed considering partial, full successful and unsuccessful paging. Moreover there is no requirement to update HLR for every location update in DAS. This in turn reduces the location update cost. Thus the total location management cost is reduced in DAS.

2.6.2. *Replication based location management*

A replication based location management scheme is proposed in [13], where the replicas of user mobility information are maintained at the most frequently visited sites by that MT. In [13], the location update cost and paging cost includes the message signaling cost and the database access cost. In this method a set containing the most frequently visited LAs by the MT user is considered and four cases are assumed.

In the first case [13], the user moves from one cell to the other belonging to the same LA. Let P_{1u} be the probability of the occurrence of first case. As the location update takes place only at VLR, the location update cost (C_{1u}) is very small and negligible.

In the second case [13], the user travels from one LA to another, but both of the LAs belong to the considered set. In this case, the location is updated both at the HLR and VLR of the most commonly visited sites by the user. The location update cost is given by [13],

$$C_{2u} = P_{2u}[bKC_v + bC_h + 2bK(C_f + C_w)] \tag{22}$$

where P_{2u} is the probability of occurrence of the second case, C_h is the average location update cost at HLR, C_v is the average location update cost at VLR, K is the average number of replicas, b is the average size of one message in bytes, C_f is the message sending cost through the fixed network and C_w is the message sending cost through the wireless network.

In the third case, the user moves from one LA to another which does not belong to the considered set. In this case, both HLR and VLR are updated as well as an extra update cost is required to insert or delete a record in the database based on the direction of movements needed. If P_{3u} is the probability of occurrence of this case, the location update cost in the case is calculated as [13],

$$C_{3u} = P_{3u}[(bK+1)C_v + bC_h + 2(bK+1)(C_f + C_w)]. \tag{23}$$

In the fourth case, the user moves from one LA to another where both of the LAs do not belong to the considered set. The probability of this case is $(1 - (P_{1u} + P_{2u} + P_{3u}))$. In this case along with the HLR and VLR update, two extra update costs are required to delete the record from old site, and insert the record into the new site. Hence the location update cost in fourth case is determined as [13],

$$C_{4u} = (1 - (P_{1u} + P_{2u} + P_{3u}))[(bK+2)C_v + bC_h + 2(bK+2)(C_f + C_w)]. \tag{24}$$

The total location update cost is given by [13],

$$Cost_{lu\_13} = C_{1u} + C_{2u} + C_{3u} + C_{4u}. \tag{25}$$

In case of paging, three cases are considered in [13]. As four cases are considered during location update, the paging costs in each of these three cases are divided by 4. In the first case, it is assumed that the called MT and the caller MT both are present at the same site. Thus in this case, only a small cost is required to access the local MSC for authentication purpose for connection establishment. Let the probability of occurrence of this case be P_{1g}. Hence the paging cost in the first case is given by [13],

$$C_{1g} = P_{1g}[C_{pv} + 2C_w]/4 \tag{26}$$

where C_{pv} is the average cost of processing a query in VLR.

In the second case, the caller MT and the called MT exist at the same database where both presents in the common visited sites. In this case, the called MT finds the address of the caller MT by searching its database and the HLR is not accessed. Hence the paging cost in the second case is given by [13],

$$C_{2g} = P_{2g}[C_{pv} + 2(C_f + C_w)](1/4) \tag{27}$$

where the probability of occurrence of second case is P_{2g}.

In the third case, the caller MT and the called MT exist in different databases. The probability of this possibility is $(1 - (P_{1g} + P_{2g}))$. Hence the paging cost in the third case is calculated as [13],

$$C_{3g} = (1 - (P_{1g} + P_{2g}))[C_{pv} + C_{ph} + 2(C_f + C_w)] \tag{28}$$

where C_{ph} and C_{pv} are the average cost of processing a query in HLR and VLR respectively.

Therefore the total cost of paging in [13] is calculated as,

$$Cost_{pg\_13} = C_{1g} + C_{2g} + C_{3g}. \tag{29}$$

The total location management cost is given by [13],

$$Cost_{lm\_13} = \lambda_m Cost_{lu\_13} + \lambda_c Cost_{pg\_13} \tag{30}$$

where λ_c is the call arrival rate and λ_m is the movement rate of the MT in the network. The difficulties of this method [13] are:

- It requires updating HLR and VLR both each time it enters into a new LA that introduces high location update cost.
- Replicas are required to be maintained at frequently visited sites that introduces high storage cost.

To reduce the location update cost, an extension of this replication based scheme [13] is proposed in [14], where the location updating takes place only at VLR and the HLR is updated only once in a day. In [14], four cases are considered similar to [13]. Hence in the first case the location update cost (C_{1u1}) is negligible as in [13]. As HLR is updated once in a day, the location update cost in the second case is calculated as [14],

$$C_{2u1} = P_{2u}[bKC_v + b(C_h/24) + 2bK(C_f + C_w)]. \tag{31}$$

The location update cost in the third case is calculated as [14],

$$C_{3u1} = P_{3u}[(bK+1)C_v + b(C_h/24) + 2(bK+1)(C_f + C_w)]. \tag{32}$$

The location update cost in the fourth case is determined as [14],

$$C_{4u1} = (1 - (P_{1u} + P_{2u} + P_{3u}))[(bK+2)C_v + b(C_h/24) + 2(bK+2)(C_f + C_w)]. \tag{33}$$

The total location update cost is given by [14],

$$Cost_{lu\_14} = C_{1u1} + C_{2u1} + C_{3u1} + C_{4u1}. \tag{34}$$

The paging cost determined in [14] is same as in [13]. Thus the total location management cost in [14] is given by,

$$Cost_{lm\_14} = \lambda_m Cost_{lu\_14} + \lambda_c Cost_{pg\_13} \tag{35}$$

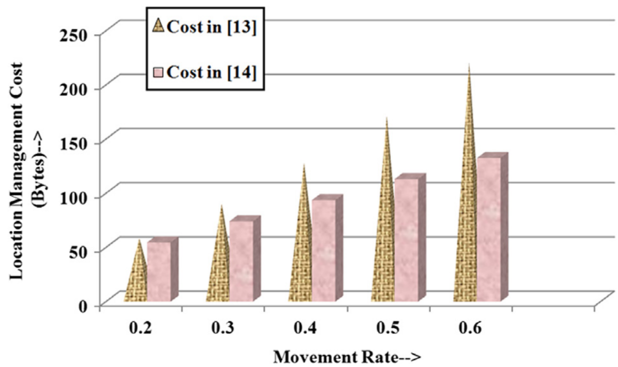


Fig. 3 – Comparison of location management cost between [13] and [14].

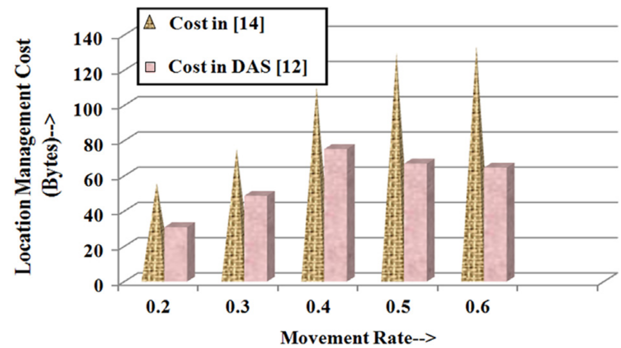


Fig. 4 – Comparison of location management cost in [12] and [14].

where λ_c is the call arrival rate and λ_m is the movement rate of the MT in the network.

The location management cost in case of [13,14] are calculated and presented in Fig. 3 with respect to the movement rate of the MT. From Fig. 3, it is observed that the paging costs in [13,14] are approximately ≤200 bytes and <150 bytes respectively. Hence it is observed that updating HLR once in a day as in [14], 2%–39% of location management cost can be reduced than [13].

In the next section, a comparison is performed between the mobility based and replication based location management schemes.

2.7. *Comparison between mobility based and replication based location management schemes*

In Sections 2.6.1 and 2.6.2, different types of mobility and replication based location management schemes are discussed. It is observed in Section 2.6.1 that DAS [12] is cost effective user mobility based location management scheme than the other mobility based schemes. On the other hand, it is observed in Section 2.6.2 that the method proposed in [14] is cost effective than the other replication based scheme. The location management cost in DAS [12] and in [14] are compared in this section to identify which is more cost effective.

The location management cost in DAS [12] and in the method of [14] are presented in Fig. 4 with respect to the movement rate. From Fig. 4, it is observed that the location management cost in [12,14] are approximately ≤120 bytes and <80 bytes respectively. It is observed from Fig. 4 that the mobility based location management scheme DAS [12] is 31%–51% cost effective than the replication based location management scheme proposed in [14].

The mobility and replication based location management schemes are tabulated in Table 3 with their features, advantages and challenges.

2.8. *Location management for femtocell based mobile network*

Now-a-days LTE (Long Term Evolution) femtocells are used along with the macrocells to achieve improved QoS at indoor environment. Deploying the self-optimized and portable femtocells, high traffic load can be managed. When a MT moves among the femtocells and macrocells within a LA, then no location update is needed [44]. If the MT moves to a cell in another unregistered LA, then the location is updated. In such a system, a LA contains macrocells where a macrocell may contain large number of overlay femtocells. Thus for an idle mode MT, only the registered LA is known. So to track the MT, all the cells contained in that LA are required to search. If φ_f is the resource occupation of paging in femtocell and φ_m is the resource occupation of paging in macrocell, then the paging cost is calculated as [44],

$$C_c = I(N_f \phi_f + \phi_m) \tag{36}$$

where N_f is the number of femtocells and I is the number of idle mode MTs for paging per second per unit area. The paging delay in such a system is calculated as [44],

$$d_c = T \tag{37}$$

where T is the time delay of one paging.

If a user is registered under a femtocell, then paging in macrocells as well as femtocells is redundant. On the other hand unnecessary paging to macrocell reduces its capacity which is undesirable. Hence location management in LTE system containing macrocells as well as femtocells is a great challenge.

For overlay LTE macrocell and femtocell, a two-step paging is proposed in [44]. In this two-step paging, the femtocells are first searched. If the MT is not found in femtocells, then the macrocell is searched [44]. The probability of finding the MT in the coverage of a femtocell is given by [44],

$$p_f = \frac{N_f S_F}{S_M} \tag{38}$$

where S_F is the effective coverage area of a femtocell and S_M is the effective coverage area of a macrocell. The probability of finding the MT in the macrocell excluding femtocells is given by [44],

$$p_m = 1 - p_f = 1 - \frac{N_f S_F}{S_M}. \tag{39}$$

As two-step paging is performed, the delay in such a LTE macrocell–femtocell based network is calculated as [44],

$$d_p = [p_f + 2(1 - p_f)]T. \tag{40}$$

Table 3 – Comparison between mobility based and replication based location management schemes.

Criteria of location management	Features	Advantages	Challenges
Mobility Based	MT user's mobility i.e. the movement pattern is considered to identify the frequently visited LAs and cells by the MT to track the user easily. MT user's probabilities of visiting different locations are considered.	Minimizes either the paging cost or the location update cost but maintains a trade-off between the location update and paging cost.	A profile or cache or both are required to be maintained to find out the movement pattern of the MT user.
Replication Based	Replicas of user profile are maintained at the frequently visited sites by the user to identify the lastly visited LA and cell by the user to track the user easily.	Minimizes the paging cost but increases the location update cost as updating takes place at all of the frequently visited sites.	Replicas are maintained at the frequently visited sites of the MT user; thus storage cost as well as location update cost is increased.

The cost consumed in two-step paging is determined as [44],

$$Cost_{pg\_44} = N_f Ip_f \phi_f + Ip_m \phi_m. \quad (41)$$

To remove redundant traffic due to location update and paging, a probabilistic paging method is proposed in [50]. Another mobility management scheme based on traffic forwarding in femtocell based LTE network is proposed in [51]. The difficulties of the existing location management approaches in macrocell–femtocell network are:

- To track a user, both macrocell and femtocells are searched during paging which increases the paging cost and delay.
- If location update is performed each time a user visits a femtocell, then the location update cost as well as the network traffic is increased.

To overcome these difficulties, two approaches are proposed for location management in our previous works [52,53]. These methods are extension of DAS [12]. In a macrocell–femtocell network, femtocells are deployed within a macrocell to provide good indoor coverage. In [52], a database named as De–Mukherjee (DM) is maintained inside the macrocell BS to keep track of the MTs belonging to that macrocell or femtocells within it. The macrocell BS containing the DM database is shown in Fig. 5.

A flag is maintained for each MT to denote whether it belongs to the macrocell or a femtocell. If a MT belongs to the macrocell, the flag is set to 0; else it is set to 1. This flag helps to track a MT by avoiding unnecessary paging cost and delay. When a user visits a LA, an update takes place at the VLR. When a user enters a femtocell, the flag is updated at the DM database. For the paging purpose, the user profile is checked at VLR. From the VLR the current LA ID is obtained and the cache is checked. The macrocell BS currently containing the MT is traced using the selective paging strategy of DAS [12]. After tracing the macrocell BS, the DM database is accessed to check whether the MT is in the macrocell or femtocell coverage. If the flag is set to 1, the femtocells are searched. Else the macrocell coverage excluding the femtocells is searched. After tracing the MT, the call is delivered. To calculate the paging cost, successful and unsuccessful events are considered.

The successful paging cost is calculated as [52],

$$Cost_{pgs\_52} = call\{(N_{fAj}S_F/S_M)N_{fAj} + (1-(N_{fAj}S_F/S_M))\}\{(N_{csi}/N_i)N_{csi}Np_{\cos t1}\} \quad (42)$$

where $call$, N_{fAj}, N_{csi}, N_i, Np_{cost1} are the number of call attempts per unit time, number of active femtocells within a macrocell, number of macrocells considered in selective paging, number of macrocells in the current LA, and number of byte transmitted in successful paging respectively.

The unsuccessful paging cost is determined as [52],

$$Cost_{pgu\_52} = [call\{(N_{fAj}S_F/S_M)N_{fAj} + (1-(N_{fAj}S_F/S_M))\}\{(1-(N_{csi}/N_i))N_i\}Np_{\cos t2}] \quad (43)$$

where Np_{cost2} is the number of byte transmitted in unsuccessful paging. Therefore considering the successful and unsuccessful scenarios, the paging cost is determined as [52],

$$Cost_{pg\_52} = Cost_{pgs\_52} + Cost_{pgu\_52}. \quad (44)$$

The delay in case of successful paging is calculated as [52],

$$D_{ps\_52} = T \times call \times [\{(N_{csi}/N_i)N_{csi}\}\{(N_{fAj}S_F/S_M) \times N_{fAj} + (1-(N_{fAj}S_F/S_M))\}] \quad (45)$$

where T is the time delay for paging a cell.

The delay in case of unsuccessful paging cost is determined as [52],

$$D_{pu\_52} = T \times call \times [\{(1-(N_{csi}/N_i))N_i\}\{(N_{fAj}S_F/S_M) \times N_{fAj} + (1-(N_{fAj}S_F/S_M))\}]. \quad (46)$$

Therefore considering the successful and unsuccessful scenarios, the paging delay is determined as [52],

$$D_{p\_52} = D_{ps\_52} + D_{pu\_52}. \quad (47)$$

It is observed in [52] that maintaining flag inside the DM database, a MT can be found at low cost and low time. But the disadvantage of this scheme is that maintenance of a database inside the macrocell BS introduces storage overhead. To recover this problem an extension of this method is proposed in [53]. In this case instead of maintaining the DM database inside the macrocell BS, it is stored inside the cloud as shown in Fig. 6.

The macrocell BS is connected to the cloud to access the DM database. In this case, communication cost and delay are involved. In this case, a cache is maintained to store the recently visited femtocell IDs to track the MT at small delay. In this approach the successful paging cost is given by [53],

$$Cost_{pgs\_53} = call([\{((N_f/N_{fA})N_f) + (1-(N_f/N_{fA}))(N_{fA}-N_f)\}(N_{fAj} \times R_f^2/R_m^2) + (1-(N_{fAj} \times R_f^2/R_m^2))][(N_{csi}/N_i)N_{csi}])Np_{\cos t1} \quad (48)$$

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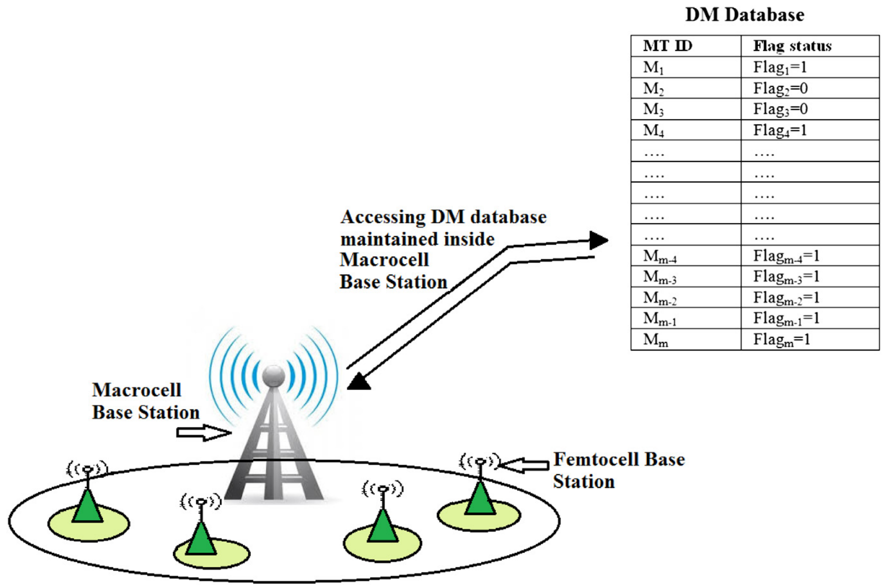

Fig. 5 – DM Database at the macrocell base station [52].

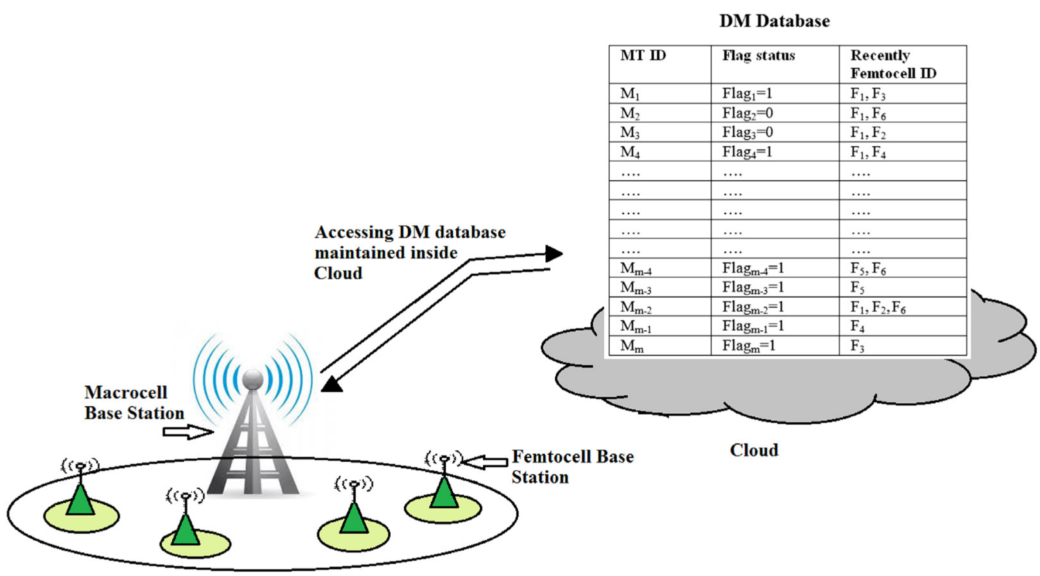

Fig. 6 – DM Database stored inside the cloud [53].

where N_f, R_f and R_m are the number of femtocells whose IDs are maintained in cache, radius of femtocell coverage and radius of macrocell coverage respectively.

The unsuccessful paging cost is given by [53],

$$Cost_{pguns\_53} = call([\{((N_f/N_{fAj})N_f) + (1-(N_f/N_{fAj}))(N_{fAj}-N_f)\}(N_{fAj}\times R_f^2/R_m^2) + (1-(N_{fAj}\times R_f^2/R_m^2))][(1-(N_{csi}/N_i))N_i]) \times Np_{\cos t2}. \quad (49)$$

Considering the successful and unsuccessful events, the paging cost is calculated as,

$$Cost_{pg\_53} = Cost_{pgs\_53} + Cost_{pguns\_53} + (call \times Num_a) \quad (50)$$

where Num_a is the number of message required for accessing the DM database per call.

The delay in successful paging is given as [53],

$$Del_{pgs\_53} = T \times call \times [[\{((N_f/N_{fAj})N_f) + (1-(N_f/N_{fAj}))(N_{fAj}-N_f)\} \times (N_{fAj}\times R_f^2/R_m^2) + (1-(N_{fAj}\times R_f^2/R_m^2))] \times ((N_{csi}/N_i)N_{csi})]. \quad (51)$$

The delay in unsuccessful paging is given by [53],

$$Del_{pguns\_53} = T \times call \times [[\{((N_f/N_{fAj})N_f) + (1-(N_f/N_{fAj}))(N_{fAj}-N_f)\} \times (N_{fAj}\times R_f^2/R_m^2) + (1-(N_{fAj}\times R_f^2/R_m^2))] \times \{(1-(N_{csi}/N_i))N_i\}]. \quad (52)$$

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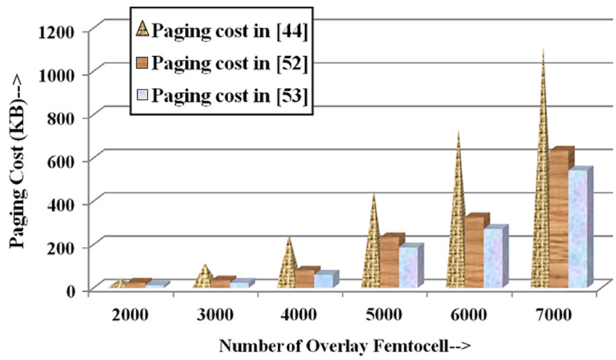

Fig. 7 – Comparison of paging costs between [44], [52] and [53].

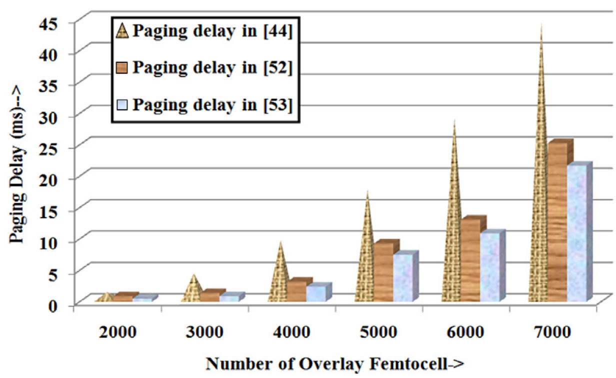

Fig. 8 – Comparison of paging delays between [44], [52] and [53].

The paging delay considering both successful and unsuccessful events is given by,

$$Del_{pg\_53} = Del_{pgs\_53} + Del_{pguns\_53} + (call \cdot Del_a) \tag{53}$$

where Del_a is the delay in accessing the DM database per call.

Figs. 7 and 8 present a comparative analysis between the paging costs and delays involved in the three paging schemes for macrocell–femtocell based LTE network [44,52,53].

From Fig. 7, it is observed that the paging costs in [44,52, 53] are approximately ≤1000 kB, ≤600 kB and <600 kB respectively. From Fig. 8, it is observed that the paging delays in [44,52,53] are approximately <45 ms, <25 ms and ≤20 ms respectively. Hence it is observed that maintaining DM database inside the cloud [53], paging cost can be reduced to approximately 51%–60% and 11%–50% than [44,52] respectively, and paging delay can be reduced to approximately 51%–58% and 14%–44% than [44,52] respectively.

3. Future scope of location management

Although several location management schemes are proposed, still this is a challenging research area. The future scopes of location management are discussed as follows:

(i) **Energy efficient location sensing**: Nowadays cloud computing has been integrated in location based services and applications. But such services require high energy consumption. Location Based application (LBA) is a location sensing application which obtains user's current location and provides various user position related services such as social network, mobile commerce etc. [54,55]. Energy efficient robust position tracking for mobile devices (EnTracked) is a low power location sensing scheme which locates MTs in an energy efficient way. Energy efficient trajectory tracking for mobile devices (EnTrackedT) [56] is an extension of EnTracked. It performs trajectory tracking instead of position tracking. Cell-ID Aided Positioning System (CAPS) is another trajectory tracking scheme [57]. Another energy-efficient location sensing scheme, Energy Efficient Localization for mobile phones (EnLoc) is proposed in [58], where people's actual mobility is recorded using Logical Mobility Tree (LMT). Although some strategies have been proposed, still green i.e. energy-efficient location management is a promising research field.

(ii) **Location management in 5G mobile network**: Fifth generation (5G) mobile network deals with heterogeneity [59,60]. In order to provide good coverage, small cells like picocells and femtocells are allocated inside the large cells like macrocell and microcell. This results in dense deployment of BSs which raises densification [61,62] as a critical problem of 5G network. In such a case, location update while moving between cells, can introduce huge number of message transmission. This increases the network traffic as well as the location update cost. In [63], location tracking schemes are discussed along with their applicability in 5G mobile network. As densification exists in 5G network, development of novel location tracking strategies for 5G mobile network is another future research area.

4. Conclusion

Location management is a key issue in the area of mobile computing. In order to provide best QoS to the subscribers, it is necessary to accurately track the location of MT to deliver a call to the user at low cost and low delay. Various existing location management approaches are discussed and compared in this paper to inspect the challenges in this field. Firstly the basic methods of location management are described. Rapid growing load for personal communication network along with the growth in number of active mobile subscribers, increase the number of location updates. This significantly consumes bandwidth and electronic power of handset battery along with high traffic. To reduce the traffic generated due to location update, various schemes are proposed. In these schemes a profile is maintained for individual MT to store and update the mobility information of that MT. This mobility information provides the probability of movement of each MT in each location area in the network. This helps to predict the movement pattern of the user for proper resource utilization. If location tracking is performed based on the short term or long term mobility information of the user, the scheme is known as mobility based location management scheme. By replicating mobility information of the MTs at frequently visited sites, location tracking cost can be reduced. Both of these mobility based or replication based

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schemes have their own advantages and limitations. In this paper a comparative analysis is performed between these two types of methods. To provide better QoS to the massive number of mobile users especially at indoor environment, femtocells are allocated inside the macrocells. Different location management schemes for macrocell–femtocell based LTE network are also discussed and compared with respect to their cost consumption and delay. Finally the future research scopes of location management are explored in this paper.

Acknowledgment

Authors are grateful to Department of Science and Technology (DST) for sanctioning a research Project entitled "Dynamic Optimization of Green Mobile Networks: Algorithm, Architecture and Applications" under Fast Track Young Scientist scheme reference no.: SERB/F/5044/2012-2013, DST-FIST reference no.: SR/FST/ETI-296/2011, and No. DST/INSPIRE Fellowship/2013/327 under which this article has been completed.

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