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Historical based location management strategies for PCS networks

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Abstract Due to the current popularity of wireless communication, personal communication service networks have attracted a lot of attention. As mobile terminals (MTs) in such networks have the ability to communicate on the move, location management (LM) is a critical issue that should be handled carefully. Managing MTs locations is to simultaneously perform two main operations, which are; location update and paging. A good LM strategy maintains both operations with the minimum time and signaling penalties. Although several LM strategies have been introduced, they still suffer from several drawbacks. This paper introduces three novel LM strategies, which are; historical based location management (HBLM), direction based location management (DBLM) and trajectory based location management (TBLM). TBLM strategy is based on geographical position of MTs, while HBLM and DBLM are based on geographical position of MTs as well as time aspects. Visited locations are saved in MT's internal cache in the form of cell identifier as well as the corresponding time interval. Location tracking is fully supervised by the MT's current visitor location register (VLR). On the other hand, the collected location information in MT's cache is sent to VLR when MT passed through a previously defined number of cells or when a previously defined number of time periods has elapsed. In HBLM, paging is done according to the historical movements saved in VLR, while DBLM takes also MT's movement direction into consideration while in TBLM, paging is done according to the historical trajectories that MTs are used to follow. Experimental results have shown that the proposed LM strategies significantly improve MTs' tracking process as they introduce the minimum signaling penalty (for paging and registration) with an acceptable paging time delay compared with recent LM strategies.

Keywords Personal communication service (PCS) · Location management (LM) · Location update · Paging · Visitor location register (VLR) · Home location register (HLR)

1 Introduction

Recently, cellular communication has been experiencing a rapid growth. It has been evolved from a costly and limited service towards being a vital alternative to the classical wired telephone service [1]. This led to the development of a new generation of mobile communication network called personal communication services (PCS), which are gaining huge attention in both research and application perspectives [2]. PCS network is a mobile communication system that enables mobile terminals (MT) to transfer any form of information on the move at any time.

In a PCS network, a given geographically serviced area is divided into smaller areas of hexagonal shape called cells [3]. In each cell, there is a fixed base station (BS), which is used to communicate with MTs, such as cellular phones using their radio transceivers, over the pre-assigned radio frequencies. A BS is connected to the mobile switching

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center (MSC), which is usually connected to the public switched telephone network (PSTN) [4]. This makes the mobile services widely accessible to the public. On the other hand, to facilitate the tracking of a moving MT, PCS network is partitioned into many Registration Areas (RAs). Each RA, usually includes several (tens or hundreds) cells, is serviced by a database called Visitor Location Register (VLR). Another database called Home Location Register (HLR) is associated with several VLRs [5]. The communication area served by one HLR is called Service Area (SA). As the PCS network consists of several service areas, therefore it owns several HLRs.

The two-tier database system of HLR and VLR is employed for managing MTs locations in PCS networks. Permanent data (e.g., profile information, directory number, current location, and validation period) of the MTs whose primary subscription is within a certain SA is stored in the HLR serving such SA [6]. For each MT, HLR contains a pointer to the VLR serving the RA where such MT is currently located to assist routing incoming calls. One VLR is associated with each Mobile Switching Center (MSC), which contains a temporary record for each MT currently visiting the RA serviced by the entire MSC. Accordingly, VLR maintains vital information for handling calls to or from a visiting MT [5].

In the research arena, a large number of studies are being performed for introducing better services in PCS networks [2]. Most of these research efforts concentrate on the development of effective location management (LM) schemes. This is due to the increasing demands for heterogeneous services, which necessitate the network to effectively locate roaming MT. LM is also critical to maintain calls in progress as MTs can exchange data on the move [7]. Moreover, as the number of network subscribers increases, the system overheads involved with LM will increase beyond the capacity of the current network designs. Methods for reducing the overheads are critically important for the design and implementation of PCS networks. In general, there are two basic operations in LM, which are; *location registration* and *call delivery*.

Location registration (location update) is the process through which the network tracks the locations of roaming MTs. Each MT reports its up-to-date location information dynamically [8]. When an incoming call arrives, the network searches for the called MT (MT_c) by sending a location request message to its HLR. Then, HLR determines the VLR of MT_c, and sends a location message to the associated MSC. Finally, MSC sends polling signals to all the cells in the RA to determine the cell location of the MT_c [6]. This searching process is called the call delivery (paging).

Generally, there is a tradeoff between location update and paging in terms of signaling cost. The more the location updates, the less the paging signaling cost and vice versa [7]. The existing location management scheme applied in the current networks is a static one, which performs location update for a MT if it crosses the border of a fixed registration area (RA). When a MT is called, the cell hosting the MT is paged along with all other neighbored cells in its registration area (RA), which increases the signaling cost. Therefore, selective paging became essential, which means to pick out a cell or a set of cells to be paged in several paging rounds according to specific criteria, rather than paging the whole RA's cells simultaneously [8].

Looking at the need of efficient LM, this paper develops three novel LM strategies in which each strategy includes new location registration and call delivery schemes. The proposed LM strategies are; historical based location management (HBLM), direction based location management (DBLM) and Trajectory Based Location Management (TBLM). Both HBLM and DBLM strategies depend on saving MT's movements in its local cache in the form of cell IDs as well as the corresponding entrance time intervals in its local cache. TBLM strategy depends on saving MT's trajectories in its local cache in the form of consecutive visited cell IDs. Mobile cache refers to a memory storage area that stores copies of information that is likely to be needed in the near future, so it can be accessed faster [9]. Cell ID refers to the unique number of each cell used in the location database. Cache contents are sent to the VLR serving the hosting RA based on some parameters, like number of movements or a predefined time period. The sent cached data is saved in location database, which is used as a historical movement behavior for each MT. In the proposed strategies, novel paging schemes are developed in order to minimize the time delay and paging costs. In HBLM the proposed paging scheme is based on the previously saved location database, while DBLM on the other hand considers also the MT's movement direction. TBLM has a new paging scheme that depends on trajectories weight. A simulation is done based on real scenario measurements. Moreover, a comparison is carried-out between the proposed LM strategies as well as recent LM strategies. Experimental results have shown that the proposed LM strategies (e.g., HBLM, DBLM and TBLM) outperform other LM strategies as they introduce the minimal signaling costs for paging and registration with an acceptable paging time delay.

The rest of the paper is organized as follows: Sect. 2 presents PCS network architecture. Section 3 discusses related work, and identifies bottlenecks. The proposed LM strategies (e.g., HBLM, DBLM and TBLM) are discussed in Sect. 4. Section 5 presents the cost analysis, Sect. 6 illustrates the proposed LM strategies in a simple example. Section 7 illustrates the experimental results, Sect. 8 discusses the implementation and costs, and finally Sect. 9 underlies the conclusion and future work.

2 PCS network architecture

As depicted in Fig. 1, PCS Service Area (SA) is divided into several Registration Areas (RAs), which are sub-partitioned into various cells [4]. A cell is the territory managed by one Base Station (BS). Base stations in the same registration area are joined with one Mobile Switching Center (MSC), which is a phone switch committed for PCS applications [4]. It is responsible for a lot of switching services. Home location register (HLR) is connected to a lot of VLRs. Table 1 illustrates the detailed description of how the traditional registration is done [6]; it's also illustrated in Fig. 1.

In a general sense, to deliver a call from a MT to another, the current cell of the MT_c must be identified as well as its hosting VLR. The general steps of the traditional call delivery scheme are illustrated in Table 2 and Fig. 1 [6].

3 Related work

Location management process refers to the set of techniques used to effectively locate the network MTs. The main target is to reduce the overall cost of the location management, which includes both location update and paging costs. Many strategies for location management have been proposed, which can be categorized into some main categories as will be illustrated through the following paragraphs.

The first category is location based strategies, in which location updates (LU) take place whenever the MT passes through a cell boundary or a registration area [10, 11]. In [11], some of the cells are flagged, so that the mobile terminal performs a location update whenever it passes through any of these cells. In [3], RA structure is designed to be a group of stacked flowers, the center of each flower is considered to be a hot spot. Location update is done when the MT passes through any of the hot spots in the RA. In [12], the signaling overhead is between MSC and HLR is decreased by making a forward pointer. When the mobile terminal passes by the registration area border, the old VLR contains a pointer that points to the ID of the new MSC. Thus, when the MT is called, the network communicates the first VLR and takes after the chain of pointers to find the hosting registration area. However, a pointer chain threshold must be specified to avoid long delay.

On the other hand, the second category for LM in PCS network is distance based strategies, in which LU is done when the MT overpass a pre-defined distance. In [13], a new model is introduced to calculate the distance threshold for the distance based strategy. In [14], two algorithms are compared; traditional Distance Based Registration (DBR), and Distance Based with Implicit Registration (DBIR). DBIR depends on calculating the distance between the current BS and the last registered BS in case of delivering a

Fig. 1 PCS architecture. Existing registration scheme. Existing call delivery scheme

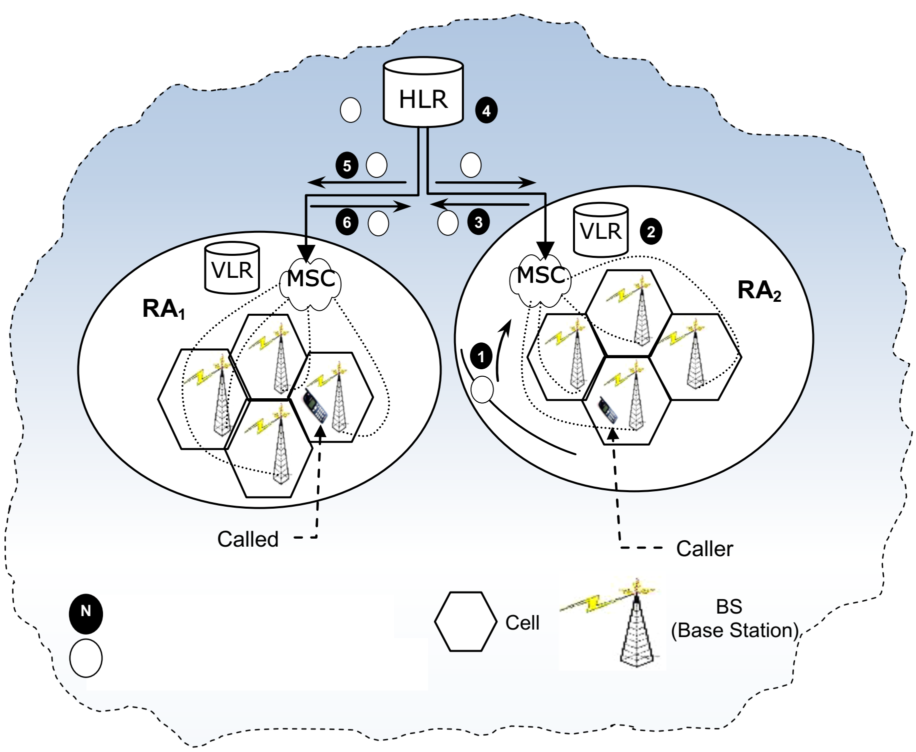


Table 1 Steps of traditional registration scheme

If a MT crosses a new registration area boundary, it is listed in the new VLR, by passing a message of registration request to the new MSC using the base station of the existing cell
A new record of the mobile terminal is inserted to the VLR, and then a message is sent from the VLR to the HLR informing it of the MT's existing location
The location message is directed to a Signal Transfer Point (STP), which gets the HLR of the MT using its Mobile Identification Number (MIN). HLR identification is known by a table lookup procedure called Global Title Translation (GTT). Eventually, the message is forwarded to the MT's HLR
The MT's location record in HLR is updated to mirror the existing location of MT (current serving MSC), then sends a registration confirmation to the existing MSC
The MT's HLR sends a registration cancel message to the previous VLR to delete the MT's location record
The previous VLR sends a cancellation confirmation message to the MT's HLR

Table 2 Steps of traditional call delivery scheme

The caller MT initializes the call by contacting the BS covering its hosting cell. Then, BS forwards the "call initialization" signal to the serving MSC
A location request message is sent from the MSC to the caller MT's HLR
The location request is forwarded to the HLR of the MT_c
A message is sent with a location request from the MT_c's HLR to the MSC serving the registration area of the MT_c
MSC then locates the MT_c's hosting cell, assigns it a Temporary Location Directory Number (TLDN). Lastly, MSC sends that TLDN to the HLR of the MT_c
As the calling MSC receives the pre assigned TLDN, it initializes a connection with the called MSC through which the call is performed

call. In [15], probability distribution of a MT's moving distances was performed between the most recent LU and the following received call. Then, an effective sequential paging technique is introduced, which guarantees to locate a mobile terminal in the first paging round.

The third category is the time based strategies, in which LU is triggered periodically by a pre-defined timer [16]. In this scenario, a timer based algorithm is introduced, which uses the mobility of each MT and the time of movement to form personalized RAs [17]. In [18], the variability of the blocking probability to a RA is analyzed, with the service rate, timeout period, and expected and actual numbers of MTs in the RAs. Another strategy is introduced in [19]. This strategy proposes an activity based mobility prediction technique, which uses activity prediction and Markov modeling techniques. This technique aims to devise a prediction methodology, which could make accurate predictions than existing techniques.

The fourth category is the movement based strategies, in which LU is done if the MT crosses a pre-defined number of cell borders. In [7], one movement based scheme is presented, using mobility information of MTs in cellular mobile networks. Such scheme adapts the location prediction of MTs, according to their mobility patterns and call arrival frequency. In [8], each MT keeps a counter of the number of cells visited. A location update is performed when this counter exceeds a predefined threshold value. This scheme allows the dynamic selection of the movement threshold on a per-user basis.

The performance of the above discussed schemes (movement based, distance based as well as timer based schemes) was analyzed in [20], where it was shown that the distance based scheme performs better than time based or movement based schemes in several cases. However, the distance based strategies are difficult, as MTs need information about the topology of the underlying cellular network. Moreover, it needs sophisticated method to be implemented in a real-world network [21].

The fifth category is the speed (velocity) based strategies, which keep track of MT movements as well as its moving speeds. In these schemes, paging area is calculated according to MT's velocity. An algorithm is proposed in [22], which uses speed distribution and random walk model to develop look-up tables for each MT. A subarea size is concluded from these tables to be paged. In [23], location tracking runtime information is gathered using a velocity class concept. In [24], the network predicts a MT's future location, by using the recent MT's report of velocity and location. In [25], a moving direction identification technique is introduced, which detects the moving direction changes using simple computations, and accordingly updates the MT's location.

Other research works concerning LM are provided. In [26], a hybrid mobility prediction strategy is proposed, It combines evidence from three different predictors, which are; probabilistic predictor (PP), group-based predictor (GP), and spatial predictor (SP). PP relies on Bayes theorem, GP uses ant colony optimization (ACO), while SP tries to detect the topological architecture of the current registration area to enhance the prediction process. Munadi and Ismail [27] proposes, validates, and evaluates the performance of a new LU strategy using fuzzy logic for cellular radio system. In this research, three metrics are proposed and used for fuzzy evaluation, which are; movement speed, MT density, and residence time. On the other hand [28], estimates the location of the MT based on geometric location, which illustrates hybrid proposed schemes. Such research combines angle of arrival (AOA) information at the serving BS and time of arrival (TOA) at three BSs, in order to locate the MT. Finally, Chandra and Das [12] proposes a pipeline paging, which is based on collecting more than one MT to be paged in parallel. If one or more MTs are found, their paging requests are obsolete, while new requests are added to the list of requests in the next paging round.

4 The proposed location management strategies

In this paper, three novel LM strategies are introduced. The first is the Historical Based Location Management (HBLM), which is based on the collected historical data of the MT's movements. The second is the Direction Based Location Management (DBLM), which takes the movement direction of the MT into consideration. Hence, DBLM is based on collected historical data of MT's movements along with the expected MT's movement direction. On the other hand, the third LM strategy is the Trajectory Based Location Management (TBLM), which is based on historical trajectories of the MT. The next subsections will illustrate the proposed LM strategies (e.g., HBLM, DBLM, and TBLM) in details.

4.1 Historical based location management (HBLM) strategy

HBLM strategy is based on two basic schemes; the first is a timer based movement logs collection, while the second is selective paging scheme. According to the first, when a MT enters a new cell, it saves the cell ID, which is received from the new cell BS, as well as the entrance time in its own cache. The day time is sectioned into 24 durations (time stamps), 1 h each. The contents of the MT's cache is sent to the VLR managing its current registration area, in one of three situations, which are; (1) when MT passes by a certain number of cell borders, (2) when a certain time duration has elapsed (one or more intervals), or (3) when the MT performs deregistration. The cache content of a specific MT is saved in a location database that can be considered as movement logs, where a MT log refers to a record of the MT movements. In HBLM, MTs movement logs are collected through a timer based scheme, which is illustrated in the next subsection.

4.1.1 *Movement logs collection scheme for HBLM (LCS_H)*

In this subsection, the proposed methodology used to track the MT's movements for HBLM will be discussed in details, which is also illustrated in Algorithm 1. Through this subsection, the movement Logs Collection Scheme for HBLM (denoted as; LCS_H) will be explained in details.

As mentioned before, the MT's cache is sent to VLR in three different situations. Whenever a movement threshold has been reached, the movement logs are sent in the form; [(T_i, C_1), (T_i, C_2) … (T_i, C_k)], where T_i is the time interval number i, C_x is the ID of the x^{th} cell, and C_k is the ID of the last cell of the MT's current trajectory. On the other hand, when the time interval threshold is reached, the sent movement trajectory is sent in the form; [(T_i,C_1), (T_i, C_2), (T_i, C_2) … (T_i, C_2)]. In such case, it is noticed that the same cell is repeated in multiple intervals, which means that MT stays in C_2 for a long time period. However, if MT is performing deregistration (either by leaving the current RA or by a voluntary shutdown), it will be asked to send the preregistered cache contents before deregistration. Therefore, in the above mentioned cases, the last cell from which the trajectory was sent to VLR is flagged as the Last Registered Cell (LRC) for the considered MT.

Generally, VLR has more detailed mobility information stored in its mobility database such as the Number of Occurrences (NO^2) of each MT in each cell during each time interval. NO^2 of a MT in a specific cell C_i at a certain time interval T_j refers to the number of times at which that MT crosses C_i during T_j. The structure of VLR's mobility database is represented in Fig. 2. Such database consists of two basic tables with one-to-many relation. The first is the MT_LRC table, which records the last registered cell for each MT. The second is the MOVEMENT_HISTORY table, which stores some other data such as NO^2 in all intervals (T_1 … T_{24}) for each MT. The last column in MOVEMENT_HISTORY table represents the Total Visits Number (TVN), which stores the total NO^2 for all intervals in each cell.

Logs Collection Algorithm for HBLM (LCA_H)

1- When the MT enters a new cell

If it is a new RA then :
- Send MT's cache to old VLR.
- Reset MT's cache.
- Reset counters ($M = 0$, $I_{int} = 0$).

Else
- Store cell Id and time interval in MT's cache.
- Increase movement counter ($M= M+1$)
- If movement threshold is reached ($M=M_{th}$) then
  - ➢ Send MT's cache to VLR.
  - ➢ Reset MT's cache.
  - ➢ Reset counters ($M = 0$, $I_{int} = 0$)

  End if;

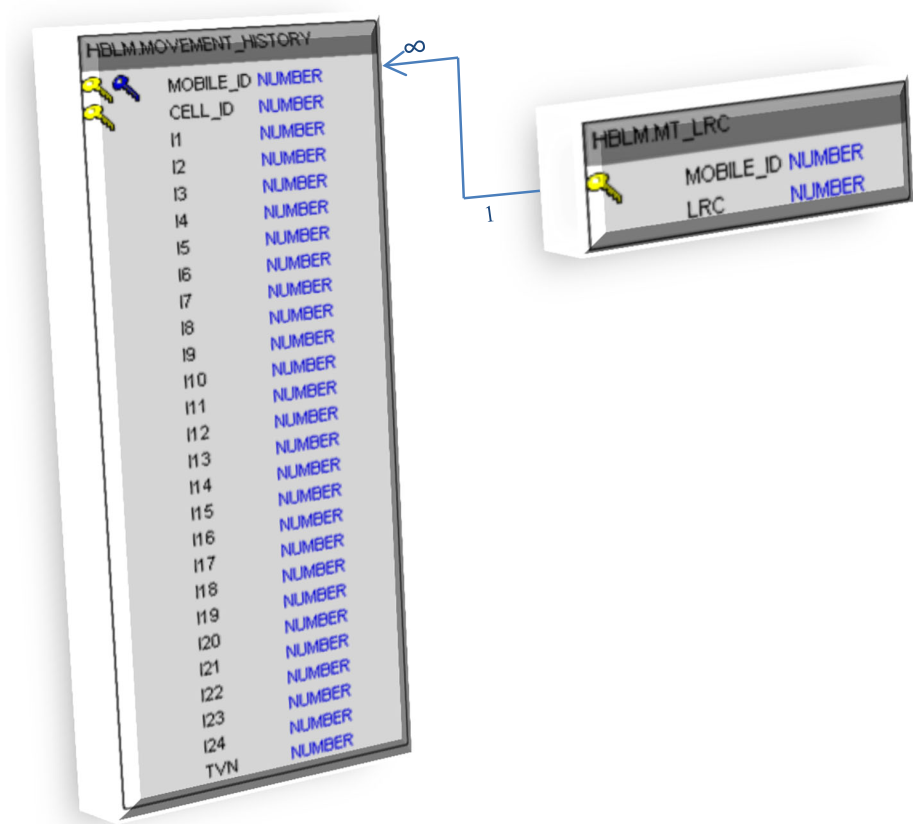
End if;

2- When a new time interval is reached
- Store cell Id and time interval in MT's cache.
- Increase the interval counter ($I_{int}=I_{int}+1$)
- If interval threshold is reached ($I_{int} =I_{th}$) then
  - ➢ Send MT's cache to VLR.
  - ➢ Reset cache.
  - ➢ Reset counters ($M = 0$, $I_{int} = 0$).

  End if;

Algorithm 1: Logs Collection Algorithm for HBLM (LCA_H)

Fig. 2 HBLM mobility database in VLR



4.1.2 Selective paging scheme for HBLM (SPS_H)

Setting up a call is a challenging task as it requires a precise identification of the current location of the called *MT* (denoted as; MT_c). Although the blanket paging can be used to accomplish such task, it warmly consumes the network bandwidth. Through this subsection, a new Selective Paging Scheme for HBLM, denoted as; SPS_H, will be introduced.

According to SPS_H, if a *MT* is called, its last registered cell is identified, and then a list of cells is prepared within the predefined movement threshold. The list of Elected Cells (EC) for paging can be identified by considering an imaginary circle whose center is the last registered cell of MT_c, while the movement threshold is its radius. Then, to obtain the list of Paging Cells (PC), those cells that are located outside the current RA are removed from *EC* as illustrated in Fig. 3, which are considered as redundant cells. Hence, $PC = Cells(RA_c) \cap EC$, where RA_c is the current registration area of the MT_c and $Cells(RA_c)$ is the set of $cells \in RA_c$. Afterword, all $cells \in PC$ are arranged based on the data stored in VLR's mobility database of the current time interval. Hence, the cells are arranged descending based on NO^2, *TVN* number, and *SD* (Shortest Distance to LRC) respectively. The result is the Ordered Paging Cells (OPC). For illustration, if $OPC = <C_x, C_y, C_z>$, then, it will be better to page cell C_x before C_y and page C_y before C_z as the Probability Of Existence (POE) of the MT_c in C_x at time interval T_i, denoted as; $POE(MT_c, C_x, T_i)$, is greater than both $POE(MT_c, C_y, T_i)$and $POE(MT_c, C_z, T_i)$, while $POE(MT_c, C_y, T_i) > POE(MT_c, C_z, T_i)$.

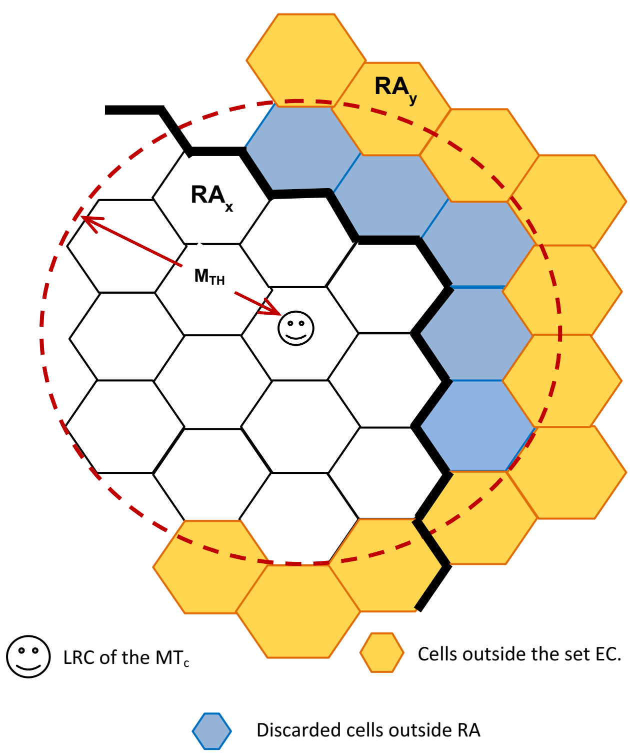


Fig. 3 SPS_H technique illustration

Finally, *OPC* is divided into equal numbered groups starting from the most probable cells, and then page those groups sequentially from the most probable group to the least probable one. In order to identify the maximum allowed number of paging rounds denoted as; *MAPR*, which can be calculated by Eq. (1).

$$MAPR = \frac{MAD}{\psi} \tag{1}$$

where *MAD* is the Maximum Allowed Delay time that the caller MT has to wait until the call is initiated, and ψ is the time delay taken by the network for performing a single paging round (e.g., the time delay for paging a cell group).

However, if the MT_c has no or insufficient history at the LRC, the cells∈PC are ordered descending based on both his insufficient NO^2 as well as the pre-stored NO^2 of other MTs who have passed through these cells during the current time interval (denoted as; $T_{current}$). However, MT_c's NO^2 will have more weight, which means that every cell will be ordered based on $NO^2(MT_c)*\delta + NO^2(other\ MTs)$, where δ is a weighting factor set by the network administrator. An important issue that should be considered precisely is how to decide that MT_c has insufficient history at LRC_i. To accomplish such aim, the average NO^2 of all cells∈PC for MT_c at the current time interval ($T_{current}$), denoted as; $ANO^2(MT_c, LRC_i, T_{current})$ is calculated. Then, a decision is taken that MT_c has a sufficient history at LRC_i if $ANO^2(MT_c, LRC_i, T_{current}) \geq \lambda$, where λ is a threshold value set by the network administrator. The assumption to use social behaviors to predict the future movement of the MT_c has been employed before. For illustration the use of ant colony, in which the movement of neighboring MTs can be employed in the prediction process [29]. In such situation, the history of MT_c's neighbors can be employed. This is a logical employment since, for illustration, when the MT is on a highway; it surely goes in the same direction as its neighboring MTs. In the same way, the behavior of a new student will be similar to his fellow students, as they frequently move between the campus and the stadium.

The proposed selective paging scheme for HBLM is depicted in Algorithm 2, which is also summarized through the following steps:

1. Identify last registered cell (LRC) of MT_c, denoted as; $LRC(MT_c)$.
2. Identify the cells around $LRC(MT_c)$with a circle radius equals to the predefined movement threshold (e.g., EC).

3. Remove redundant cells, which are located at other (neighboring) RAs. The result then is the set of paging cells (e.g., PC).
4. Calculate $ANO^2(MT_c, T_{current})$ for all cells∊PC.
5. If $ANO^2 \geq \lambda$,then arrange cells∊PC in descending order based on NO^2 of each cell stored in the movement history table for the MT_c.
6. If $ANO^2 < \lambda$, then PC is ordered in descending order based on both NO^2 of the MT_c as well as NO^2 of other MTs who have pre-registered histories at LRC(MT) at the current time interval.
7. Cells with the same NO^2 are ordered by TVN, then by SD (shortest distance to LRC).
8. Divide PC into a number of equal groups.
9. Each group is paged individually, until MT_c is found.

4.2 Direction based location management (DBLM) strategy

As the movement direction of the roaming MTs can seriously influence their expecting next locations, through this section, a modification will be done in HBLM to consider MTs' movement direction. Surely, if the movement direction of the called MT (e.g., MT_c) is effectively identified, a smaller paging area will be selected, which in turn minimizes the paging costs in terms of signaling and time penalties. DBLM shares several aspects with HBLM. It also consists of two basic schemes, which are; (1) a movement Logs Collection Scheme (denoted as; LCS_D) and (2) a selective Paging Scheme (denoted as; SPS_D). However, DBLM takes the movement direction of MT_c

HBLM Paging Algorithm

Inputs

MT_c ,Interval of the call (I_x)

EC , N, MAD, ψ, λ, β

Output

Cell id (the address of cell hosting MT)

Parameter	Description
MT_c	Called MT ID
MAD	Maximum allowed delay time
ψ	Time needed to page single paging round
EC	Cells surrounding LRC within M_{TH}
N	Count(EC)
N_{APR}	Number of allowed paging rounds
N_{CR}	Number of cells in each paing round
OPC	Ordered Paging Cells
λ	History average threshold
β	History weight
I_c	Interval of the call

Steps

```
-- get number of paging rounds
N_APR = MAD / ψ;
-- get number of cells in each round.
If mod(N/ N_APR) = 0 then
    N_CR = N/ N_APR;
Else
    N_CR =round(N/ N_APR, 0) + 1;
End if;
-- Identify MT's last registered cell
Select LRC
from MT_LRC
where mobile_id = MT_c;
--
Select avg(I_c)
Into avg_history
From movement_history,EC
Where EC.C_x = movement_history.cell_id;
If avg_history ≥λ then
    -- order EC by NO^2, TVN, SD
    Select movement_history.cell_id
    Into OPC1
    From movment_history join EC
    Where EC.C_x = movement_history.cell_id
    And movement_history.mobile_ID = MT_C
    Order by NO^2, TVN, SD descending;
Elsif avg_history <λ then
    -- order EC by NO^2, TVN, SD
    Select movement_history.cell_id, (called.I_c*β+
    other.I_c) NO^2
    Into OPC1
    From movement_history as called join
    movement_history as other join EC
    Where EC.C_x = called.cell_id
    And called.mobile_ID = MT_C
    and called.cell_id = other.cell_id
    Order by NO^2 , TVN, SD descending;
End if;
--
For I in 1.. N_APR -1 loop
    Sequentially_page (first N_CR cells {OPC});
    If MT_found then
        Return cell_id;    -- hosting cell id
        Exit loop;
    Else
        OPC = OPC – first N_CR cells{OPC};
    End if;
End loop;
If not MT_found then
    Sequentially_page (first N_CR cells {OPC});
    Return cell_id;
End if;
```

Algorithm 2: HBLM Paging Algorithm

into consideration, and then chooses the paging area accordingly.

4.2.1 Movement logs collection scheme for DBLM (LCS_D)

In this scheme, MT's movement logs (trajectories) are collected (e.g., sent from MT to the VLR serving the current RA) based on two situations, which are; (1) when the MT overpasses a pre-defined number of cell boundaries, or (2) when the MT performs deregistration (e.g., when MT leaves his hosting RA or performs a voluntary shutdown).

In DBLM, MT's cache is sent to VLR in the form; [(T_i, C_1), (T_i, C_2)… (T_i, C_k)], where T_i is the ith time interval, C_x is the xth cell of the current RA (e.g., RA_c), while C_k is the last registered cell. Each cache segment (T_i, C_x) indicates that the MT passed by C_x during the time interval T_i. The mobility database located at VLR stores the NO^2 for each trajectory saved in the cache (two consecutive segments with different cell IDs). Each stored trajectory clarifies that C_x moved to C_y during the interval T_i.

Considering Fig. 4, LRC is the last registered cell for MT_c. As any cell is surrounded by other six cells, there are six allowed movement directions for MT_c to those six surrounding cells. Each surrounding cell can be considered as a gateway to a paging area. Hence, as depicted in Fig. 6, if the predicted movement of MT_c is to C_A, then it will be more effective to page the region R_A first as it is located in the same direction of the predicted MT_c's next movement. This is the basic idea of the Selective Paging Scheme used in DBLM, denoted as; SPS_D, which will be explained in the next subsection. Hence, the gateways of MT_c's LRC (e.g., the six surrounding cells to $LRC(MT_c)$) are first identified. Then, only those gateways that belong to the current RA (e.g., RA_c) will be considered while discarding other gateways that belong to neighboring RAs. Finally, based on the pre-stored historical trajectories of MT_c's at the current time interval, the probability that each of the considered gateways to be the next target for MT_c's is calculated. Then, the θ paging areas behind the θ gateways (where $\theta \leq 6$) can be prioritized based on the probability of the corresponding gateway.

As illustrated in Fig. 5, the database structure for DBLM consists of four related tables, namely; two master tables and two detail tables. The first master table is MT_LRC, which records MTs' last reported locations. The second is the TRAJECTORIES table, which stores the trajectory's data like its code, source cell id, and destination cell id. On the other hand, the first details table is MOVEMENT_HISTORY, which stores the mobile ID, trajectory code, NO^2 in all intervals (I_1 … I_{24}) for each trajectory. The last column in MOVEMENT_HISTORY represents the total number of visits (TVN), which indicates the total NO^2 for each trajectory. The second details table is MOVEMENT_DIRECTION, which stores the trajectory code as well as its corresponding paging region.

For illustration, consider in which $LRC(MT_c)$ is surrounded by the cells C_A, C_B, C_C, C_D, C_E, and C_F. The cell from where MT_c comes is assumed to be C_C. Assume that MT_c is currently called at the time interval T_i. Then, the probabilities that MT_c enters the surrounding gateways of LRC (e.g., C_A, C_B, C_C, C_D, C_E, and C_F) at T_i are calculated based on the previously collected trajectories of MT_c, which are also illustrated in Fig. 6. Hence, using the calculated probabilities for each gateway, the corresponding paging regions (e.g., G_A, G_B, G_C, G_D, G_E, and G_F) are prioritized accordingly. Based on the probabilities reported in Fig. 6, the suggested paging regions are prioritized in the

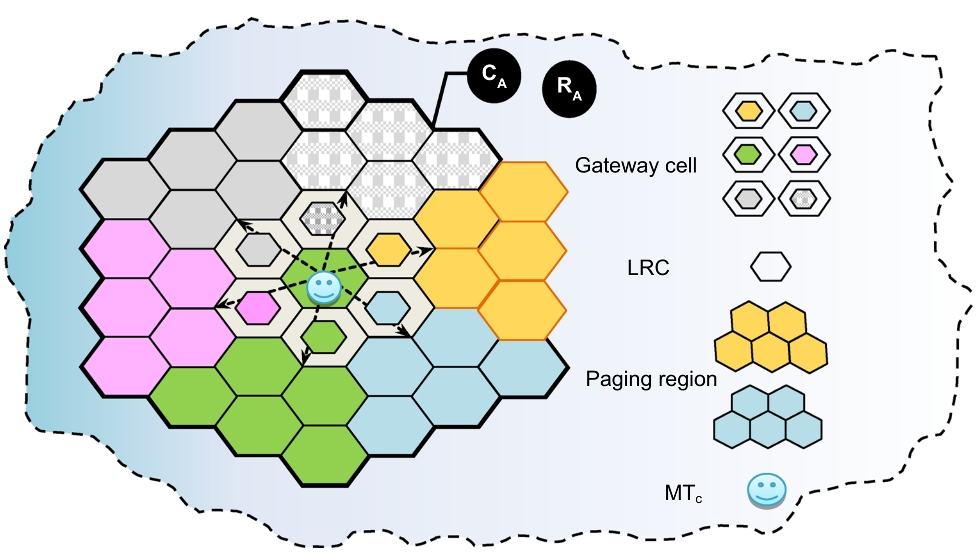


Fig. 4 Expected area of cells hosting MT by detecting direction

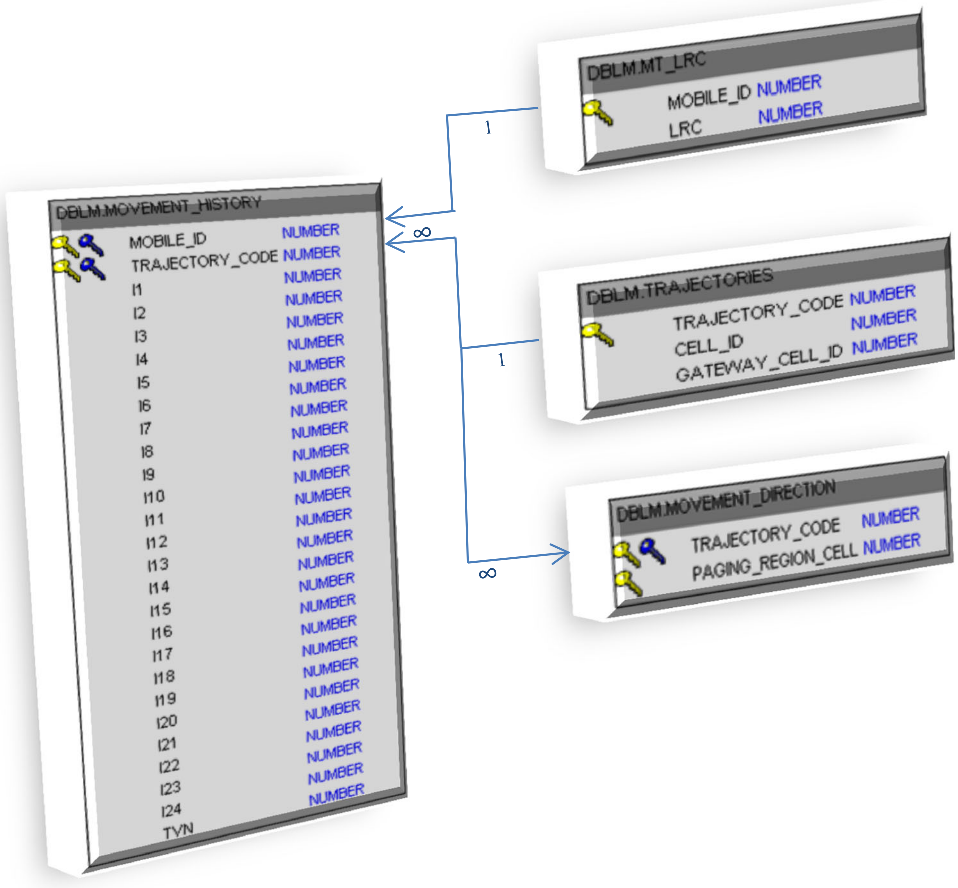


Fig. 5 Mobility database structure for DBLM

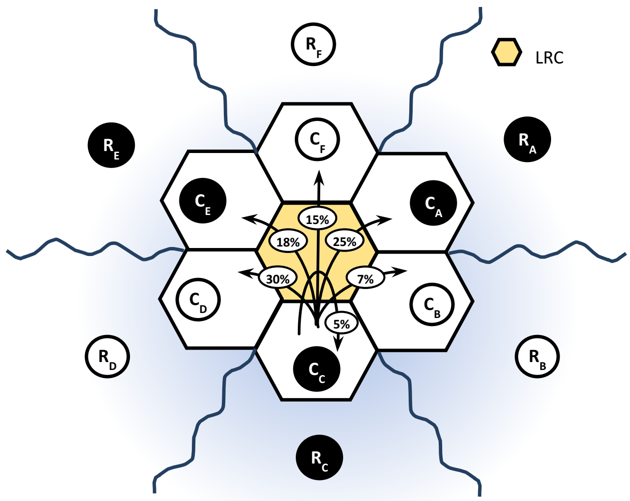
order; G_D, G_A, G_E, G_F, G_B, then G_C. On the other hand, Fig. 7 clarifies when to discard a gateway.

4.2.2 Selective paging scheme for DBLM (SPS_D)

When a call is being initiated by the calling MT, for routing the call, the challenging task is to identify the current cell of MT_c. Such aim can be accomplished by retrieving the LRC of MT_c from VLR mobility database. An elected set of paging cells is prepared, denoted as; EC, by selecting a circle of cells around LRC(MT_c) with radius equals the pre-defined movement threshold, then, discard the cells outside RA_c. The next step is to identify the gateway cells, denoted as; GC, from database. Gateways are the cells directly surrounding LRC(MT_c). Although LRC(MT_c) is surrounded by six cells, then it should have six gateways, some gateways may be located outside RA_c. Those foreign gateways should be discarded from GC, hence, in this case, LRC(MT_c) will have less than six gateways. Afterword, all gateways∈GC are ordered descending by; NO^2 and TVN respectively to obtain a list of ordered gateway cells (OGC), where $|OGC| \leq 6$. Each gateway G∈OGC is a representative to a paging region (PR), which is the set of cells behind G with depth equals to the pre-defined movement threshold as illustrated in Fig. 8. Those PRs are prioritized descending by the order of the corresponding gateway in OGC. Hence, if $Order(G_x) < Order(G_y)$ in OGC, then PR_x should be paged before PR_y.

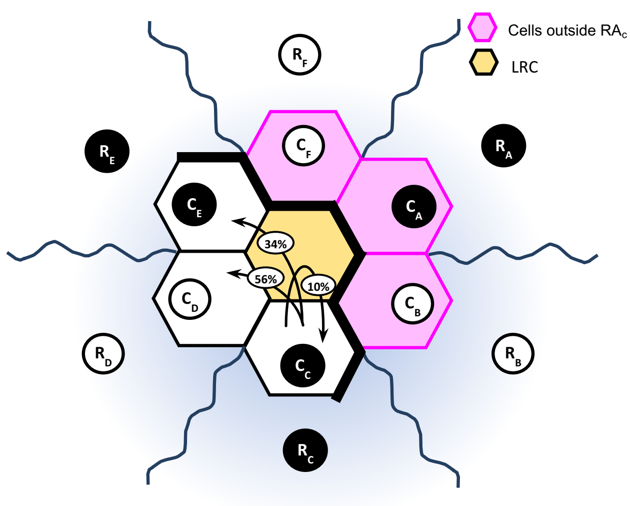
Generally, identifying the current location of MT_c can be done by sequentially paging regions behind the identified valid gateways (e.g., gateways of LRC(MT_c) that are located inside RA_c). Accordingly, the number of valid paging regions can be expressed as; $N_{PR} = |GC| \leq 6$. However, the time penalty (delay) for paging those regions, denoted as; $\xi = N_{PR} * \psi$ (where ψ is the time delay for one paging round) may be unacceptable by the caller MT. To go around such hurdle, the maximum allowable paging rounds must be calculated first, denoted as; MAPR, which can be calculated as HBLM by Eq. (1).

Where MAD is the maximum allowed acceptable delay for setting up a call and ψ is the time delay for a single paging round. Then the number of maximum allowed paging rounds, denoted as N_{APR} can be calculated using Eq. (2).



Considered Gateways	Probability
C_A	25%
C_B	7%
C_C	5%
C_D	30%
C_E	18%
C_F	15%

Fig. 6 Illustrative example of DBLM



Considered Gateways	Probability
C_C	56%
C_D	34%
C_E	10%

Fig. 7 Discarded gateways outside the current registration area

$$N_{APR} = \begin{cases} N_{PR} & \text{if } MAPR \geq N_{PR} \\ MAPR & \text{if } MAPR < N_{PR} \end{cases} \quad (2)$$

Hence, if MAPR $\geq$ N_{PR}, the paging regions behind the valid gateways are paged sequentially starting from the region with the highest priority until finding MT_c, otherwise, it is concluded that MT_c is voluntary closed or involuntary

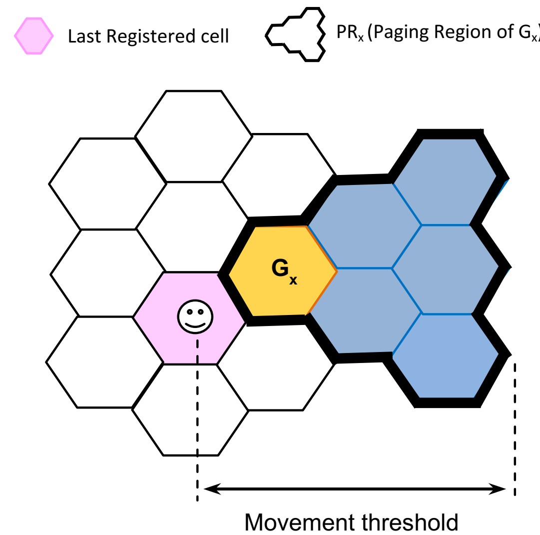


Fig. 8 Paging region

through a sudden death of its battery, or it enters uncovered area. On the other hand, if $N_{APR} < N_{PR}$, the first $|N_{APR} - 1|$ highest priority PRs are paged first. If MT_c still not identified, the remaining PRs are then paged in a blanket manner.

However, if the MT_c has no or insufficient history at the LRC, the probability that each gateway becomes the target of the next movement of MT_c is calculated based on the previously collected trajectories for other MTs that come from the same source cell during the same time period. Then, the corresponding paging regions are prioritized accordingly.

The proposed selective paging technique for DBLM is illustrated through Algorithm 3, which can also be clarified through the following steps.

1. Identify last registered cell of MT_c (e.g.,LRC(MT_c)).
2. Select the cells around LRC with a circle radius of movement threshold (EC).
3. Remove cells outside RA_c other than the MT_c's RA from EC.
4. Retrieve trajectories and gateway cells (e.g., GC) of the MT_c (where cell_ID = LRC) in descending order by NO^2 and TVN respectively to obtain a list of ordered gateway cells (OGC).
5. If MT_c has no history in this area, the trajectories of other MTs along with their gateways are retrieved. These trajectories start from LRC and end with the retrieved gateways.
6. Retrieve paging region cells (PR) for the first gateway cell in OGC.
7. The intersection between EC and PR is paged for each gateway cell in OGC until the MT is found.
8. If the MT is not found, the rest of cells in EC are paged sequentially.

DBLM Paging Algorithm

Inputs

- MT_c
- Interval of the call (I_x)
- EC
- MAD -- maximum delay time allowed
- Ψ -- time needed to page one paging group

Parameter	Description
MT_c	Called MT
MAD	Maximum allowed delay time
ψ	Time needed to page single paging round
EC	Cells surrounding LRC within M_{TH}
N_{APR}	number of allowed paging rounds

Output

Cell id (the address of cell hosting MT)

Steps

```
  -- get number of paging rounds
 N_APR = MAD / ψ;
 --
 -- Identify MT's last registered cell
 Select LRC
 from MT_LRC
 where mobile_id = MTc;
 --
 For I in ( select trajectory_code
            from movement_history M
                 join trajectories T
            where M.trajectory_code =
                  T.trajectory_code
            and   mobile_id = MTc
            and   cell_id = LRC
            order by Ix,TVN descending)
 loop
 Select paging_region
 Into   PR
 From movement_direction
 Where trajectory_code = I.trajectory_code
 Sequentially_page(cells{PR});
 If MT_found then
     Return cell_id ;          -- hosting cell id
     Exit loop;
 Else
      N_APR = N_APR -1;
      EC = EC – PR;
 End if;
 If N_APR = 1 then
      Sequentially_page(cells{EC});
      Return cell_id ;
 End if;
 End loop;
```

Algorithm 3: DBLM Paging Algorithm

4.3 Trajectory based location management (TBLM) strategy

As stated in [30, 31], MTs exhibit some sort of regularity in their movements. They also exhibit similarities in their current and past behaviors; for example, if a MT has followed a certain trajectory to reach a given destination, it will usually follow the same route to go to the same destination later. People go to work almost using the same route daily. Therefore, it is possible to draw on the past to predict the future. The recorded movement history of a MT on a daily basis can be used to create a movement pattern for that MT. This recorded pattern can be effectively used to predict the future movement of the considered MT by looking for similarities between the pattern and the MT's Last Registered Trajectory (LRT).

In this section, a new location management strategy will be introduced by recording the MTs trajectories. Then, LRT of MT_c is compared with its previously recorded trajectories to predict its current location. Similar to HBLM and DBLM, TBLM consists of two basic schemes, which are; (1) a movement logs collection scheme and (2) a selective paging scheme.

4.3.1 Movement logs collection scheme for TBLM (LCS_T)

In this scheme, MT's trajectories are collected, as in DBLM, based on two situations, which are; (1) when the MT crosses a predefined number of cell boundaries, or (2) when the MT performs deregistration. The mobility database structure of TBLM consists of three tables, which are illustrated in Fig. 9. The first is MT_LRT table, which records the last registered trajectory (LRT) for each MT. The second table is TRAJECTORIES, which stores the trajectory data like its code, and path. On the other hand, the third table is MOVEMENT_HISTORY, which stores the mobile ID, trajectory code, next trajectory code, and NO^2.

When the movement threshold is reached, the MT sends the saved trajectory in its cache to the VLR serving RA_c. The TRAJECTORIES table is checked for the received trajectory. If it is found, it will be considered as a next trajectory for the LRT. Otherwise, if it is not found, then the received trajectory is inserted into the MOVEMENT_HISTORY and TRAJECTORIES tables as a new trajectory with a new code. Assuming that the movement threshold is α, then every trajectory has (6^{α}) as maximum possibilities of next trajectory.

Considering Fig. 10, assuming that $\alpha = 2$, mobile_id = 010, LRT = 2 (which is the trajectory code of the path C_6–C_5), while the considered MT is saving C_{15} as a trajectory start in its cache. If the MT moves from C_{15} to C_{19}, then the movement threshold is reached. The trajectory_code is selected from the TRAJECTORIES table (where trajectory_path = C_{15}–C_{19}).

Assuming that the code selected is (trajectory_code = 4). The NO^2 is increased for MOVEMENT_HISTORY table (where mobile_id = 010 and trajectory_code = 2(LRT) and next_trajectory_code = 4). If there is no consecutive trajectories 2, 4 (C_6–C_5, C_{15}–C_{19}) in the MOVEMENT_HISTORY table, then the table is updated as follows (next_trajectory_code = 4, $NO^2 = 1$ where MT = 010 and trajectory_code = 2). At last, the MT_LRT table is updated (LRT = 4 where mobile_id = 010).

If the trajectory code is not found for the path C_{15}–C_{19}, a new record is inserted in the TRAJECTORIES table (Assume trajectory_code = 5 and path = C_{15}–C_{19}). A new record is inserted also in the MOVEMENT_HISTORY table (mobile_id = 010, trajectory_code = 5). The MT_LRT table is updated (LRT = 5 where MT = 010). Hence, the mobility database is continually updated as the MT sends the saved trajectories in its cache.

4.3.2 Selective paging scheme for TBLM (SPS_T)

When a call is being initiated, LRC(MT_c) is first identified from VLR's mobility database, which is the last cell of the LRT. Similar to HBLM and DBLM, an elected list of cells is prepared (e.g., EC) by selecting a circle of cells with LRC as the center, while and the movement threshold as the radius. Then, all cells outside RA_c are discarded. A list of possible next trajectories is retrieved (denoted as; NT) from the MOVEMENT_HISTORY table ordered descending by their NO^2. A list of the paging cells (denoted as; PC) is prepared by splitting all trajectories∈NT into the corresponding cells in which every cell inherits the NO^2 of the trajectory it belongs to. However, if a cell is repeated in multiple trajectories, it inherits NO^2 of all trajectories it belongs to. Hence, assuming that a cell C_x that belongs to several trajectories which are expressed by the set Traj(C_x), then, NO^2 of a cell C_x, denoted as; $NO^2(C_x)$, can be calculated using Eq. (3).

$$NO^2(C_x) = \sum_{\forall T_x \in Traj(C_x)} NO^2(T_x) \quad (3)$$

Afterword, PC is ordered descending by NO^2 then divided into paging groups. The paging process is done for

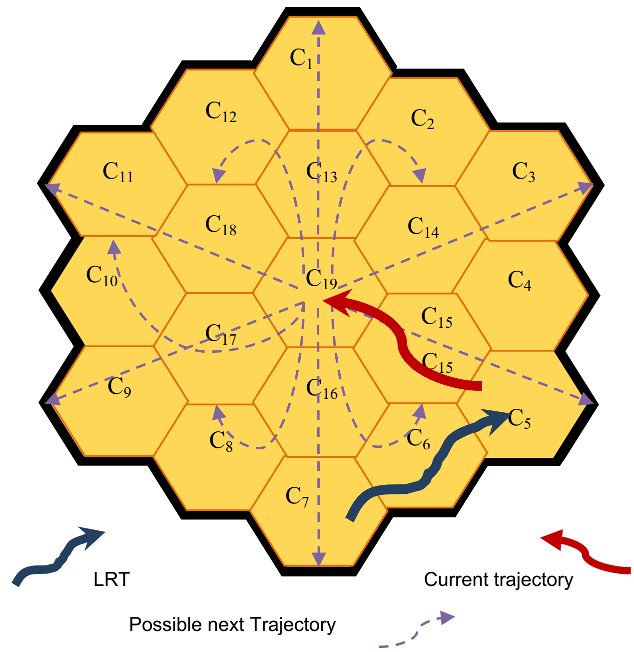


Fig. 10 Illustrative example for TBLM

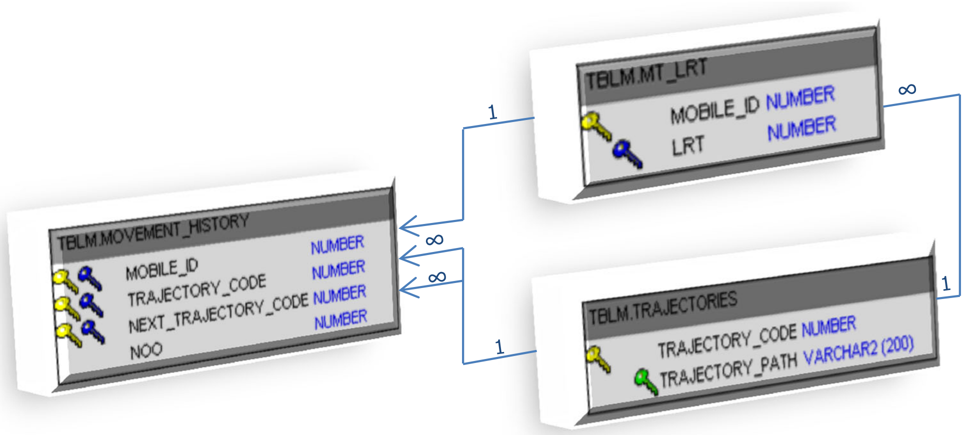


Fig. 9 Mobility database structure for TBLM

each group, one at a time until the mobile terminal is located. The number of allowed paging groups can be calculated according to Eq. (4)

$$N_{APG} = \frac{MAD}{\psi} - 1 \quad (4)$$

where MAD is the Maximum Allowed Delay time in call delivery and ψ is the time delay for a single paging round. If N_{APG} is reached without finding the MT_c, the rest of cells in EC are paged in a blanket manner. However, if the MT_c has no or insufficient history at the LRT, the probability of the next trajectory is calculated based on the previously collected trajectories for other MTs that come from the same source trajectory.

The proposed selective paging technique for TBLM is illustrated through Algorithm 3, which can also be clarified through the following steps.

1. Identify last registered cell (LRC) of the MT_c (last cell of the LRT).
2. Select the cells around LRC with a circle radius of movement threshold (EC).
3. Remove cells in RAs other than the MT_c's RA from EC.
4. Retrieve possible next trajectories (where trajectory_code = LRT) in descending order by NO^2 (NT).

TBLM Paging Algorithm

Parameter	Description
MT_c	Called MT
M_{TH}	Movement threshold
MAD	Maximum allowed delay time
ψ	Time needed to page single paging round
EC	Cells surrounding LRC within M_{TH}
N	Count of EC
N_{APG}	number of allowed paging groups
PC	Paging cells
OPC	Ordered paging cells

```
Input
    MTc
    MTH
    EC
    N
    MAD                 -- maximum delay time allowed
    ψ                   -- time needed to page one paging group
Output
    Cell id (the address of cell hosting MT)

Steps
    -- get number of paging groups
    NAPG = (MAD / ψ)-1;

    -- Identify MT's last registered trajectory
    Select LRT
    Into  v_LRT
    from MT_LRT
    where mobile_id = MTc;
    -- Retrieve list of possible next trajectories
    For I in (select next_trajectory_code nxt_traj
              , NO2
              from  movement_history
              where mobile_id = MTc
              and    trajectory_code = LRT
              order by NO2 descending)
    loop
    for j in 1.. MTH loop

        -- Convert trajectories into cells
        insert  cell_number_j(I.nxt_traj), I.NO2
        Into    PC;
     End loop;
     End loop;
    -- Remove redundancy
    Select cell_id,sum(NO2)
    Into    OPC
    From  PC
    Group by cell_id
    Order by NO2 descending;

-- get number of cells in each group.
If mod(N/NAPG) = 0 then
    NCG = N/NAPG ;
Else
    NCG =round(N/NAPG, 0) + 1;
End if;

-- Selecting number of cells in list_3 (paging list)
Select count(cell_id)
Into n
from OPC ;

-- Paging process
loop
    Sequentially_page (first NCG cells {OPC});
    If MT_found then
        Return cell_id ;    -- hosting cell id
        Exit loop;
    Else
        EC = EC – first NCG cells{OPC);
        OPC = OPC – first NCG cells{OPC);
        NAPG = NAPG – 1;
    End if;
    If NAPG = 0 then
        Sequentially_page(cells{EC});
        Return cell_id;
        Exit loop;
    End if;
End loop;
```

Algorithm 4 TBLM Paging Algorithm

5. If the MT_c has no history, the possible next trajectories of other MTs are retrieved, and then ordered in descending order by the sum of their NO^2.
6. Convert the retrieved trajectories list into cells list (PC), each cell have NO^2 of its own trajectory.
7. Remove redundant cells from the list by summing up NO^2.
8. Order the PC list descending by NO^2, and divide it into paging groups.
9. Page each group individually until the MT is found.
10. If the MT is not found, the rest of cells in EC are paged sequentially.

5 Cost analysis

Generally, two types of costs can be considered, which are; (1) signaling cost, which is the signaling penalty required performing registration and paging operations and (2) time delay cost. Each of the above mentioned costs will be discussed individually for traditional location management, and for the proposed location management strategies (HBLM, DBLM and TBLM), in order to conclude the overall saved costs when applying any of them.

5.1 Signaling cost

In this sub-section, the signaling cost for traditional and the proposed LM strategies will be is discussed for both registration and paging operations.

5.1.1 Registration signaling cost

The traditional registration is done when the mobile terminal passes by the RA border. This is also applied in the proposed LM strategies. Therefore, the registration signaling cost will be neglected in the mentioned strategies. However, the logs collection signaling cost cannot be neglected. Assuming that the cost of one time sending cache is α, the logs collection cost for HBLM will be calculated according to Eq. (5)

$$LCC = (N_{ra} + N_{Mth} + N_{Ith}) * \alpha \quad (5)$$

where N_{ra} is the number of cache sent on crossing RA boundary while N_{Mth} is the number of cache sent on reaching the movement threshold, and N_{Ith} is the number of cache sent on reaching the interval threshold.

On the other hand, logs collection cost for DBLM and TBLM will be calculated according to Eq. (6)

$$LCC = (N_{ra} + N_{Mth}) * \alpha. \quad (6)$$

5.1.2 Paging signaling cost

Assuming that the signaling cost to page one cell is $\mho$. In the traditional paging, all cells in the RA will be paged at the same time. Assuming that N is the number of cells in the RA, the paging cost will be calculated according to Eq. (7)

$$PC_{Traditional} = N * \mho \quad (7)$$

In Eq. (8), the traditional paging cost is calculated for x number of calls

$$PC_{Traditional}(xcalls) = x * N * \mho \quad (8)$$

On the other hand, in HBLM some cells will be paged according to the number of paging groups; the paging cost is calculated according to Eq. (9)

$$PC_{HBLM} = G * C * \mho \quad (9)$$

where G is the number of paging groups, while C is the number of cells in each group.

In Eq. (10), the paging cost of HBLM is calculated for x number of calls

$$PC_{HBLM}(xcalls) = \sum_{k=0}^{x} (G_k * C_k * \mho) \quad (10)$$

The saved paging cost will be calculated as the difference between traditional paging cost and HBLM paging cost as in Eq. (11).

$$SPC(xcalls) = PC_{Traditional}(xcalls) - PC_{HBLM}(xcalls) \quad (11)$$

The saved paging cost for HBLM can be calculated by substituting from Eqs. (8), (10) in (11), resulting in Eq. (12) as follows:

$$SPC_{RA}(xcalls) = \sum_{k=0}^{x} ((N_k - G_k * C_k) * \mho) \quad (12)$$

The overall saved signaling cost will be calculated as the difference between saved paging cost and logs collection cost as in Eq. (13)

$$SSC_{tot} = SPC - LLC \quad (13)$$

The total saved cost for HBLM can be calculated by substituting from Eqs. (5) and (12) in (13), as illustrated in Eq. (14)

$$SSC_{RA}(xcalls) = \sum_{k=0}^{x} ((N_k - G_k * C_k) * \mho) - (N_{ra} + N_{Mth} + N_{Ith}) * \alpha \quad (14)$$

where N is the number of cells in the registration area, G is the number of paging groups, C is the number of cells in each paging group, $\mho$ is the cost of paging one cell, NRa is the number of cache sent due to RA boundary crossing, NMth is the number of cache sent due to reaching the movements threshold, and NIth is the number of cache sent due to reaching the interval threshold, and α is the cost of one time sending the mobile cache. In DBLM and TBLM the total saved cost can be calculated using Eq. (15).

$$SSC_{RA}(xcalls) = \sum_{k=0}^{x}((N_k - G_k * C_k) * \mho) - (N_{ra} + N_{Mth}) * \alpha \quad (15)$$

5.2 Time delay cost

The time delay cost for one cell paging process is assumed as β. In the traditional paging, all cells in the RA will be paged at the same time. The time cost to page one cell will be calculated using Eq. (16)

$$TC_{Traditional} = \beta \quad (16)$$

In Eq. (17), the traditional time cost is calculated for x number of calls

$$TC_{Traditional}(xcalls) = x * \beta \quad (17)$$

On the other hand, in the HBLM, some cells will be paged according to the number of paging groups. The time cost for HBLM is calculated using Eq. (18)

$$TC_{HBLM} = G * \beta \quad (18)$$

where G is the number of paging groups.

In Eq. (19), the time cost is calculated for x number of calls

$$TC_{HBLM}(xcalls) = \sum_{k=0}^{x}(G_k * \beta) \quad (19)$$

The added timing cost will be calculated as the difference between the traditional timing cost and the HBLM timing cost as in Eq. (20)

$$ATC(xcalls) = TC_{HBLM}(xcalls) - TC_{Traditional}(xcalls) \quad (20)$$

The resulted additional time cost can be calculated by substituting from Eqs. (16) and (19) in (20) as illustrated in Eq. (21)

$$ATC_{RA} = \sum_{k=0}^{x}((G_k - 1) * \beta) \quad (21)$$

where G is the number of paging groups and β is the time cost to page one cell. On the other hand, in DBLM and TBLM the additional time cost can also be calculated using Eq. (21).

6 Illustrative example

In this section, all the proposed location management strategies will be illustrated in a simple example. Assuming the registration area of 27 cells shown in Fig. 11, and the movement threshold is 2 cells. The example is illustrated based on a call delivery to the MT number 125 at 5:23 PM (interval I_{18}).

6.1 HBLM

In this subsection, an illustrative example of SPS_H scheme is introduced. Assuming mobility database in Table 3 and Table 4, the selective paging steps in Sect. 4.1.2 will be followed as illustrated below.

1. The last registered cell is identified for the MT number 125 from Table 4 (LRC = 4)
2. A list of cells surrounding C_4 is prepared with half diameter of 2 cells (movement threshold). The list will be [C_{14}–C_5–C_1–C_4–C_3–C_{10}–C_{11}–C_{12}–C_{13}–C_{32}–C_{33}–C_{34}–C_{35}–C_{36}–C_{15}–C_6–C_7–C_2–C_9], and it will be referred as [EC]
3. The cells outside the MT's current RA is discarded [C_{32}–C_{33}–C_{34}–C_{35}–C_{36}], and the resulted list will be; [C_4–C_{14}–C_5–C_1–C_3–C_{10}–C_{11}–C_{12}–C_{13}–C_{15}–C_6–C_7–C_2–C_9]. The result is the set of paging cells (referred as PC).
4. Calculate $ANO^2(MT_{125}, T_{18})$ for all cells in PC. $ANO_2 = (73 + 86 + 66 + 43 + 54 + 12 + 65 + 34 + 67 + 9+36 + 98 + 23 + 34)/14$
5. If $ANO^2 \geq \lambda$, then PC is ordered descending by the NO^2 (interval I_{18} for the specified cells). The resulted paging list will be [C_7–C_{14}–C_4–C_{13}–C_5–C_{11}–C_3–C_1–C_6–C_9–C_{12}–C_2–C_{10}–C_{15}]
6. If $ANO^2 < \lambda$, assuming that $\beta = 10$, then PC is ordered descending based on $NO^2(MT_{125})$ as well as sum of NO^2 for other MTs that have history in these cells (in our case MT_{111} and MT_{157}) as in Table 5. And the cells will be ordered as the last column (SUM), the resulted paging list will be [C_7–C_{14}–C_4–C_5–C_{13}–C_{11}–C_3–C_1–C_9–C_6–C_{12}–C_2–C_{10}–C_{15}].
   Note: in this example MT_c (MT_{125}) have history, so this step is not applied.
7. Cells [C_9–C_{12}] are noticed to have the same NO^2. Thus, they are ordered by TVN, and the resulted paging list will be [C_7–C_{14}–C_4–C_{13}–C_5–C_{11}–C_3–C_1–C_6–C_{12}–C_9–C_2–C_{10}–C_{15}]
8. The paging list is divided to three groups; G_1 [C_7–C_{14}–C_4–C_{13}], G_2 [C_5–C_{11}–C_3–C_1–C_6] and G_3 [C_{12}–C_9–C_2–C_{10}–C_{15}].
9. Page each group individually, until the MT is found.

6.2 DBLM

In this subsection, an illustrative example of SPS_D will be introduced. Assuming RA in Fig. 12, mobility database in Tables 4, 6, 7, and 8 the selective paging steps in Sect. 4.2.2 will be followed as illustrated below.

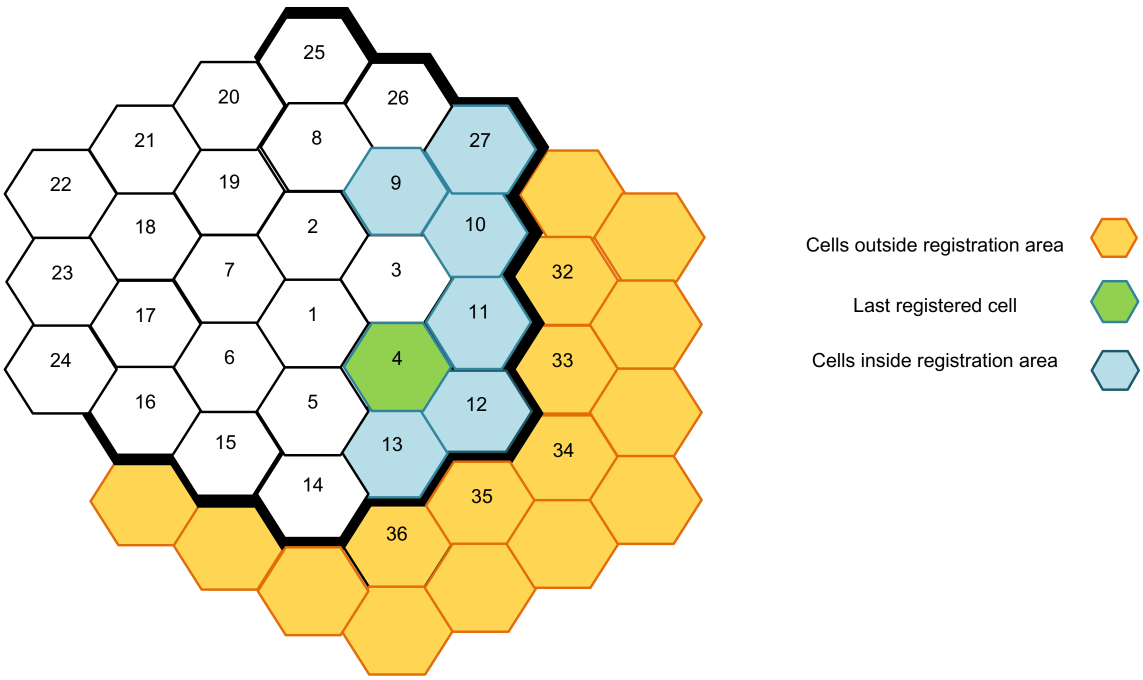


Fig. 11 Illustrative example

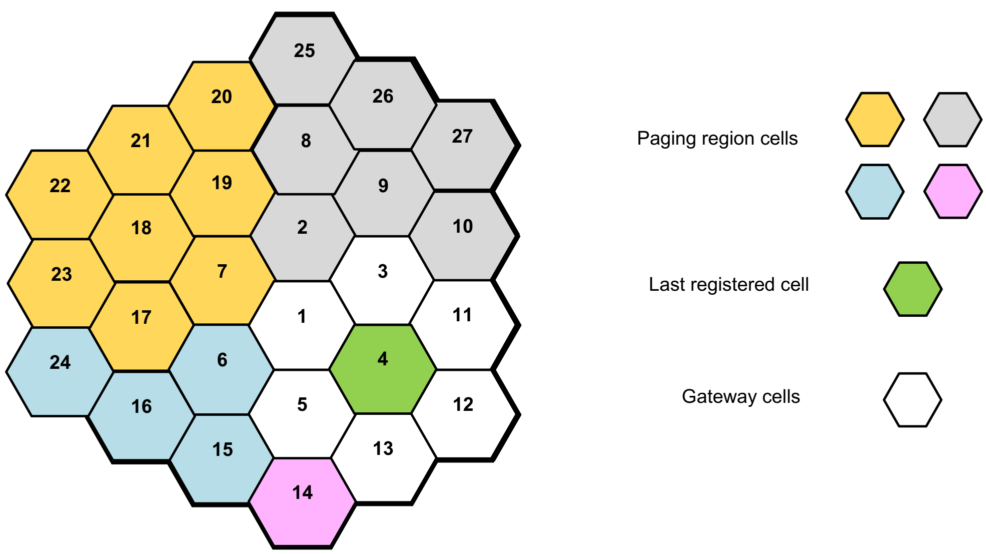


Fig. 12 SPS_D illustrative example

1. The last registered cell is identified for the MT_{125} from Table 4 (LRC = 4)
2. A list of cells surrounding C_4 is prepared with half diameter of 2 cells (movement threshold). The list will be [C_{14}–C_5–C_1–C_4–C_3–C_{10}–C_{11}–C_{12}–C_{13}–C_{32}–C_{33}–C_{34}–C_{35}–C_{36}–C_{15}–C_6–C_7–C_2–C_9], and it will be referred as EC.
3. The cells outside the MT's current RA is discarded [C_{32}–C_{33}–C_{34}–C_{35}–C_{36}], and the resulted list will be; [C_{14}–C_5–C_1–C_4–C_3–C_{10}–C_{11}–C_{12}–C_{13}–C_{15}–C_6–C_7–C_2–C_9].
4. The list of gateway cells and trajectories is selected from Trajectories table (where cell_id = 4) in descending order by NO^2. The list will be [17-20-16-18-19-15], and it will be referred as GC.
5. If MT number 125 has no history of trajectories starting from cell_id = 4, then trajectories of other MTs are retrieved starting from cell_id = 4. These trajectories

Table 3 HBLM Movement_History

Mobile_ID 125					Mobile_ID 111					Mobile_ID 157				
Cell_ID	…	I_{18}	…	TVN	Cell_ID	…	I_{18}	…	TVN	Cell_ID	…	I_{18}	…	TVN
C_1	…	43	…	124	C_1	…	55	…	124	C_1	…	21	…	234
C_2	…	23	…	654	C_2	…	61	…	654	C_2	…	54	…	534
C_3	…	54	…	214	C_3	…	53	…	214	C_3	…	26	…	134
C_4	…	73	…	634	C_4	…	42	…	634	C_4	…	24	…	734
C_5	…	66	…	124	C_5	…	35	…	124	C_5	…	65	…	234
C_6	…	36	…	76	C_6	…	26	…	765	C_6	…	34	…	365
C_7	…	98	…	325	C_7	…	34	…	325	C_7	…	75	…	245
C_8	…	73	…	349	C_8	…	16	…	349	C_8	…	16	…	409
C_9	…	34	…	539	C_9	…	33	…	539	C_9	…	64	…	539
C_{10}	…	12	…	239	C_{10}	…	29	…	239	C_{10}	…	34	…	349
C_{11}	…	65	…	457	C_{11}	…	73	…	457	C_{11}	…	16	…	507
C_{12}	…	34	…	864	C_{12}	…	39	…	864	C_{12}	…	24	…	654
C_{13}	…	67	…	845	C_{13}	…	27	…	875	C_{13}	…	51	…	745
C_{14}	…	86	…	945	C_{14}	…	69	…	985	C_{14}	…	53	…	845
C_{15}	…	9	…	324	C_{15}	…	11	…	324	C_{15}	…	34	…	924
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

Table 4 MT_LRC

Mobile_ID	LRC
111	…
125	4
157	…

Table 5 Calculating NO_2 if MT_c has insufficient history

	β*MT_{125}	MT_{111}	MT_{157}	SUM
C_4	10*73	42	24	796
C_{14}	10*86	69	53	982
C_5	10*66	35	65	760
C_1	10*43	55	21	506
C_3	10*54	53	26	619
C_{10}	10*12	29	34	183
C_{11}	10*65	73	16	739
C_{12}	10*34	39	24	403
C_{13}	10*67	27	51	748
C_{15}	10*9	11	34	135
C_6	10*36	26	34	420
C_7	10*98	34	75	1089
C_2	10*23	61	54	345
C_9	10*34	33	64	437

are ordered in descending order by the sum of NO^2 for all these MTs. The result is [18-16-19-20-15-17].

6. Retrieve paging region cells PR for the first trajectory in GC, which is selected from movement_direction table (Table 7), it also can be driven from Fig. 10. There is no paging region for the first trajectory (trajectory number 17) as noticed in Fig. 10. The result is [C_4–C_{12}], which are the LRC and the gateway cell for the trajectory number 17.
7. The intersection between EC and PR is [C_4–C_{12}]. This resulted list of cells is paged and considered as the first paging round.
8. If the MT is found, then the call is delivered. If it is not found, then list 1 is updated by removing the previously paged cells.

Table 6 DBLM Movement_history

Mobile_ID	Trajectory_code	I_1	I_2	…	I_{18}	…	TVN
125	15	…	…	…	14	…	534
	16	…	…	…	32	…	653
	17	…	…	…	43	…	214
	18	…	…	…	23	…	634
	19	…	…	…	15	…	134
	20	…	…	…	41	…	765
111	15	…	…	…	11		135
	16	…	…	…	32		351
	17	…	…	…	12		216
	18	…	…	…	54		354
	19	…	…	…	12		153
	20	…	…	…	35		354
157	15	…	…	…	26		215
	16	…	…	…	24		135
	17	…	…	…	15		234
	18	…	…	…	35		254
	19	…	…	…	42		365
	20	…	…	…	10		234

Table 7 Movement_direction

Trajectory_code	Paging_region_cell
15	2
15	9
15	10
…	…
18	14
…	…

Table 8 Trajectories

Trajectory_code	Cell_ID	Gateway_cell_ID
15	4	3
16	4	11
17	4	12
18	4	13
19	4	5
20	4	1

Table 9 MT_LRT

Mobile_ID	LRT
111	…
125	53
157	…

Table 10 Movement_history

Mobile_id	Trajectory_code	Next_trajectory_code	NO^2
125	53	2	15
	53	52	19
	53	54	22
	53	55	29
111	53	2	13
	53	52	15
157	53	55	10
	53	2	7

9. PR is prepared for the next trajectory in list 2(trajectory number 20).The resulted list will be [C_1–C_7–C_{19}–C_{20}–C_{17}–C_{18}–C_{21}–C_{22}–C_{23}].
10. The intersection between EC and PR is [C_1–C_7]. This resulted list of cells is paged and considered as the second paging round.
11. If the MT is not found, then the last 3 steps will be repeated until the MT is found.

6.3 TBLM

In this section, an illustrative example of TBLM paging scheme is introduced. Assuming mobility database in Tables 9, 10, and 11, the selective paging steps in Sect. 4.3.2 will be followed as illustrated below.

1. The last registered cell is identified (last cell of LRT) for the MT number 125 from Table 9 (LRC = 4)
2. A list of cells surrounding C_4 is prepared with half diameter of 2 cells (movement threshold). The list will be [C_{14}–C_5–C_1–C_4–C_3–C_{10}–C_{11}–C_{12}–C_{13}–C_{32}–C_{33}–C_{34}–C_{35}–C_{36}–C_{15}–C_6–C_7–C_2–C_9], and it will be referred as EC.
3. The cells outside the MT's current RA is discarded [C_{32}–C_{33}–C_{34}–C_{35}–C_{36}], and the resulted list will be; [C_{14}–C_5–C_1–C_4–C_3–C_{10}–C_{11}–C_{12}–C_{13}–C_{15}–C_6–C_7–C_2–C_9].

Table 11 Trajectories

Trajectory_code	Trajectory_path
2	C_9–C_{10}
…	…
52	C_3–C_{10}
53	C_6–C_1
54	C_5–C_{15}
55	C_1–C_5
…	….

Table 12 Next trajectories probabilities if MT_c has insuffecient history

Next_Trajectory_code	NO^2
2	20
52	15
55	10

Table 13 Converting trajectories into cells

Cell_id	NO^2
C_9	15
C_{10}	15
C_3	19
C_{10}	19
C_5	22
C_{15}	22
C_1	29
C_5	29

Table 14 Removing redundant cells

Cell_id	NO^2
C_9	15
C_{10}	34
C_3	19
C_5	51
C_{15}	22
C_1	29

Fig. 13 Sample data

OID	STARTDATE	ENDDATE	LONGITUDE	LATITUDE	CELL_ID
22	8/31/2009 3:43:00.000	8/31/2009 3:44:00.000	13.39611111	52.52944444	55995
23	8/31/2009 3:51:00.000	8/31/2009 3:53:00.000	13.40333333	52.52638889	444
24	8/31/2009 3:53:00.000	8/31/2009 4:12:00.000	13.40972222	52.52833333	20929
25	8/31/2009 4:12:00.000	8/31/2009 4:36:00.000	13.42194444	52.52833333	29630
26	8/31/2009 4:36:00.000	8/31/2009 4:37:00.000	13.42138889	52.52388889	32506
27	8/31/2009 4:37:00.000	8/31/2009 4:41:00.000	13.41305556	52.52555556	27973
28	8/31/2009 4:41:00.000	8/31/2009 4:47:00.000	13.40972222	52.52833333	20929
29	8/31/2009 4:47:00.000	8/31/2009 4:51:00.000	13.40444444	52.53166667	37130
30	8/31/2009 4:51:00.000	8/31/2009 5:13:00.000	13.41	52.53583333	65402

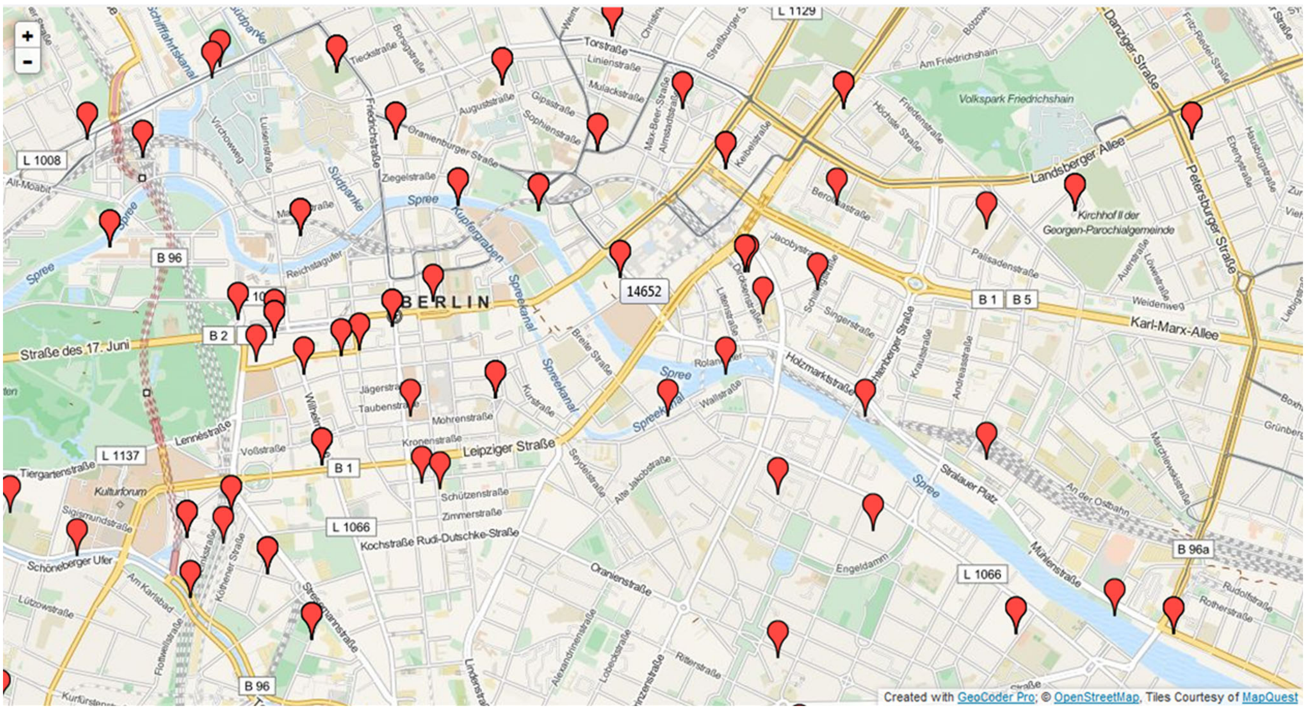


Fig. 14 Map of cells

4. Possible next trajectories are retrieved from the Movement_history table in descending order by NO^2. The result is [55-54-52-2], and it will be referred as NT.
5. If the MT has no history, the possible next trajectories of other MTs are retrieved along with their NO^2 as in Table 12, and then ordered by sum of NO^2. The result is [2-52-55].
6. The retrieved trajectories are converted into a list of paging cells (PC), as in Table 13.
7. Redundant cells are removed by summing up NO^2. The result is in Table 14.
8. The resulted cells are ordered descending by NO^2. The result is [C_5–C_{10}–C_1–C_{15}–C_3–C_9], which is referred as OPC.
9. OPC is divided into groups; each group is paged sequentially until the MT is found.
10. If the MT is not found, all the non-paged cells in EC are paged sequentially.

7 Performance evaluation

The proposed schemes were simulated using an oracle application. This application used mobile phone records of the German Green party politician Malte Spitz, stored by Deutsche Telekom in 2009–2010, and collected in a period of 6 months [32]. More than 1400 records of movement

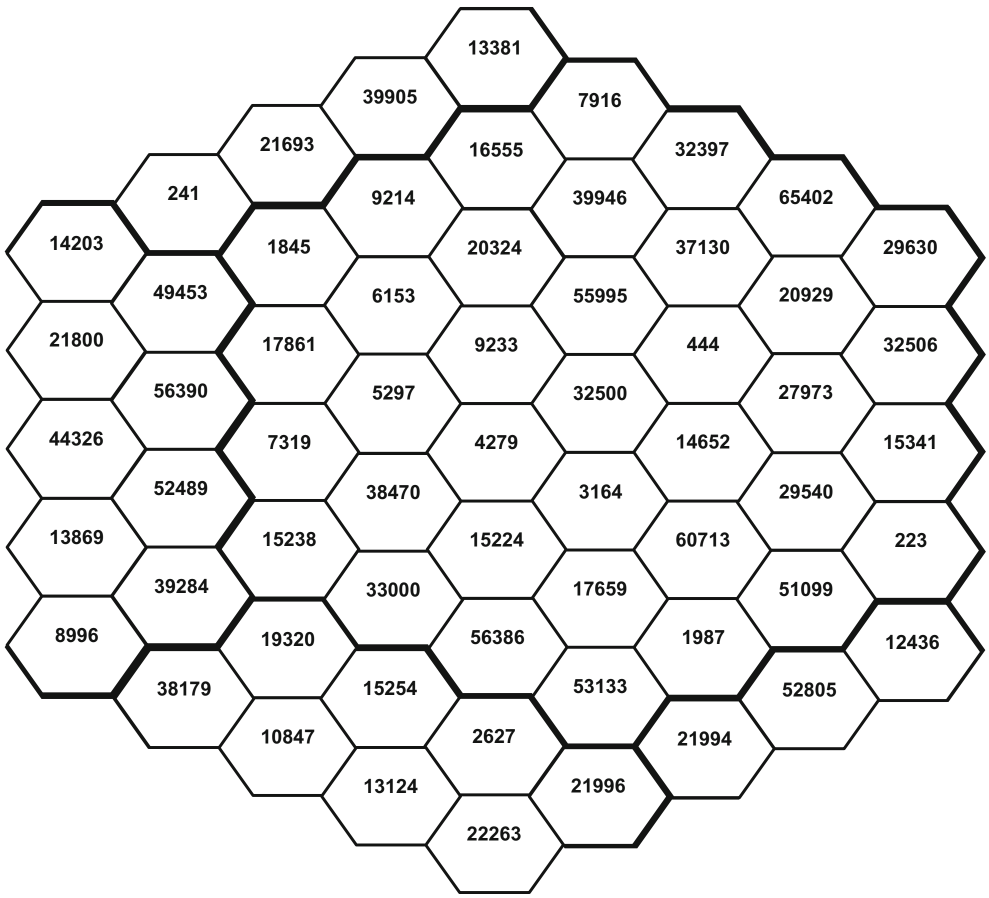


Fig. 15 Sample cells

history, Call and connection records were collected by the phone company. The location data for each record was mostly estimated by the signal strength received by cell towers. The data was exported to an oracle database, in which oracle SQL and oracle PL/SQL were used in the simulation. A sample of data is shown in Fig. 13.

A map of cells was made using a maps application (Geocoder pro) by locating the cell using the longitude and latitude data of each cell (Fig. 14). The simulation is based on a sample of these cells. The map is transferred into the known structure of PCS network in Fig. 15, while the entire service area is considered as shown in Fig. 16. Table 15 represents the parameters used in our work as well as their values.

A comparison has been made between traditional location management, HBLM, DBLM, TBLM and three other location management strategies in [33, 34] which are:

1. Random paging (RP) where paging is done by selecting random groups of cells to be paged.
2. Probabilistic based location management (PBLM) where logs collection is done by saving MT movements in its cache, and sending it to VLR, when the MT's cache is full.
3. Modified probabilistic based location management (MPBLM): where logs collection is done by saving MT movements along with time in its cache, and sending it to VLR, when the MT's cache is full.

7.1 Measuring optimum thresholds

Since performance mainly depends on the movement threshold as well as interval threshold values, in this sub-section, their optimum values are calculated. The cost results are tested by estimating the saved signaling cost, using different values of movement and interval thresholds as shown in Figs. 17 and 18.

As shown in Fig. 17, the best average saved signaling cost is achieved at an interval threshold of 5 h. On the other hand, as illustrated in Fig. 18, the average saved signaling cost increases and reaches maximum, when the movement threshold reaches 3 movements, and gradually decreases afterwards.

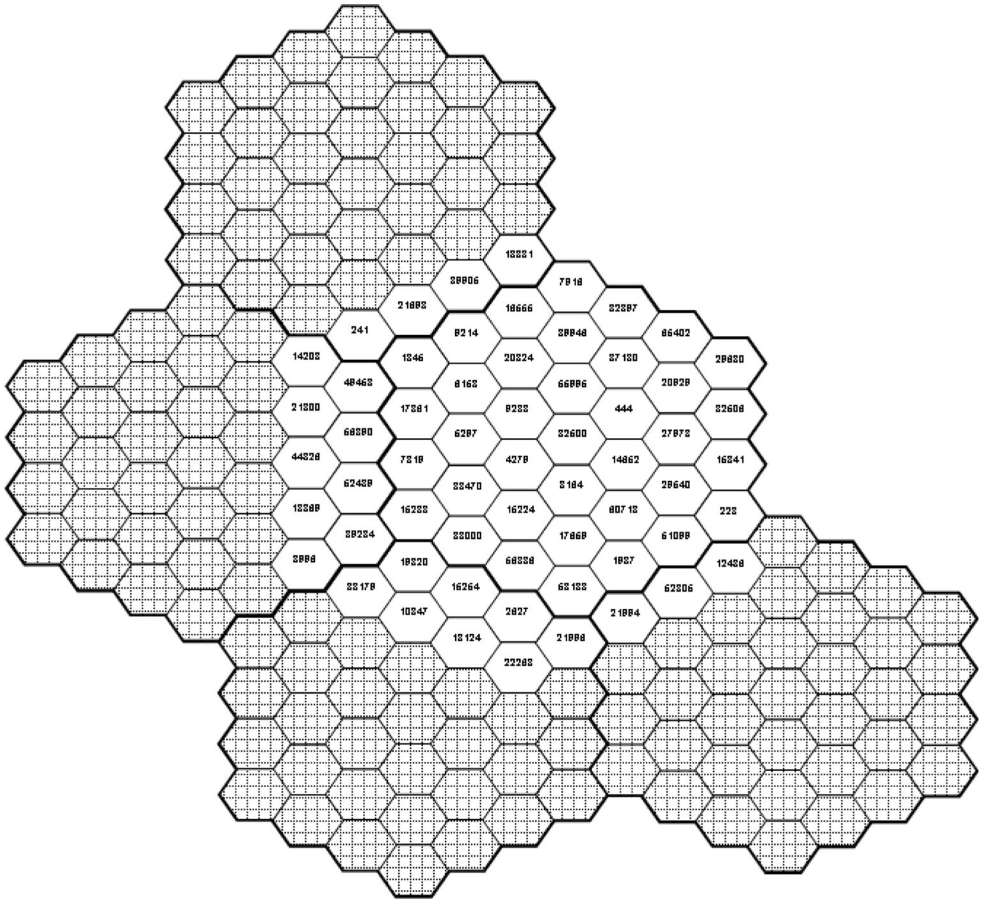


Fig. 16 Service Area

Table 15 Parameters used in evaluating the performance

Strategy	Parameter	Description	Value
Shared (HBLM, DBLM and TBLM)	MAD	Maximum allowed delay time	0.1
	ψ	Time needed to page single paging round	0.03
	M_{TH}	Movement threshold, which is the number of cells passed before sending the mobile cache	3
	£	Signaling cost to page one cell	1
	α	Signaling cost to send the cache one time to VLR	0.01
	β	The time delay cost for one cell paging process	1
HBLM	I_{TH}	Interval threshold, which is the number of intervals passed before sending the mobile cache	5
	λ	Threshold value of the average NO^2 of all cells ∊ PC for MT_c at the current time interval ($T_{current}$)	100
	δ	History weight	10

7.2 Measuring logs collection signaling cost

In this subsection, the signaling cost of sending MTs' cache to VLR database is measured. As shown in Fig. 19, PBLM, MPBLM, HBLM, DBLM as well as TBLM appear to increase in parallel with the number of calls. However, as random and traditional location management neither store location data in MT cache nor send it to VLR, logs collection could not be estimated for them.

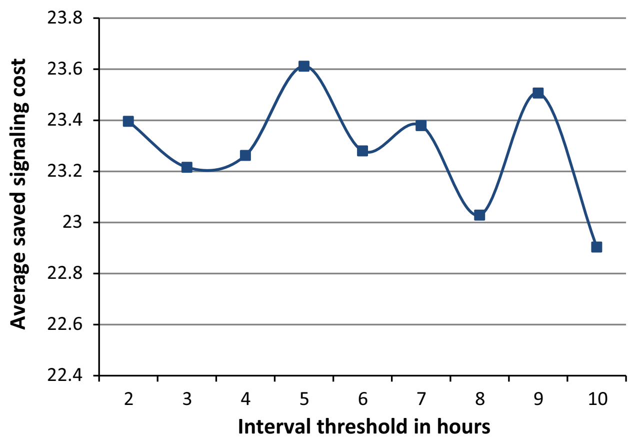


Fig. 17 Average saved signaling cost using different interval thresholds

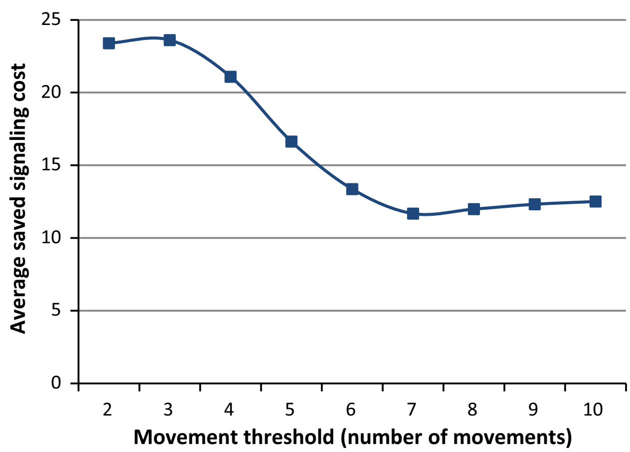


Fig. 18 Average saved signaling cost using different movement thresholds

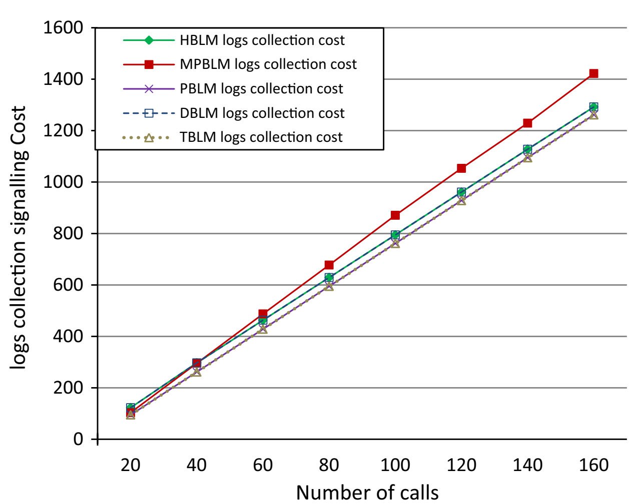


Fig. 19 Logs collection signaling cost

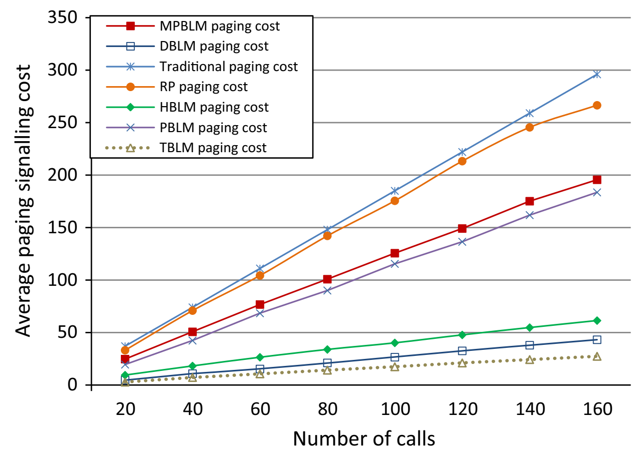


Fig. 20 Average paging signalling cost

7.3 Measuring the paging signaling cost

In this subsection, the signaling cost of paging is measured. As illustrated in Fig. 20, the highest paging cost is associated with the traditional paging, followed by the random paging, PBLM, MPBLM, HBLM and DBLM while the least paging cost is associated with TBLM.

7.4 Measuring the saved signaling cost

In this subsection, the saved signaling cost is measured for all strategies in the comparison. As shown in Fig. 21, the least saved cost is associated with the random paging, followed by the MPBLM, PBLM, HBLM and DBLM while the highest saved cost is associated with TBLM. The figure shows also that average saved signaling cost for HBLM, DBLM and TBLM increase gradually with the number of calls. The more calls the mobile terminal receives the better results our strategies show.

7.5 Measuring the timing cost

In this subsection, the timing cost is measured for all compared strategies. As shown in Fig. 22, the traditional location management has the least timing cost followed by TBLM, HBLM, DBLM, PBLM and MPBLM, while the highest timing cost is associated with RP location management. Experimental results show that our proposed strategies outperform all compared location management schemes (RP, PBLM, MPBLM, Traditional) in paging cost. Signaling cost is minimized with an acceptable time delay. Although the time delay is an important issue, the signaling cost is more important from the quality of service point of view. In this respect, saving the network bandwidth will allow more calls to be performed, and in the same time, solving the problem of lost calls due to MT's movements between cells.

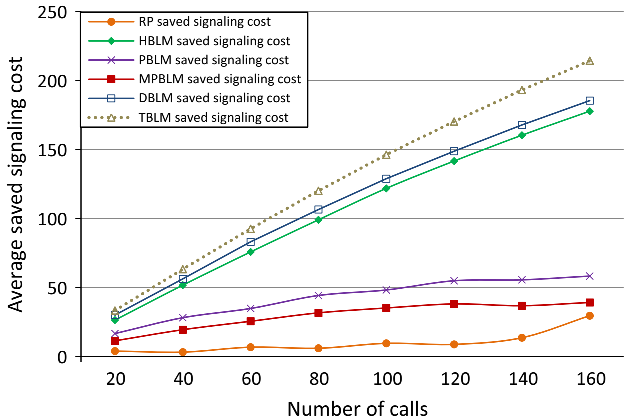


Fig. 21 Average saved signaling cost

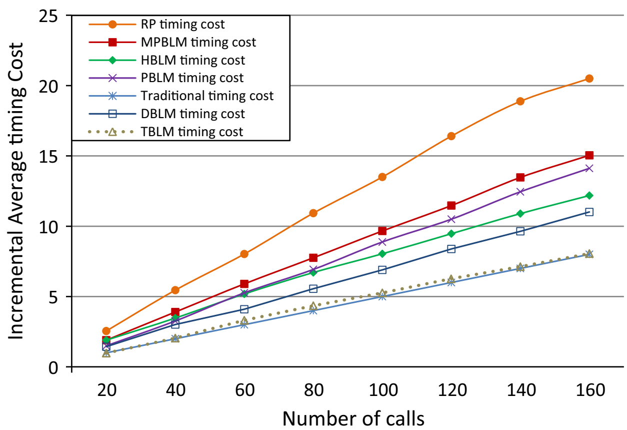


Fig. 22 Average timing cost

8 Implementation and costs

Our proposed strategies can be implemented in operational networks at low costs. This is further discussed below.

8.1 Network level

In this subsection, the modifications needed in the network level are discussed along with their associated cost. These modifications can be categorized into database and software modification as follows:

8.1.1 Database updates

As the proposed strategies are totally managed by the VLR, the database changes are needed on the VLR level. The existing VLR contains a temporary record for each MT currently visiting the RA serviced by the MSC [35]. The proposed strategies introduced a new mobility database in the visitor location register, which will be added to the existing database in the current networks. Each of our proposed strategies has a mobility database with a different structure. To apply any of the proposed strategies on an operational network, the tables of the corresponding strategy can easily be added to the existing database. The associated cost of such technical modification will be minimum as it can be done by applying an SQL patch one time within the VLR.

8.1.2 Software updates

One of the most important modifications needed to apply the proposed strategies is the software modification at the network level. There are two software modifications needed; one for each of the registration and paging processes. The former concerns processing the received data from the MT's cache before updating the newly added mobility database, while the latter concerns replacing the currently used paging process with the proposed one. For example, in HBLM logs collection scheme (LCS_H), the VLR may receive a movement log from a MT in the form [(T_5, C_1), (T_8, C_4)… (T_9, C_7)]. In this case, this data is processed by increasing NO^2 of intervals I_5, I_8, I_9 for the cells C_1, C_4, C_7 respectively, while the LRC of the corresponding MT is updated to C_7, while the traditional paging needs to be replaced with (SPS_H). Hence, Algorithm 2 must be applied. The associated cost of such modifications will be in the form of applying and testing a patch of code to be run once at all MSC's serving all the RA's.

8.2 User equipment terminal level

In this subsection, the modification needed at the MT level to implement the proposed strategies is discussed. The only modification needed for the MT is a software update, which is needed to keep the cell location data in the MT. The mobile vendors would push this update to the mobile terminals. The programming process of MTs to collect location information has been employed before such as in the reality mining project [36] using Nokia 6600 phones. Some android applications such as the Cell Tracker can get the location information of mobile phones without a need for the GPS technology. The associated cost of such software updates can be kept at minimum by the network operators.

9 Conclusion and future work

This paper introduces three location management strategies for PCS networks, which are HBLM, DBLM, and TBLM. In each strategy, a new paging scheme is proposed, based on historical movements, movement direction, and current trajectory of the called MT respectively. The implementation of our Experimental results, based on real scenario measurements, have shown that the proposed LM strategies introduce the minimum signaling penalty (for paging and registration) with an acceptable paging time delay compared with the recent LM strategies. Moreover, based on the provided comparison, it is found that TBLM outperforms other approaches.

In crowded urban areas, microcells can be useful because they add network capacity. The proposed strategies can be applied in microcells. The only difference is the movement threshold, which have to be increased as the MTs cross a lot of cell boundaries passing the same distance. The main idea is how to balance the movement threshold value between different cell sizes, which is open for further research.

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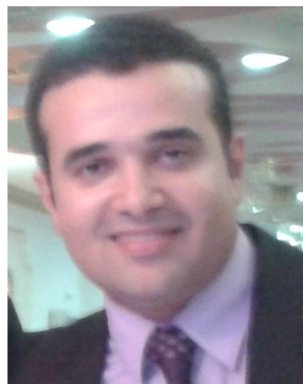

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