

# Tracking of Mobile Terminals Using Subscriber Mobility Pattern with Time-Bound Self Purging Indicators and Regional Route Maps\*

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**Abstract.** This paper presents a new location management scheme that integrates two key ideas, namely, (i) Subscriber Movement Profile (SMP) based on spatial and temporal locality of the movement of a mobile terminal and (ii) localized updates known as Time-bound Self Purging Indicators (TSPI) generated by a probabilistic approach when a mobile terminal does not adhere to registered profile. The SMP registered by a mobile host is used to predict its cell location based on time specific movement history. The transient deviations from the registered SMP are handled efficiently by TSPIs using a Regional Route Map (RRM).

## 1 Introduction

Personal Communication Service (PCS) networks enable people to communicate independent of their locations. The system facilitates communication by maintaining a location database that maps a subscriber number to its current location. However, wireless network pose significant challenges due to several factors including unconstrained movements of subscribers, limited radio frequency spectrum, radio channel impairments, among others. A number of efficient location management schemes have been proposed [1], [2], [3] for tracking locations of mobile users. The focus of this work is on some of the recently proposed location management schemes [4], [5], [6] which subsume location data with various degree of imprecisions. In particular we are concerned with the location management scheme proposed in [4], [5]. Both the schemes use subscriber's mobility pattern (SMP) to predict a small set of probable locations of the callee when a call arrives. The call delivery will then be possible through a selective paging executed on the set of those predicted locations. The scheme proposed in this paper is a hybrid of above two schemes. Our motivation here is three-fold:

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- To reduce signaling traffic for tracking a mobile by making it responsible for predicting, maintaining and registering its own SMP.
- To efficiently handle the predictive transient deviations from registered SMP by using secondary cluster of cells determined through a regional route map.
- To reduce global signaling traffic at the cost of limited increase in local traffic to tackle unexpected deviation of a mobile from its registered SMP. The deviation of a mobile is considered as unexpected when it is not covered by secondary cluster.

The paper is organized as follows. Section 2 is concerned with the system model. It presents an overview of the database to be maintained in the mobile terminal as the network changes dynamically. The location management scheme proposed in this paper is described in Section 3; and the call setup protocol is discussed in Section 4. Experimental results have been presented in Section 5. The paper ends with concluding remarks in Section 6.

## 2 System Model

The coverage area of a mobile service provider can be represented by a finite set of cells  $C = \{c_1, c_2, c_3, \dots, c_n\}$ . Location areas (LAs) define a partition of cells of  $C$ . An LA may consist of one to few geographically adjacent cells of  $C$ . The union of LAs form a complete covering of  $C$ . The information of a user  $U_i$  will be maintained at the base station of his/her Home Location Area (HLA). This will include the currently registered Subscriber Mobility Patterns (SMPs) of  $U_i$  and his/her call profiles. Call profiles will be used to calculate the call to mobility ratio (CMR) values. Let  $\rho$  denote the arrival rate of calls for the user  $U_i$  and  $\kappa$  denote the mobility rate of  $U_i$ , then  $\omega = \rho/\kappa$  represents CMR for  $U_i$ .

A Subscriber Mobility Database (SMD) will be maintained by the mobile terminal itself. An SMD consists of a number of Subscriber Mobility Patterns (SMPs), one of which will be registered with the network. The registered SMP is a sequence of LAs (base stations) which the Mobile Terminal (MT) is expected to visit. If a mobile terminal deviates from its registered SMP, it will rely the local network for fuzzy determination of the location area where the local Time bound Self Purging Indicator (TSPI) has to be stored. The important SMP related data are as follows:

- SMP:  $\{LA_1 \rightarrow LA_2, \dots, LA_{n-1} \rightarrow LA_n\}$
- $P_a$ : Prob(MT) moves to a new LA not in SMD.
- $P_b$ : Prob(MT) moves to a LA  $\in$  SMD but not in registered SMP.
- $P_c$ : Prob(MT) moves in its registered SMP.

An LA ID which is a part of two SMPs will be stored twice in SMD. The advantage this is apparent when a new record gets added to the database. The SMP which has aged most, will be removed. Deletion of an LA ID will not affect its other duplicates which may be present in other SMPs. The overhead of maintaining duplicate LA IDs in different SMPs also retrieved in the form of amortization of cost for extra deletions.

The set of global attributes and cell related attributes stored in SMD are provided in the table below.

Global attributes	Cell attributes
$N_{nd}$ : Number of consecutive deviations from registered SMP.	Cell Id: Cell identifier
$P_{sid}$ : SMP Id currently in use.	SMP Id: SMP identifier
$SC_{cids}$ : Secondary clusters' cell Ids	$E_{at}$ : Expected arrival time
$REP_{callerSMP}$ : Replicated caller SMPs	$E_{et}$ : Expected exit time
$P_{cid}$ : Present Cell Id	$E_{st}$ : Expected slack limit for arrival
$T_r$ : Total number of records	Next LA: Next location area
$NR_{smp}$ : Registrations count each SMP	Previous LA: Previous location area
$LF_{SMP}$ : Lifetime of each SMP	

### 3 Algorithm Description

There are three key concepts, namely, secondary clusters, regional route map and TSPI, which categorize the input requirements for the proposed location management scheme.

#### 3.1 Secondary Clusters

Our protocol requires some inputs from the mobile users at the time of subscription to a new service. This information will be utilized by the HLA in selection of places that have a high probability of being frequented by the user apart from the those specified by the user profile. These alternative cells are collectively referred to as secondary clusters. One of the important attribute for secondary cluster, for example, could be the information about the subscriber's occupation. A mobile user may be an official, a travel agent, a student, or a house wife. Such an information will help to select certain cells which are not in user's profile, but may be visited in future.

#### 3.2 Regional Route Map (RRM)

Another key input is the Regional Route Map (RRM). A RRM indicates the physical route map of roads in the neighborhood of a location area. Such a map along with the user supplied profiles will be stored at the base station of home location. It helps in a quick discovery of cells that fall in the vicinity of the registered SMP of the user. These are LAs in which the user can roam without including them either in the registered SMP or generating a TSPI. The motivation of employing RRM is driven by the fact that the users might not usually go to certain cells. But these places match the places of highest interest to the users. So, a high probability is attached to these places of being visited by a user. If an MT visits one of these places, it need not send a location update.

### 3.3 Time-Bound Self Purging Indicators (TSPI)

If a user has moved into a location which is not a part of its registered SMP or its secondary cluster, it first creates a Time Bound Self Purging Indicator (TSPI). TSPI is a special register entry maintained at the VLR of the expected LA as per the registered SMP of the mobile terminal. TSPI stores the new location where the MT is found at present. It may be considered as a forwarding pointer [3] stored in the VLR of the base station of the expected LA. An expiry time is also associated with the TSPI. The motivation here is to increase small amount of local traffic in place of multiple hops that may be needed to register in the HLR, thus saving valuable network bandwidth. Associating an expiry time with TSPI eliminates the need for extra signaling which MT otherwise have to do for removing the pointer [3].

The LA where the TSPI will be registered is decided by a fuzzy network controlled machine colocated with the VLR location. It chooses between the base stations of the expected LA and the HLA of the MT, based on a number of dynamic network parameters such as: (i) relative number of hops required to reach MT at its current position from HLA and from the expected LA in the registered SMP, (ii) available network bandwidth, (iii) tariff, and (iv) certain other network specific runtime parameters.

### 3.4 Creation of SMP

Each MT creates and maintains its SMPs. A new SMP creation procedure `buildNewSMP` is given below.

---

```

procedure buildNewSMP(LA) {
  if (Day is over) { /* New SMP creation is complete */
    reset the smpBuild flag;
    Increment the LF values of all SMPs;
  }
  else {
    if (SMPbuild == false ) {
      SMPbuild ← true; newSMP_Id ← getNewSMPId;
      /* Create a replication of registered SMP from
         beginning till the LA visited last.*/
      newSMP ← copyAllNode(currSMP,currTIME);
    }
    Create a new node of this LA;
    LastNode_of_SMP.next ← newNode;
    Prev.newNode ← LastNode_of_SMP;
    newNode.next ← NULL;
  }
}

```

---

When an MT moves into a LA (base station) not in its SMP and its `smpBuild` flag is `false`, then MT sets the flag to `true`. The MT then copies the nodes (LAs) of the current SMP as the preceding nodes of the new SMP till the last perfectly followed LA as per the registered SMP. The MT continues to add subsequent new nodes into the new SMP, till the time of the day is over. The span of each SMP is 24 hours. Thus after an SMP has been created a 24-hour period, it is included as a complete SMP in the SMD and the `smpBuild` flag is reset.

### 3.5 Maintenance of SMP

It may be argued that instead of building a new SMP, we could do by only updating the time field in an already present SMP when a time lag is noticed in visiting an LA but the order of the nodes in the SMP remains same. The reason for not following this approach is: even a small amount of transient deviation can make us loose a carefully formed otherwise frequently used SMP. So it is always better to keep track of the deviations as a freshly built SMP.

If the MT moves into a new LA that is present in its SMD but not a part of the registered SMP, then we store this LA into a separate data structure called the Transient Deviation Pattern (TDP). A TDP is allowed grow to as a sequence of maximum of three LAs to which the MT has deviated. When a TDP grows to its full size, the SMD is searched for the TDP. If the TDP is found to be a part of an existing SMP then the update algorithm returns a value 3. This indicates that the MT is following a new SMP; and, hence, needs to register the same. It also resets the current SMP building process or purges the partially built SMP. The reason for this can be explained as follows. If an MT consecutively follows three locations of another SMP in the SMD leaving its own registered SMP, then it is highly likely that MT would continue to move according to the former SMP as indicated by its stored movement pattern. If the TDP match returns a `false`, it means that the user is moving in an entirely new patten which is not present in the SMD. So this TDP is retained as a part of a new SMP which is under creation. Notice that we keep track of only the last three consecutively deviated locations, and update them by swapping the locations.

There might be a condition of SMD overflow. It occurs when no more nodes can be added to it. In this case an entire SMP deleted. There are two factors in support of this deletion, namely

- (i) The partial SMP can not be registered unless it is padded with the missing LAs by arbitrary data.
- (ii) Since the process of building a new SMP has been initiated, it is likely that there will be a requirement of additional space to accommodate more newly created data.

The victim SMP to be selected for deletion is decided on the basis of  $\varphi = NR_i/LF_i$ , which is the ratio of number of times a SMP has been registered to the number of days it has been formed. Since  $NR_i$  gives a count of the number of times SMP  $i$  has be registered it also determines the aging SMPs. The SMP

which have been registered to the network the least number of time provides a low  $NR_i$  value. The ratio  $\varphi$  helps in determining obsolescence of an SMP. It ensures that recently formed SMPs are not selected as victims. After the deletion of an SMP,  $NR_i$  and  $LF_i$  values for all other SMPs are reduced by a factor  $\varphi$ . This ensures that these values do not increase to some large values for other SMPs present.

Let expected slack time  $E_{st}$  (see the cell attributes described in section 2) be defined on the basis of certain fuzzy runtime conditions represented by  $\theta$ . The argument  $\theta$  is decided by the central network taking into account the importance of the place. A MT need not update the network registration if it is within the slack bound. So the permissible time of stay in an LA before a TSPI creation procedure is initiated is specified by the following bounds.

$$E_{at} - (E_{st} + \theta) \leq T(stay) \leq E_{et} + (E_{st} + \theta)$$

Based on the above bounds it is straightforward to determine the when TSPI generation could be initiated. The procedure `CurrentSMPfollowed` provide below returns `true` if a mobile user is following the registered SMP or has deviated.

---

```

procedure CurrentSMPfollowed(LA) {
  if (LA-ID matches expected LA)
    if ( $E_{at} - (E_{st} + \theta) \leq t \leq E_{et} + (E_{st} + \theta)$ ) return true;
    else return false;
}

```

---

On the basis of above discussion, we can now put together the process of maintenance of SMP in the form of a procedure `UpdateSMP`. We summarize the key points concerning update process as follows. When a mobile terminal moves to a new LA it gets the corresponding LA ID in its incoming signal. If the user has moved into a location which matches the expected LA in its currently registered SMP, then the update process exits with a value 1, indicating no action. There will not be any increase in network traffic due to the MT in this situation. Though the above scenario appear to be the best case, indeed this scenario is the usual case. Most users will likely to continue a fixed schedule for weeks at a stretch [7]. More precisely, there are only two cases under which an MT creates traffic for location update. These cases are characterized as: (i) when an MT is switched on for the first time, or (ii) when an MT moves out of a region of its registered SMP.

The `updateSMP` procedure will be executed by an MT whenever it moves to a different LA (base station). The values returned by this procedure represent four states of location updates. These are: (i) state 1: perfect schedule is followed, (ii) state 2: deviation is expected, (iii) state 3: deviations match with another stored SMP which should be registered, and (iv) state 4: deviations indicate a new SMP to be built. In states 3 and 4, a TSPI has to be registered in expected LA.

---

```

procedure UpdateSMD (currentLA) {
    expectedLA = getPredictedLA(SMP);
    if (currentLA == expectedLA)
        return 1;
    TDPcount++; TDP[TDPcount] = currentLA;
    if (currentLA ∈ SecondaryCluster) {
        if (TDPcount == 3) {
            TDPcount--; TDP[1] ← TDP[2]; TDP[2] ← TDP[3];
        }
        return 2;
    }
}
else {
    CreateNewTSPI(currentLA, expectedLA, validTime);
    if (TDPcount==3) {
        if (new SMP is identified) {
            TDPcount=0; return 3;
        }
        if (SMD is full) {
            find victim SMP with least  $\varphi$  value
            remove victim-SMP from SMD;
            for (each remaining SMPs ∈ SMD) {
                 $NR_i \leftarrow [NR_i * \varphi]$ ;  $LF_i \leftarrow [LF_i * \varphi]$ 
            }
        }
        smpBuild = true;
        BuildNewSMP(LA);
        return 4;
    }
}
}

```

---

Whenever a new SMP is registered in the HLA, this new SMP is also cached at  $m$  most frequently calling mobile terminals. The value of  $m$  can be decided based on network parameters, and this value may vary over the network.

## 4 Call Set-Up Protocol

There are two distinct cases for call setup. First one is where the callee MT's SMP is replicated in the SMD of caller MT. The second case is when the SMP of callee is not available in SMD of the caller.

#### 4.1 Callee's SMP Replicated in Caller's SMD

In this case the call setup process is realized as follows.

- The caller looks up the current location area of the callee from latter's profile and sends a message to its local LA/MSC specifying the expected LA of the callee to which it wants to connect.
- The local LA/MSC instead of going to HLA of the callee, just pages the LA in which callee is expected to be present, so the callee is located either in its first page or it pages to the link pointed by the TSPI. So the lookup at the home location is saved.

#### 4.2 Callee's Registered SMP Not Replicated in Caller's SMD

This case caters to the situation where caller does not frequently call up the callee. The call setup in this case is more expensive than the previous case as indicated below.

- The caller sends a request to the local LA(BS)/MSC specifying the callee's MT Id. The LA finds the home location of the callee, and sends a call connection request.
- The home location of the callee then looks up the SMP registered by the MT and fetches the current expected location. After which the paging protocol is initiated. The callee is located either in its first page or on second page to the link pointed by the TSPI if the callee has deviated from its registered SMP.

#### 4.3 Paging Procedure

The paging procedure has to take several cases into account.

**Case 1:** *The callee is in an LA in registered SMP or has a TSPI.*

The first page is done at the expected LA which is obtained from the registered SMP based on the current time. If there is no answer at the first page, but a TSPI register set to true, the second page is done at the LA pointed to by the TSPI. The MT must answer at the second page otherwise the mobile is not in this state.

**Case 2:** *The callee is not present in its SMP or TSPI indicated LAs.*

In this case the Home LA prepares a priority list of the secondary cluster LAs present in its registered SMP. The priority list is created taking the following into account: (i) The Regional Route Map ( RRM) which is a map of the paths in the city indicating places and routes. (ii) The Slack time specified in the SMP. (iii) The importance of the place based on the preferences given by the user at the time of registration. (iv) Congestion rates at those points. The paging is done in all these secondary clusters based on the priority list thus created above.

**Case 3:** *MT can not be located in any of the secondary clusters.*

A second level priority list will be created which will include the LA based on: (i) the proximity to the expected LA in its SMP. (ii) proximity to the expected

LA in the time frame. The paging is done again in all these LA given in the secondary level priority list thus created above till a page time-out is reached.

**Case 4:** *A page time-out is encountered.*

All the LAs in the current registered SMP are paged.

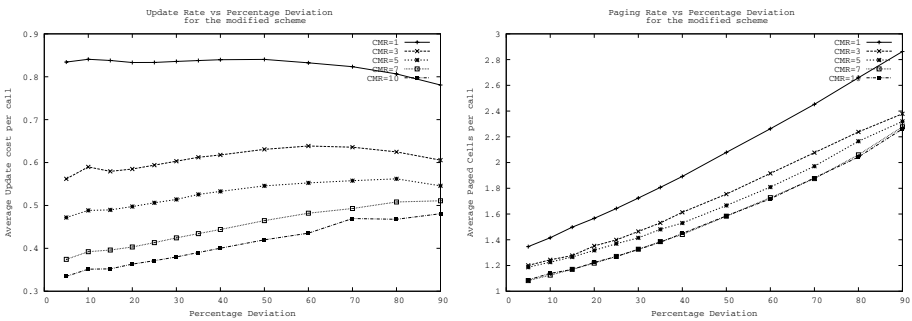
**Case 5:** *If callee still can not be located.*

It is considered to have been one of the following state: (i) has switched off without de-registering itself, (ii) has encountered a power failure, (iii) has moved to a region not covered by the network.

## 5 Simulation and Performance Evaluation

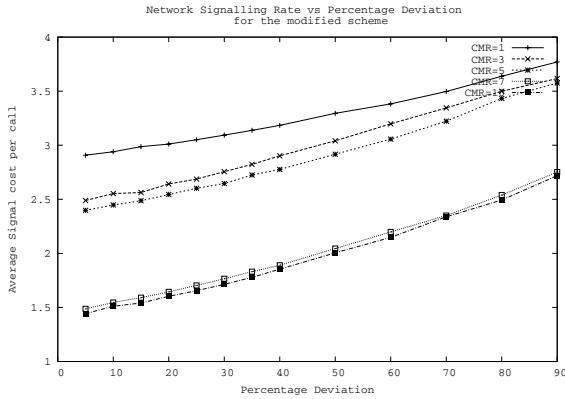
The performance was evaluated for a MSC with 50 cells. The topology of the network, i.e. the connectivity between the nodes and their weights is randomly generated. The simulation time is taken to be 200 units. The calls for the host were also randomly generated during this time. The deviation for the host were randomly generated. The scheme is simulated for varying call to mobility ratios (CMR) and percentage deviations ranging from 5% to 90%. The total number of moves made by host is taken to be 10. Here, we only mention some extracts of the simulations due to lack of space.

The simulation results are compared with the two previous location management schemes, viz., User Mobility Pattern Based [4] and Movement Prediction Based [5]. The various costs are averaged over a number of simulations and varying input patterns.



**Fig. 1.** Update and paging costs for the present scheme

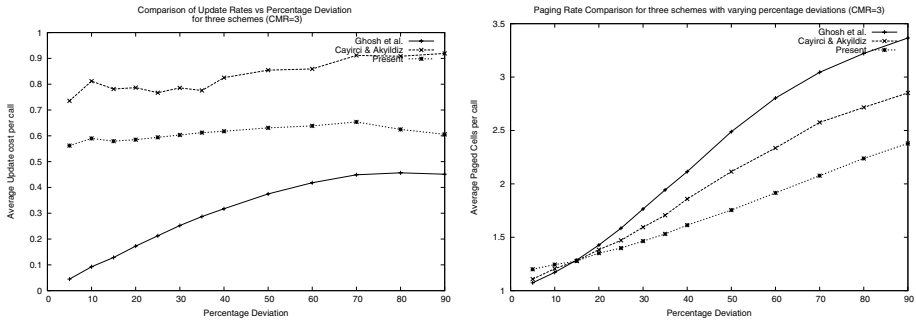
Figures 1 and 2 respectively show the location update costs and paging costs and the network signaling costs respectively for the present scheme with respect to varying percentage deviations and CMR values. It may be observed that the number of paged cells reduces considerably due to the TSPI entry and secondary cluster search even for large deviations. Of course, the TSPI updates increase signaling cost slightly. The average paging cost is found to be 1-3 cells per call. Even for large deviations, it is found to restrict the number of paged cells to



**Fig. 2.** Network signaling costs for the present scheme

less than 3 which will be quite high in two other schemes. This is possible since the TSPI entry allows fast tracking of the transient deviations. Although it will increase in case the host deviates appreciably without coming back to regular patterns, resulting in expiration of TSPI entry more frequently. Hence, selection of TSPI expiration timer should also be set carefully.

The increase in update rate for larger deviations reduces for higher mobility as the pattern is registered only if TDP entry is found to be full, i.e the pattern is registered only if the host possess high probability to follow it and the transient deviations are tackled through the TSPI entry.



**Fig. 3.** Comparison of update and search costs for the three schemes for  $CMR=3$

Figures 3, 4 and 5 provide comparison of update and paging costs for the three schemes for different CMR ratios. From the results it is clear that the present scheme leads in significant reduction in the paging costs even for larger deviations compared to two other schemes. The present scheme restricts the paging costs to 3 cells per call while the other schemes reach higher values for high mobility.

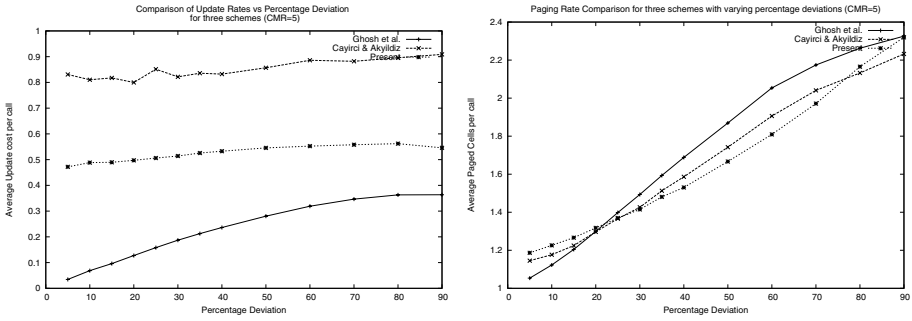


Fig. 4. Comparison of update and search costs for the three schemes for CMR=5

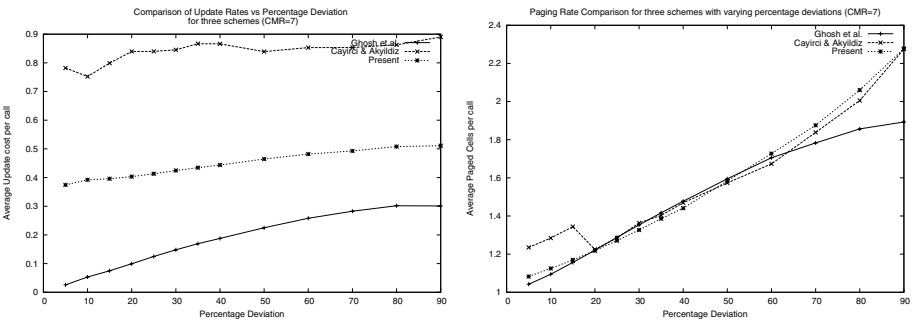


Fig. 5. Comparison of update and search costs for the three schemes for CMR=7

Table 1. Comparison of the requirements of computation times\* of two schemes

Percentage of deviation	CMR=3		CMR=5		CMR=7	
	Ref [5]	Present	Ref [5]	Present	Ref [5]	Present
10	48.1539	0.6734	46.8386	0.6722	51.4070	0.7078
20	47.0098	0.7010	47.2671	0.6761	46.5180	0.6798
30	49.2073	0.7111	48.8414	0.6898	46.9925	0.7131
40	49.0009	0.7409	47.5483	0.7045	52.1262	0.7460
50	47.5154	0.7452	47.3935	0.7290	47.0002	0.7149
60	48.5142	0.7874	47.7017	0.7986	47.2307	0.7567
70	48.2995	0.8181	47.6270	0.7757	47.2038	0.7694
80	50.0146	0.8291	47.4702	0.8172	47.4376	0.8028
90	49.3896	0.8503	47.6759	0.8597	47.1307	0.8541

\* All times are in microseconds

The movement prediction based location management scheme proposed in [5] employs best-first search in the neighborhood of the expected locations of the MT with the help of a regional route map to find its location in case of unexpected deviations. The present scheme handles transient deviations through

TSPI entries which helps in quickly locating the mobile host instead of best-first search. The computational requirements for best-first search puts significant load at base stations. Therefore the scheme proposed in [5] can not scale up easily. Table 1 provides a comparison of the requirements of computation time of the scheme proposed in [5] and the present scheme.

## 6 Conclusion

In this paper we proposed a new location tracking scheme for mobile users. The scheme can be viewed as an amalgamation of the two previously proposed schemes [4], [5]. Each mobile device stores a small number of movement patterns as in [4]. One of the stored patterns is registered by the user as current pattern of movements. When the mobile user deviates from the registered SMP he/she is most likely to follow one of the other pre-declared SMPs. But there may be instances when a user makes either a predictive or an unexpected deviation. Unexpected deviations result in creation of a new movement pattern. But a predictive deviation is transient in nature and typically the user is expected resume registered pattern very soon. To minimize the extra computation load on base station and also to minimize signaling, we introduced the use TSPI. The scheme proposed in this paper relies on the MT to update the TSPI entries. Though it increases signaling cost slightly, but leads to significant reduction in paging costs. Moreover, the present scheme also tackles the expected deviations through secondary clusters found with the aid of regional route map. This is not handled by any of the two previous schemes [4], [5]. So, the proposed scheme not only designed to keep track of evolving new movement patterns but also to handle predictable but transient deviations.

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