A Dynamic Profile Based Algorithm to Reduce the Location Updating and Paging Cost in Mobile Cellular Networks

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***Abstract* — Future microcellular personal communications systems (PCS's) will be characterized by high user density and high mobility. It is expected that registrations will incur a large amount of the radio link signaling traffic. A profile-based scheme (PBS) is proposed for location update and paging in wireless systems where mobile terminals (MTs) maintain their history data in a database called user mobility Record (UMR). During a location update, a User Mobility Behavior (UMB) is derived from UMR and registered to the network. Unless the MT detects that it has moved out of the registered UMB, it does not perform any other location update. On the other hand, cells are paged selectively according to the cell entry times in the registered UMB upon a call arrival for the MT. The related data structures and the protocols for the PBS are presented in the paper. The experimental results show that the PBS outperforms the time-based and movement-based location update schemes as well as the blanket, selective, and velocity paging schemes.**

***Index Terms* — User mobility behavior, user mobility profile, location management, location update, registration, regularity, paging, cellular wireless systems.**

I. INTRODUCTION

A commonly used strategy for tracking mobile users is to partition the entire service area into contiguous and distinct location areas, each consisting of a group of cells. The LA of a mobile user is updated whenever the mobile user enters a new LA. When an incoming call arrives, the system pages the called mobile user through the base stations in cells of the mobile user's current LA. Both location updating and paging require a certain amount of wireless bandwidth. Generally, larger LAs allow less frequent location updating for mobile users and thus less location updating signaling traffic. However, the accompanying larger paging areas introduce more paging signaling traffic. Therefore, a tradeoff exists between the location updating cost and the paging cost [1], [2].

When an LA is comprised of a group of cells that are permanently assigned to that LA, and is fixed for all MTs, the location management scheme is called static. The dynamic location management techniques are more adaptive to the mobility characteristics of MTs. They allow dynamic selection of the location update parameters and reduce the signaling traffic due to location management.

In this paper, we introduce the profile based scheme (PBS) for the location update and paging where MTs keep track of their UMBs in a data structure called User Mobility Record (UMR). During a location update, an MT derives the most expected UMB from its UMR and registers it to the network. The registered UMB includes the cells expected to be visited and the predicted cell entry times for each of the cells in the UMB. Unless the MT detects that it has moved out of the registered UMB, it does not perform any location update. When a call arrives for an MT, it is paged in one cell at a time starting from the cell where it is expected to be according to the registered UMB. Although, MTs register a dynamic location area that consists of several cells, paging only one cell is generally enough to locate them. We show that the PBS reduces the control-signaling traffic due to location management by several orders of magnitude comparing to the time-based [3] and movement-based [4] location update, and the blanket [5], [7] and selective [6] paging schemes.

Our scheme differs from the other user profiles or history data based location update techniques [8], [9], [10], [11], [12], [13] in the following aspects:

- In our scheme, MTs are responsible for predicting and registering the UMBs. This approach reduces the signaling traffic for maintaining UMR, and increases the resolution and the accuracy of the data in UMR because MTs can track every cell that they enter without any need for extra signaling.
- A UMB is a sequence of pairs consisting of cell identification and expected cell entry times. These pairs are called UMB nodes. Since both the locations and the expected entry times are predicted in UMBs, an effective selective paging

can be executed based on the call delivery times by using them. Maintaining the expected cell entry times for UMBs also helps to make more accurate mobility behavior predictions as explained in Section 3.

The remainder of this paper is organized as follows: In section 2 we describe the mobility used in simulation. In Section 3, we explain the PBS. This section also addresses the details related to the system components like the structure of a UMR and the update procedure for a UMR. In Section 4, we describe the PBS-based location scheme and discuss the details of the PBS-based paging scheme in Section 5. We evaluate the performance of the developed schemes by several experiments in Section 6. Finally, we conclude the paper in Section 7.

II. Activity-Based Mobility Model

The goal of the mobility model is to provide, at the individual subscriber level, a realistic set of paths traversed on a daily basis. Since the model will be used to evaluate a location management algorithm which relies on a long-term user profile, a period of several days will be simulated to allow for the creation of a user profile. The model will be applied to a cellular communications system, so the routes traversed can be superimposed on a geographical framework of radio cell boundaries. The final output from the model will therefore be a list of cells traversed by an individual subscriber over a period of several days, together with the amount of time spent in each cell.

In this paper the Activity-Based mobility model [14] is used for modeling the user mobility in cells. The concept of activity, or trip purpose, is central to the simulation. Each activity has an associated time of day, duration, and location (at the level of a cell). An activity is selected based on the previous activity and the current time period. The probability of transition from one activity to another uses the activity transition matrix. Once the next activity is selected, its duration is determined using the activity duration matrix. Finally, the location of the activity is selected, based on the type of activity, and some heuristics. Since the current location of the subscriber is already known, once the location for the next activity is selected, the intermediate route (in terms of cells crossed) and the total distance are determined from a lookup table. Using a user-defined system-wide average speed, the total time and the time in each intermediate cell are calculated. The subscriber stays in the destination cell for the duration of the activity, and the sequence is repeated.

Each simulated subscriber has certain characteristics, one of the more important of which is person type. The distributions for the activity transition matrix and for the activity duration are indexed by person type. Four categories of person type were defined. This categorization attempted to create groups of somewhat similar subscribers, with similar mobility behaviors, using the information that was available from the trip survey. The four categories were:

- Full-time employed outside the home
- Part-time employed outside the home, but not a student
- Student, secondary or post-secondary, possibly employed part-time outside the home
- Not employed outside the home, and not a student

In Results section we comprise these four types with different methods.

III. The Profile-Based Scheme

Mobile subscribers usually follow a limited number of mobility behaviors in their daily lives. For example, people generally take almost the same path and same time to go to work every day. In the PBS, an MT collects the data related to these behaviors in UMR, and predicts the UMB based on the collected data. During location updates, the expected UMB is registered to the network.

A. User Mobility Behavior (UMB)

A UMB is a list of cells expected to be visited starting from a given time according to the mobility history of a mobile, and is made up of a number of nodes that have two fields, namely, cell identification (cell id) and expected cell entry time. A cell id and expected cell entry time pair identifies a node, which is unique in a UMB. However, a UMB may have two different nodes with the same cell id and different expected cell entry time values. Similarly, two different UMBs may have nodes with the same cell id because the same cell may be visited in multiple UMBs or multiple times in the same UMB. For example, one may go to work passing through a cell in the morning. The user may come back home passing through the same cell in the evening. Moreover, the same person may go somewhere else through the same cell at noon in the weekends. In these cases, an MT visits the same cell in different UMBs or in the different phases of the same UMB, i.e., the subscriber may have a single UMB that represents his way both to and from his work where some cells are visited twice at different times within the same UMB.

Note that a UMB is valid after its registration as long as another UMB is not registered, which means that a UMB can span many days. For instance, a subscriber may go to

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work and nowhere else during some days where he does not need another location update when the UMB representing the path to work is registered before in the beginning of this period.

B. User Mobility Record (UMR)

UMBs are derived from UMR which is a data structure where the mobility history of an MT is stored. Each manages its own UMR which is composed of a limited number of records with the following fields:

- flag,
- UMB identification,
- cell Id
  - expected entry time interval (EETI),
  - the earliest entry time (t_{ee}),
  - the latest entry time (t_{le})
- number of visits (NV), and
- next node structures (NN)
  - index of the next node (I_{nc})
  - number of times that the next node is visited (N_{nc})

Note that the records in a UMR are not related to cells, but to the nodes of a UMB. When an MT enters a new cell, it starts the following procedure:

- **UMRUpdating**(cell id, entry time, previous cell id, UMR)
- **Begin**
- record $\leftarrow$ create record (cell id, entry time)
- **if** record exists (record, UMR)
  - record.NV $\leftarrow$ record.NV+1
  - **if** record. t_{ee} > entry time
    - record. t_{ee} $\leftarrow$ entry time
  - **else if** record. t_{le} < entry time
    - record. t_{le} $\leftarrow$ entry time
  - previous record $\leftarrow$ get previous record (record, UMR)
  - increment N_{nc} (previous record, record)
  - **if** N_{nc} becomes the largest (previous record, record)
    - modify MP Id fields (previous record, UMR)
- **else**
  - **if** there is no space (UMR)
    - aging record $\leftarrow$ find an aging record (UMR)
    - delete the last node (UMR, aging record)
  - insert a new record (record, UMR)
  - **if** the previous node exists (previous cell id, entry time, UMR)
    - previous record $\leftarrow$ find previous record (previous cell id, entry time, UMR)
    - create next node (previous record, record)
- **End**

This procedure is composed of '**if**' statements and since a UMR has generally less than 100 records, this procedure generally requires a limited number of comparisons (i.e., less than 100). One or two update operations, makes it simple enough to run on an MT hardware.

If an MT enters a new cell, its UMR probably holds a record for that new cell. Therefore, the UMR is searched for the record of the new cell first. If a record with the same cell id is found and the expected entry time is not larger than the maximum entry interval $I_{\max}$, the N_{nc} field in the current node record are incremented. The previous node is the node from which the MT crosses to the current node.

The expected entry time interval which is the difference between t_{ee} and t_{le} must be lower than $I_{\max}$. If the cell entry time is not between t_{ee} and t_{le} when a new cell is entered, the expected cell entry time interval for the node is also modified (i.e., t_{ee} is replaced if the cell entry time is lower than t_{ee} or t_{le} is replaced if the cell entry time is higher than t_{le}).

When the maximum value for an NV field is reached, all NV fields are decremented with the exception of the records where the NV value has already become 0. The NV field is used to find the aging UMBs. When the UMR is full and a new record is needed to be inserted, one of the records with the lowest NV is replaced with the new record.

When the N_{nc} field pointing to the new cell in the previous record becomes the largest N_{nc} of its record after update, it indicates that the UMB changed starting from the previous node.

If there is no record for the node entered in the UMR (i.e., there is no record that has the same cell id or the expected entry time interval becomes larger than $I_{\max}$ after its modification of the cell entry time), the data about the new node is inserted into the first unused record, unless UMR data structure is full. Otherwise, the record with the minimum NV is found, and the next node links are followed until the next node with an NV greater than the minimum NV or a record with no next node data is reached. This ensures that we select the record related to the last node of one of the least used UMBs. The next node field in the previous node record is also modified such that it does not point to the node to be replaced anymore. Then, this record is used to store the data related to the new node. If the previous node is known and there

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is a record for it in the UMR, the links between the previous and the new node are also created after the data about the new node is inserted into the UMR.

IV. Location Update by Using The PBS

An MT starts a location update process when one of the following happens:

- when the MT is turned on, or returns back to the coverage area of the network, and
- if a new node is entered, which is not a member of the UMB registered in the last location update.

During a registration process, an MT first finds the UMB that it follows. Knowing the current cell and the current time is enough to determine the current UMB. By searching through the UMR, the MT finds the node according to its current cell and time. At the end of this search, if the MT cannot find a UMB for its current situation, it starts to create a new UMB until it enters an existing UMB. During the time when it cannot register a UMB, a static or a dynamic location update technique [3], [5], [7] may be used. In other words, when an MT does not have a UMB in its UMR for its current location, then any other location update scheme can be used.

After finding its current UMB, the MT creates a UMB registration message. The first field of this message is a header and consists of two subfields, namely the flag and number of nodes fields. The flag field is a single bit, and the network uses it to interpret the content of the message. If this bit is 0, it indicates that this message is related to a UMB which has been previously registered to the network. In this case, the number of nodes field gives the number of nodes in the registration message. The network first modifies that many nodes of the previously registered UMB and uses the modified UMB as the current UMB of the MT. If the number of nodes field is 0, it indicates that there is no need to modify the UMB before using it. When the flag bit is 1, the meaning of the message depends on the content of the number of nodes field. When the flag bit is 1 and the number of nodes field is greater than 0, either an existing UMB is replaced by a new one or UMB, which was not registered before, is sent to the network. When the flag bit is 1 and the number of nodes field is 0, it indicates that this registration message is for another location update technique.

The second field in a registration message is the UMB Identification (UMB Id) field. It may also be the location area identification when the system is in the static location area management mode. The fields for the nodes in the UMB follow the UMB Id field. Each of these fields is composed of two subfields, namely the cell identification and the expected cell entry time. When this structure is created, it is sent to the network in the payload of a registration message.

Note that the network keeps the registered UMBs and modifies them by the registration messages coming from MTs. Therefore, an MT reports only the modifications that are made in the nodes of a UMB since its last registration. It is also possible that the network discards the previously registered UMB of an MT as soon as the MT registers a new UMB. In this case, the MT must send all of the nodes in the UMB as registered to the network for location updates. Hence, when the network keeps only the current UMB and forgets the previously registered UMBs, the average size of registration messages increases. Also, note that our solution is adaptive. If an MT enters a region where it has not been before, it cannot find a UMB in its UMR for the current location. In this case, we can use another location update technique [3], [5], [7].

V. Paging by Using The PBS

When a call arrives for an MT, the cells registered by the MT in the UMB are paged sequentially starting from the cell where the called MT is most likely to be at the call arrival time. This cell is determined by searching the nodes in the UMB registered by the called MT in order to find the last node which has an expected entry time lower than or equal to the current time, i.e., there is either no node after the last node or the next node has an expected entry time greater than the current time.

If the MT is not found in the first paged cell, the cell with the closest cell residency interval to the current time is paged next. One cell at a time search is carried until either a response from the MT is received or a paging delay bound is reached. If the MT is not found in one of the paged cells until the paging delay bound is reached, all remaining cells in the UMB are paged simultaneously. If the MT is still not found, it indicates that the MT either left the coverage area of the network or turned off without deregistration (i.e., sudden death of power supply) because MTs are supposed to register a new UMB whenever they move out of the registered UMB. In such a case, the called MT is deregistered and recorded as turned off until it registers a UMB. As explained in the location update process in the previous section, whenever the MT returns to the coverage area or is turned on, it starts a location update process.

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VI. Numerical Results

In this section we analysis the performance of PBS. The analysis involved comparisons of the dynamic model with the standard fixed location management algorithm, as typically implemented in today's cellular networks. We also compare the location update and paging performance of the PBS technique against the time-based [3], and movement-based [3], [4] location update techniques, and the blanket [5], [7] and selective [6] paging techniques.

The original output from the mobility model provided details about paging and location update messages generated over time by a simulated subscriber, for each of the algorithms and for the PBS. The movements and messages generated by each subscriber were logged for 15 simulated days, an interval assumed at the outset to be long enough for the model to reach a steady state. For each set of controlled variables (person type, and number of daily call arrivals), fifteen repetitions were run, each with a different set of internal parameters (initial start time, location of home, work, and school). The number of location updates and pages were tabulated, per simulated day, for each algorithm and for each set of controlled variables. The average MT speeds from 1 cell/hour up to 5 cells/hour are simulated. To evaluate the paging performance, we assume call inter arrival times are exponentially distributed.

A. Location Updating

The graph in Figure 1 shows the number of location update messages for the different algorithms, averaged over all relevant independent variables.

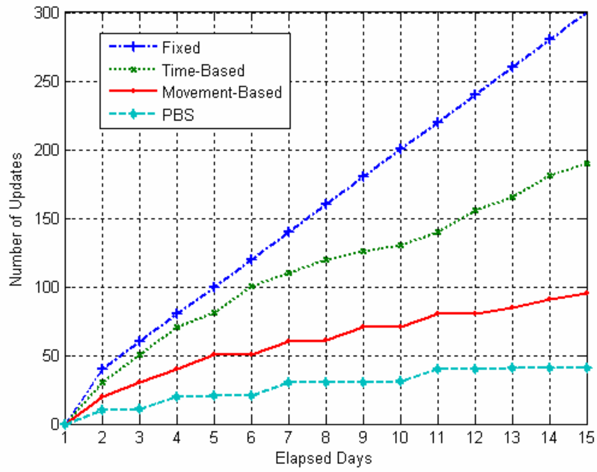

Fig. 1 Global average number of location updates versus elapsed time

B. Paging

The overall average number of cells paged is shown in Figure 2 for levels of 9 incoming calls per day.

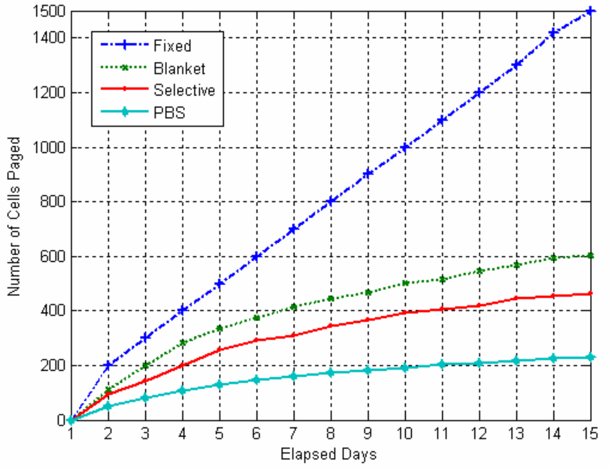

Fig. 2 Global average number of cells paged for 9 incoming calls, versus elapsed time

VII. Conclusion

In this paper, we introduce a new location management scheme, namely the Profile-Based Scheme (PBS) where MTs maintain their history data in a data structure called User Mobility Record (UMR). During location updates, an MT derives a User Mobility Behavior (UMB) from its UMR, and registers it to the network. UMBs consist of a number of nodes made up of a cell id and an expected cell entry time. Unless the MT detects that it moves out of the registered UMB, it does not perform another location update. Upon a call arrival for the MT, the cells in its last registered UMB are paged sequentially according to the expected cell entry times. If a delay bound is reached before receiving a reply from the MT, all of the unpaged cells are polled simultaneously.

We carried out analytical, statistical, and simulation-based experiments to evaluate the performance of the proposed scheme. The performance of the PBS is also compared with the time-based and movement-based location update techniques, and the blanket and selective paging techniques. The PBS technique creates less location update traffic than the other techniques. It always outperforms the other techniques in paging performance.

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