Spatial and Temporal Aware, Trajectory Mobility Profile Based Location Management for Mobile Computing

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Introduction (1)

A Generic Location Management Structure

- Mobile Host
- Base Station
- Cell Boundary
- Location Area Boundary
Introduction (2)

- Location Management:
  - Tradeoff between
    - Location update cost
    - Paging cost
  - Location update based on
    - Time
    - Distance
    - Number of cells crossed
    - Speed/direction
Introduction (3)

- Schemes
  - Non-profile based: the system treats all Mobile Hosts (MH) equally
  - Profile-based: Each MH has its own mobility profile

- Research Objective: Propose a new profile-based location management scheme that is:
  - Temporal Aware
  - Spatial Aware
  - Using Trajectory
Motivation (1)

Profile-based Location Management (*Tabbane, 1995*)

- Originally proposed as an alternative strategy to schemes that treat all MHs equally

- Associate a candidate list of location areas in the decreasing order of the most likely places where each MH is located within a set of predefined time slots (temporal aware)

- When a MH moves into a cell that is not in the list, it will perform a location update.

- Location areas in the list will be paged sequentially in the order indicated in the list when a call is initiated
Motivation (2)

Disadvantage:

- Temporal aware but not spatial aware (Candidate list is generated regardless of current MH location and moving paths)

Observations

- Cells which a MH are likely to visit in the candidate list are often spatially clustered and disjoint in a particular time slot

- A MH usually follows its routine paths in many cases. The cells along a path can be identified based on the first several cells a MH has traveled
Proposed Architecture (1)

Components

- Mobile Host Part
  - A list of candidate cells that a MH is likely to visit
  - A record for the recent trajectories (paths)

- The Network Part
  - Long-Term Profile Database (LTPD): e.g. daily profile
  - Short-Term Profile Database (STPD): e.g. profile for each hour
  - Special Event Database (SEDB): mobility pattern change events
  - Geographical Information Database (optional): e.g. cell distribution/census data/road network
  - Activity knowledge database (optional): e.g. go to work at 7am for general population
  - User registration database (optional)
Proposed Architecture (2)
General Process (1)

1. Generate initial profiles of all MHs, store them in LTPD

2. Retrieve mobility profile from LTPD to STPD for active MHs when either new MHs become active or time slots associated with the active MHs are changed

3. The system performs spatial sub-setting of mobility profiles on STPD to generate candidate lists for active MHs based on their current locations and moving paths and send them to those MHs
4. When a location update occurs:
   • MH sends recent trajectory to STPD
   • The system detects special events from STPD and updates SEDB

5. When a time slot is switched: update LTPD using profiles in STPD
Initial Profile Generation (1)

- Disadvantages in using data mining techniques to generate mobility profile
  - Data storage is huge (140M for 24 hour)
  - Many algorithms are not one-pass
  - Assuming all data can be fitted into memory
  - Huge computation overhead
  - Unacceptable delay if run in real time
Initial Profile Generation (2)

- Generate initial profiles based on semantics
  - Geographical information (e.g. census data)
  - Activity knowledge (e.g. traffic patterns)
  - User registration data as much as available

- If none of the registration information is available
  - Spatial join cell coverage data and the census data to compute the type (commercial/rural etc) of each cell
  - Give a higher probability to cells in business/residential/entertainment areas and a low probability to cells in rural areas
  - All users in this category will have the same set of initial frequently visited cells according to the order of probability
Initial Profile Generation (3)

- If only residential location from registration database is known
  - Find the communities around the MH home location from the census data and set the average profile of the MHs in communities as the MH initial profile
  - Example of MH profile: nearest grocery stores, shopping malls, kindergartens, cinemas, etc
  - Travel paths between them can also be generated

- If we know further information:
  - Such as age, sex, marriage, work places, places that are often called by friends, etc
  - Adjust the probability of occurrence that are assigned to the cells and travel paths
Mobility Profile Update (1)

Assumptions
- A candidate list of cells that a MH might be located in is transferred from STPD and stored at MH side.
- The candidate list is associated with a time slot that is statically or dynamically defined by the system.
- A MH has a limited memory to record the sequence of its trajectory.
- The MH should perform location update when:
  - The cell where the MH is currently in is not in the candidate list.
  - The trajectory memory set is full.
  - Time is slot switched.
Mobility Profile Update (2)

Upon a MH location Update

- The system will update its STPD and compute the moving speed and direction that will be used in sub-setting mobility profiles (to shorten list of candidate cells)

- The visit frequencies newly transferred from the MH will be added to the frequencies of the corresponding cells in the STPD

- The new cells a MH has recently visited but not in the STPD records will be added to STPD together with their visit frequencies.
Mobility Profile Update (3)

- Additional Strategies
  - If New mobility events occur
    - E.g.
      - Appearance in new regions
      - following new routes
    - Then
      - generate initial mobility profile under the spatial/temporal context discussed earlier
      - query LTPD to update STPD
Mobility Profile Update (4)

- If Mobility pattern changes over time slots
  - E.g. going to work at 7:30 on weekdays while going to work at 9:30 on Saturdays ➔ The cells visited by a MH are significantly different from the ones in the STPD fetched from the LTPD of the time slot

- Then
  - Do not update the LTPD for the time slot at the time of switch
  - Add special event records to the SEDB
  - The system will visit SEDB regularly to get evidence to decide whether to reorganize time slots (merge/split)
Spatially Sub-Setting Profile (1)

Objective:
- To shorten the list of candidate cells based on current MH location and moving paths

Assumptions: the network knows
- The geographical location of all the cells in the area
- Their topological (neighborhood) relationships

Compute movement parameters based on recent trajectories to subset the mobility profile
- The last cell that the MH is in
- Average moving direction and speed
- Deviations of moving direction and speed
Spatially Sub-Setting Profile (2)

- When a MH powers up (Begins to connect to the system)
  - The direction it will follow and how fast it will move is not clear
  - Query cell location database (part of geographical information database) to get maximum number of cells the candidate list allows that are near to the power up cell and visit probability higher a threshold within that particular time slot.
  - In the initial period, very likely that the cell the MH is going to enter will be not in the candidate list and thus a location update is issued
Spatially Sub-Setting Profile (3)

- At stable period (after some location updates)
  - The network is able to compute the movement parameters
  - Perform first step spatial filtering: perform range query against the cell location database to retrieve cells in a square
    - Current location as the center
    - Possible moving distance as the half length
Spatially Sub-Setting Profile (4)

- Perform second step spatial filtering
  - If the number of candidate cells or the uncertainty of the candidate list is greater than the predefined values
  - Estimate possible deviation angle of moving directions
  - Filtering area can be determined based:
    - Current location
    - The deviation angle
    - The maximum distance

Predicted Direction

Deviation Angle
Spatially Sub-Setting Profile (5)

The third type of filtering: semantic spatial filtering
- Can be used either as an alternative method or as a refinement in the second step
- Initialization:
  - Build a lookup table storing the major road network segments and the cells they run through by querying against cell locations and road network in the geographical information database
  - If the sequence of cells a MH has traveled so far is part of a road segment then
    - MH is following the road segment
    - Give the rest of the cells along that road segment higher probabilities
Analysis and Discussion (1)

- The proposed scheme is an extension to the previous profile based location management studies.

- Spatial and temporal related computation is performed at the network side instead of at the MH side.

- Provide much fewer and more accurate cells in the candidate list as mobility profiles by exploring spatial and temporal mobility context as well as movement trajectory.
Advantages

- The paging time is greatly reduced (since the time needed for sequential paging is proportional to the length of the candidate list)
- More reliability for a shorter list
- Shifting computation to server side improve the whole system performance
Analysis and Discussion (3)

Disadvantages: needs greater network support

- A geographical information database and functionalities to generate initial profile as well as look up tables

- User profiles take much more space than those used in the standard HLR/VLR scheme (storing only single cell ID)

- Location updating costs
Analysis and Discussion (4)

- Additional Comments:
  - The proposed scheme heavily relies on efficient online mobility profile management at both
    - MH side: Needs to compress its trajectory and keep the packet small and constant size for efficient location database update
    - Network side: Needs to retrieve contextual (spatial/temporal) mobility profile (LTPD/STPD).
  - The STPD in the proposed scheme actually serves as the cache between the MH and the LTPD
  - Efficient spatial and temporal query processing is essential
Summary

- Provide a novel location management scheme using user mobility profiles that are spatial and temporal context aware.

- The scheme can reduce the candidate list length of mobility profile and improve its accuracy which will reduce paging cost and latency.

- Propose a geography-based method to generate initial mobility profiles
Future Work

- Build a prototype to demonstrate the feasibility of the proposed scheme and analyze its performance

- Refine and implement several key techniques:
  - Online spatial and temporal query processing for generating context aware mobility profiles
  - Recognition of long-time mobility pattern change from the SEDB and the LTPD
Thanks!

Questions?