USER PROFILE BASED TRACKING STRATEGY
FOR
WIRELESS PCS NETWORKS

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By

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CERTIFICATE

This is to certify that the dissertation entitled " ***User Profile Based Tracking Strategy for Wireless PCS Networks*** " which is being submitted by **Mr. Narendra Pratap Singh** to the school of Computer and systems sciences, Jawaharlal Nehru University, for the award of ***Master of Technology in Computer Science and Technology***, is a record of bonafide work carried out by him.

This work is original and has not been submitted in part or full to any university or institution for the award of any degree.

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DECLARATION

This is to certify that the dissertation entitled " ***User Profile Based Tracking Strategy for Wireless PCS Networks*** " which is being submitted to the school of Computer and system sciences, Jawaharlal Nehru University, for the award of ***Master of Technology in Computer Science and Technology***, is a record of bonafide work carried out by me.

This work is original and has not been submitted in part or full to any university or institution for the award of any degree.

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Narendra Pratap Singh.

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…dedicated to my parents

Contents

ABSTRACT

The location management problem is characterized by two events viz. *paging* and *location update.* The present work deals with paging i.e. tracking of mobile user in wireless PCS networks. The past movement of user is more realistic in order to predict any mobility pattern of user, rather than assuming any arbitrary distribution on mobility pattern of user. A tracking scheme has been proposed which considers the individual mobility patterns. Most of the cellular mobile systems partition a geographical region into location areas (LAs). Using LA partitioning scheme expected number of search in terms of LAs have been computed. The expected search under the proposed tracking strategy can be shown to be minimum in number of search. The comparison with existing models have been carried out by taking an example of simulated result. An information theoretic framework using entropy per location has been carried out for the comparison of different models.

Chapter 1

INTRODUCTION

1.1 Mobile and Personal Communication

The rapid evolution in communication system has led to emergence of mobile and wireless systems. The concept in mobile and wireless communication is to provide freedom to users to access the communication resources anywhere and at any point of time. However, due to rapid evolution there is now increasing demand for these communication devices. Accordingly there is need for the network to utilize its resources in an optimal manner. The goal of the network is to provide services to its users with large set of options. The wireless and mobile communication systems use radio-wave spectrum for transmission of voice and data [13].

The radio-wave are the carrier for data and voice. The capability of radio-wave propagation in air, and being the carrier for data and voices has reduced the fixed wire-linked telephony system to wireless system. The concept of personal communication services (PCS) network has enabled us to provide universal personal communication where terminal mobility provided by wireless access is also taken into consideration.

In wireless environment, most of the systems are using radio band for transmission (Radio-waves are electromagnetic waves which can transmit through air). The radio-wave communication may be simplex channel or it may be duplex channel communication. In simplex channel communication, the communication proceeds in one way (for example radio systems, radio owner can only listen the voices which is being transmitted by the radio stations). In duplex channel communication, both way transmission is possible. Both the end can transmit voice and data. As available radio resources are limited, one is required to find an optimal way to utilize these resources. In mobile communication, users are free to roam anywhere within the service area. Accordingly the network must know the location of each user in order to deliver the calls correctly [13, 16]. To provide the free mobility within the network, the concepts of cellular system becomes relevant. The concepts of cellular system and system architecture are briefly described in the following two sections.

1.2 Reference system Architecture

The wireless network for PCS network is still built upon and underlying cellular architecture. Most of the networks in mobile communication have deployed the global system for mobile communication (GSM) architecture. In this architecture the entire network is divided into small areas called cells. Cells are served by *Base Transciver Stations* (BTS) or *Base Stations* (BS).

It also comprises *Base Station Controllar* (BSC), *Mobile Switching Centre* (MSC), and set of registers (database) to assist in mobility management and security functions. The backbone of PCS network of consists of existing wireline networks (such as PSTN, ISDN and internet) [8]. The Figure 1.1 is depicting the system architecture and signalling interface

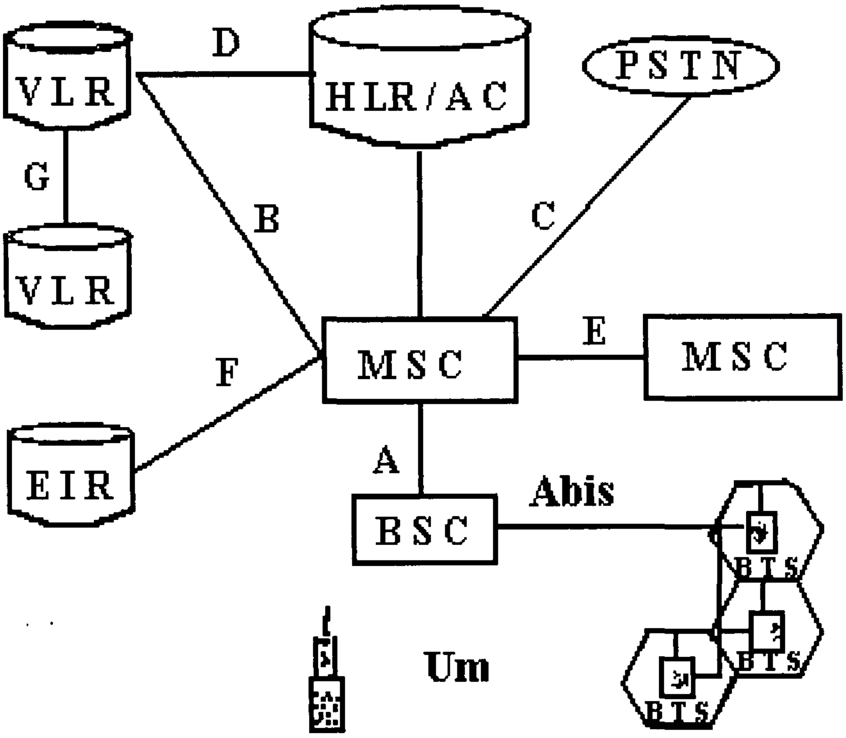


Figure 1.1 Reference architecture and Signaling interface

The *Base Station System* (BSS) comprises a *Base Station Controllar* (BSC) and one or more subtending *Base Transciver Stations* (BTS). The BSS is responsible for all functions related to the radio resources (channel) management. The BSCs are further connected to MSCs forming a tree like structure. The MSCs are connected to PSTN as most of the calls originate and terminate at the fixed wired telephony systems. The MSCs can be viewed as a local ISDN switch with additional capabilities to support mobility management function like terminal registration, location updating and handoff. The major function performed by MSCs are:

(i) Call setup, supervision and release

(ii) Call routing

(iii) Mobility management
    registration/locaton updating,
    inter-BSS and inter-MSC-call handoffs.

(iv) Paging and Alerting

(v) Managing connections to BSS,other MSCs and PSDN/ISDN.

Apart from these it consists of two major set of registers: *Home Location Register*(HLR) and *Visiting Location Register* (VLR) which acts as database. The HLR represents a centralize database that has the permanent data store about the mobile subscribers in large service area. It also maintains each and every location update of each user. The HLR keep on updating its database with current location of its subscriber in the network. It also keeps the information about those who have roamed into another network. On the other hand VLR represents a temporary data store and generally contains the information about the mobile subscribers who are currently in the service area covered by the MSC. There are another set of registers, *Equipment Identity*

Registers(EIR) which contains information about authenticate subscribers. It does not permit any fraud subscriber to utilize the services provided by the system.

1.3 Cellular Concept - System Design

There is very limited frequency spectrum available so there has to be some good technique which utilizes these limited resources without affecting the performance of the system. The cellular concept is having major breakthrough in solving problem of spectral density and user capacity. The concept offer a very high capacity in limited spectrum allocation without any major changes in the technologies. It replaces a single, high power transmitter (large cells) with a large number of low transmitter (low cells) with coverage of small geographical regions. As the availability of radio band is limited, the concept enables to reuse the frequency in far away located cells. The proper distribution of spectrum provide the means to reuse the frequencies as many times as necessary [13, 14]. Figure 1.2 is representing the typical cellular system.

As the demand for services increases (i.e. as more channels are needed within a particular region), the number of base stations may increased. Hence the need for the additional radio capacity. The concept of frequency reuse resolve the problem of additional requirement of the channel. Also the cell splitting and cell sectoring is very useful to avoid the overload of cells. Thus deployment of these things in a cellular system make it more sophisticated. But these techniques has to incorporate as per the need of the system. How the different frequencies are allocated or how the user access the carrier channel? To resolve the problem of accessing the channel, system utilizes the multiple access technologies. In the following subsections the features of the cellular system have been discussed.

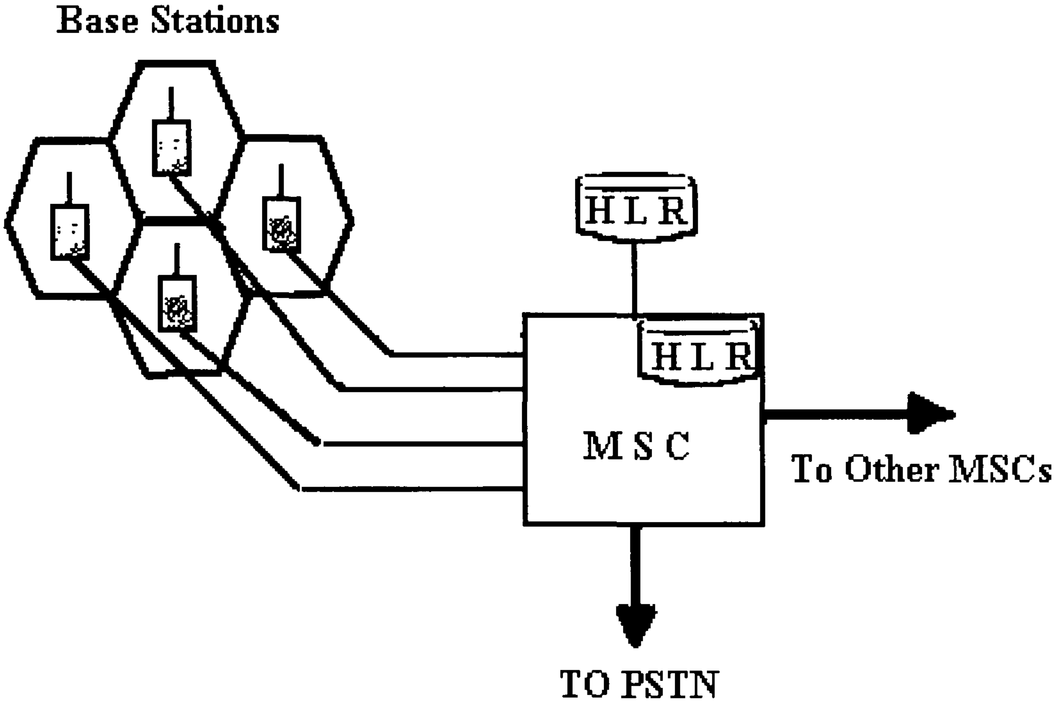


Figure 1.2 Typical Cellular System

1.3.1 Multiple Access Technologies

Due to limited amount of frequency spectrum multiple access technologies are deployed so that many users can share the available spectrum in an efficient manner. In the multiple access, signals from different sources are combined into one and then transmitted over a given radio frequency band. Upon reaching the destination these signals are separated without causing any interference [8, 14]. The three basic multiple access technologies in the cellular systems are:

(i) Frequency Division Multiple Access
(ii) Time Division Multiple Access
(iii) Code Division Multiple Access

In frequency division multiple access (FDMA), the frequency spectrum is divided into small sets of frequency bands. Each user is allocated one of these band. These bands are known as traffic channel. The different users are assigned different channels. There could be interference from the adjacent cell. The concept of guard channel and bandpass filters that maintain separation of signals associated with different users reduces the interference from the adjacent call.

In time division multiple access (TDMA), the available frequency band is divided in narrow bands like in FDMA. Now each narrow band is further divided into number of time slots. Each user is assigned frequency channel for the duration of time slot. The code division multiple access (CDMA) utilizes the spread spectrum technique. The information from an individual user is modulated by means of unique PN code assigned to each user. All the PN-code -modulated signals from different users are then transmitted over the entire CDMA frequency channel. At the receiving end the individual signals are recovered by despreading the signal.

1.3.2 Frequency Reuse

The purpose of cellular concept was to provide services with limited radio resources. As the cell provides low transmission in small area, it is important to have a proper structure of the cell so that entire service area is covered by different cells. There are three kind of cell structure : square, triangle and regular hexagon which cover all service areas without any gap. Out of these a regular hexagon is ideal choice (actual shape of the cell is different from these three structure) as it closely approximates a circle and offers a wide

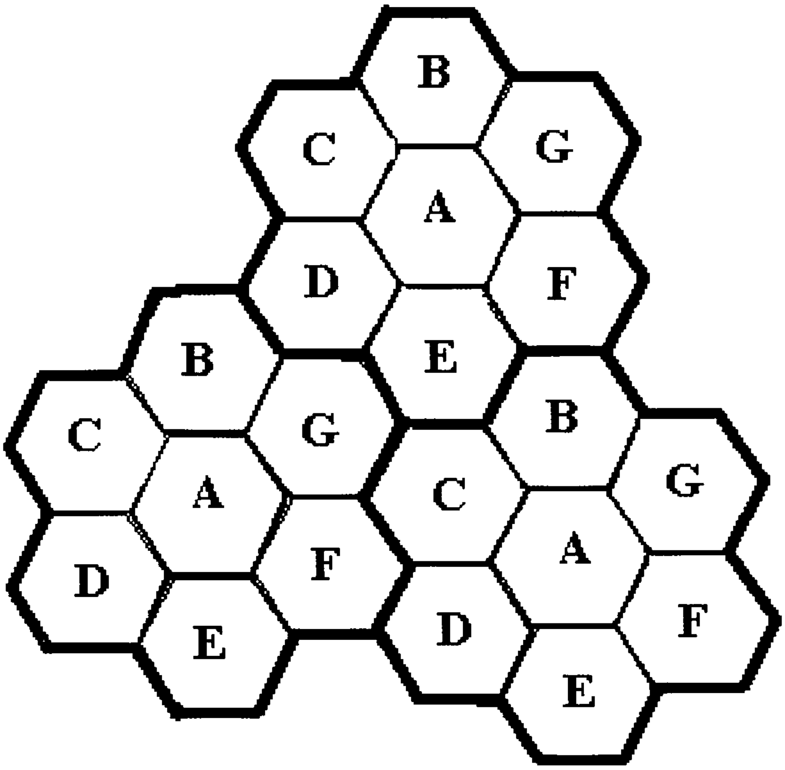


Figure 1.3 Illustration of frequency reuse in the cluster of 7-cell.Cells marked with same letter use the same set of frequency

range of tessellating reuse of cluster sizes. A tessellating reuse of cluster of size N can be constructed if

$$N = i^2 + i.j + j^2$$

where i and j are non negative integers, and $i \geq j$. It follows that cluster size would be $N = 1, 3, 4, 7, 9, 12, \ldots$. A simplified 7-cell reuse plan is shown in figure, where similarly marked cells use identical sets of carrier frequencies [13, 14]. The Figure 1.3 is depicting the frequency reuse in wireless networks.

1.3.3 Channel Assignment Strategies

The frequency reuse strategies may result in interference. The purpose of channel assignment is to minimize the interference. There are two types of channel assignment strategies : Fixed and Dynamic

In fixed channel assignment technique, each cell is allocated a predefined set of voice channels. Any call attempt within the cell is served by the unused channel in that cell. If all the channels are in use, then call is blocked. In dynamic channel assignment technique, voice channel are not allocated to different cells permanently. When a call has to make, the serving base station request a channel from MSC. The MSC only allocates a given frequency if that frequency is not presently in use [13, 14].

1.3.4 Hand-off Strategies

When a mobile user moves into different cell while a conversation is in progress, the MSC automatically transfers the call to new channel belonging to that new base station. The phenomenon is known as hand-off. The

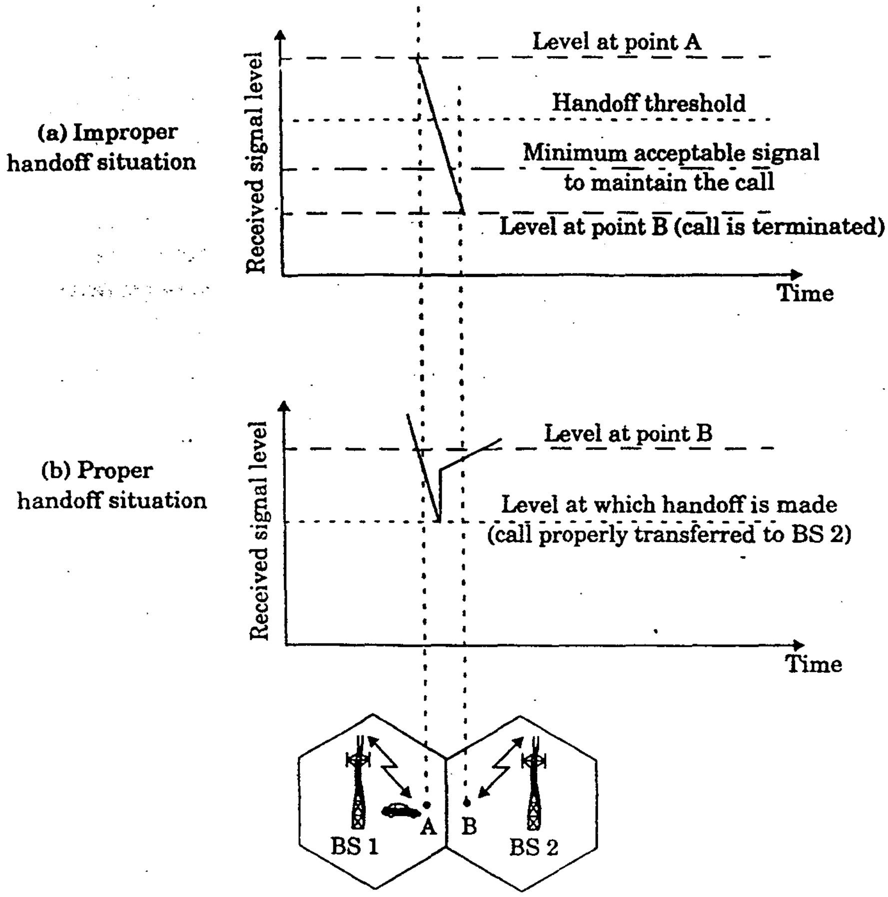


Figure 1.4 Handoffs in wireless communication

process of hand-off should be imperceptible to users. In order to meet these requirements, system designer specify an optimum signal level at which to initiate hand-off. The system defines a particular usable level of signal as acceptable voice quality and the hand-off is initiated when

$$\Delta = Pr_{handoff} - Pr_{minimum\ usable}$$

approaches to defined optimum level [8].

1.3.5 Cell Splitting

As the demand for wireless service increases, the number of channels assigned to a cell eventually becomes insufficient to support the required number of user. Cell splitting increases the capacity of the system by dividing the large congested cell into small cells, each with its own base station and a corresponding reduction in transmitter power. Defining a new cell with smaller radius (called *microcells*) between the existing cells, capacity increases due to the additional number of channels per unit area. Figure 1.5 is illustrating the cell splitting in cellular system.

1.3.6 Cell Sectoring

As shown in section 1.3.4, cell splitting increases the capacity of the system. The reduction of cell radius in cell splitting concept increases the number of channels per unit area. However, another way to increase the capacity without changing the cell radius is cell sectoring. The co-channel interference

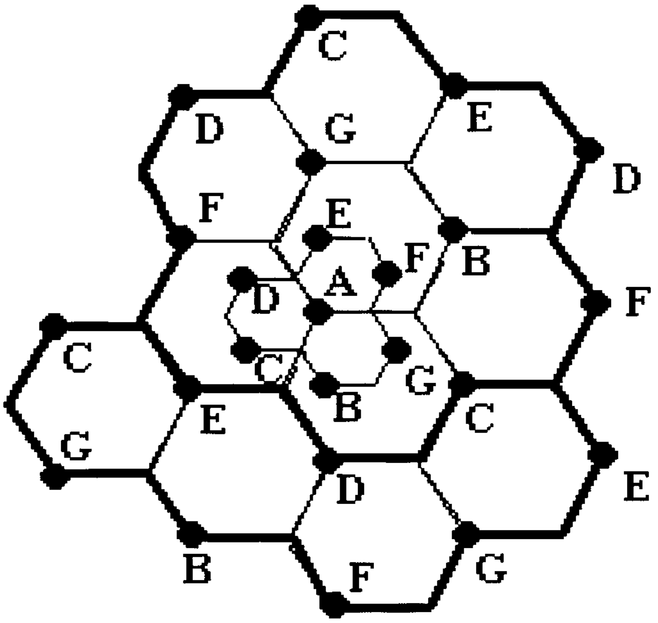
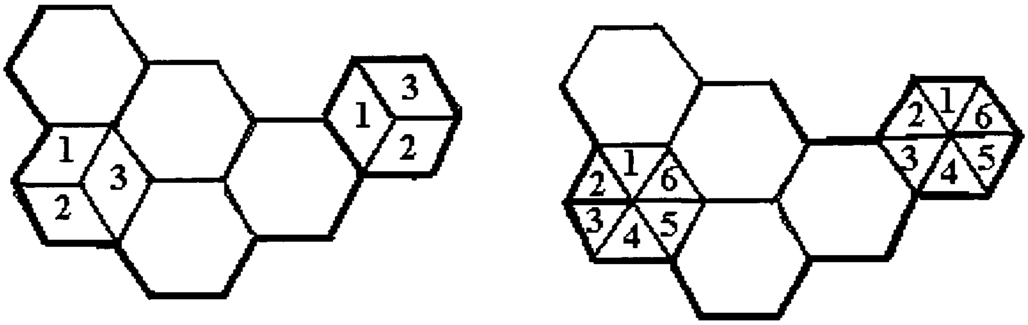


Figure 1.5 Cell splitting to increase the system capacity

in a cellular system may be decreased by replacing the single omni-directional antenna at the base station by several directional antenna.The technique for decreasing co-channel interference and thus increasing the system capacity by using the directional antenna is called *sectoring.* The factor by which the co-channel interference is reduced depends on the amount of sectoring used [13, 14]. A cell is normally partitioned into three 120^o sector or six 60^o sectors as shown in the Figure 1.6 (a) and (b).



(a) 120^o sectoring (b) 60^o sectoring

Figure 1.6 Cell sectoring of 120^o and 60^o

1.4 Call Handling in Wireless Environment

Since there is no wire-link between two mobile terminal (or user) the problem is, how the system routes an incoming calls? The mobile users are free to roam anywhere in the service area. Due to freedom for mobile terminal to roam anywhere within the network in PCS wireless communication system, there should be an efficient method to deliver the calls correctly. When a call comes for a user, network initiates a search for user by simultaneously

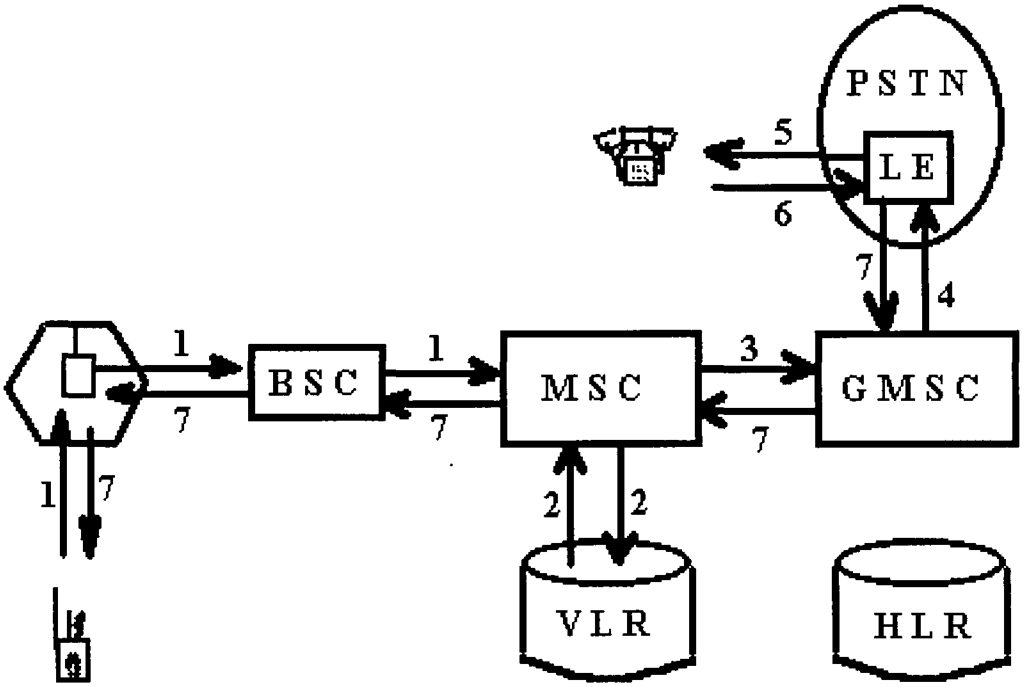


Figure 1.7 Call initialization in wireless communication

1. The MS sends the dialed number indicating service requested to the MSC (via BSS).
2. The MSC checks from the VLR if the MS is allowed the requested service. If so, MSC asks the BSS to allocate necessary resources for the call.
3. If call is allowed, the MSC routes the call to GMSC.
4. The GMSC routes the call to the Local Exchange (LE) of called user.
5. The LE alerts (applies ringing) the called terminal.
6. Answer back (ring back tone) from the called terminal to LE.

7. Answer back signal is routed back to the MS through the serving MSC which also completes the speech path to the MS.

polling (MSC sends paging signal over a designated *Forward control channel* (FCC) via BSCs in the set of cells) all the cells where it can possibly be found. Upon receiving the page signal, the target mobile user sends message back to the system through *reverse control channel*. Once the process is over the MSC direct the incoming call to the user. Again the FCC is allocated by the system and has very limited frequency band and if there is more number of calls then it may overload the FCC [8, 3]. If network is unable to track user in first attempt and meanwhile few more calls come then more call-blocks and call-drops will be there. The Figure 1.7 illustrate, how the call initiate in the wireless environment.

1.5 Organization of Dissertation

In this chapter we have provided a brief introduction of few basic concepts of wireless networks related to present work. These include architecture, cellular concepts, Call handling in wireless environment etc. The next chapter i.e., the second chapter is concerned with location management in wireless environment along with previous works on location management. The third chapter describes the system model and tracking strategy. The fourth chapter is devoted to the comparison of various tracking strategy. Conclusion and future works is given in fifth chapter.

Chapter 2

LOCATION MANAGEMENT

2.1 Introduction

The location management schemes are essentially based on users mobility pattern and incoming call rate characteristics. Whenever there is a call for user, network initiates search for the user to deliver the call. To deliver the calls correctly network must know the location of user for which the call has come. There are two kind of event (activity) in location management viz. *Location Update (Registration)* and *Paging* [5].

The focus is given to these event in the location management. The problem is, given the two activity (*Registration* and *Paging*), what is minimum effort required to track down user in the service area? There is cost associated with these two activity so the goal is to find some optimal strategy which minimizes the cost of location management. Various works have been on these two strategy in order to minimize the cost of location management (Total cost paging and update is known as location management cost).

2.2 Paging and Registration

In wireless networks whereabouts of user must be known in advance to deliver the incoming calls correctly. When a call comes for a user, network starts searching user by sending the polling signals through *forward control channel* within the service area. When the target mobile receives the polling signal, it sends back the message though *reverse control channel.* The event is called *paging.* There is cost associated with the paging event and therefore the system can not afford to page the entire network simultaneously. An alternate scheme is to divide the network area into *location areas* (LAs) which consist several number of cells. In this approach we page the LAs in the decreasing order of steady-state location probabilities whenever there is a call. While within the LA paging is to be done simultaneously [9].

One may think that if no information about the user is available to the network, the system will have to search all the cells within the service area. If an exhaustive search is performed for each and every call that arrive, the signaling traffic would become enormous for large networks. This will increase the paging cost and overload the paging signal traffic. To avoid these situation in the networks, users keep on reporting from time to time so that at specific point of time networks know the location of users. The event of frequent reporting to network is called *location update* or *registration.* Out of these two event the paging is known as system activity while registration is known as user activity. There are different schemes for location updates proposed by researchers. In the following section we are looking at these strategies.

2.3 Location Update Schemes

In a broad sense there are two kind of location update strategies viz.

(i) Static Update Scheme

(ii) Dynamic Update Scheme

2.3.1 Static Update Scheme

The scheme is based on either partitioning of cells into location area (LA) or selection of few designated cells (called reporting cells) [4]. The scheme is called static update as it is static in nature. This is static in the sense as system defined some constraint in the network and whenever user meet this constraint it update its location in the network. Once the system defined these constraint user can not do anything regarding its update in the network. The static update scheme does not have much computation complexity.

The LA partitioning is adopted by Global System for Mobile Communication (GSM) and follows the idea presented in [9]. In this scheme the service area under an MSC is partitioned into location area (LA), A mobile user updates its location whenever it crosses the boundary of LA. while in cell selection, few cells are designated as reporting cells. Whenever a mobile user enters into these cells it updates its location as dictated by Bar, Noy [4]. But the drawbacks of these strategy is that user can generate a large number of location updates while crossing the LA boundary again and again or going in the selected cells very frequently. Thus there will be increase in location update cost. Figure 2.1 illustrates the location update sequence in wireless systems

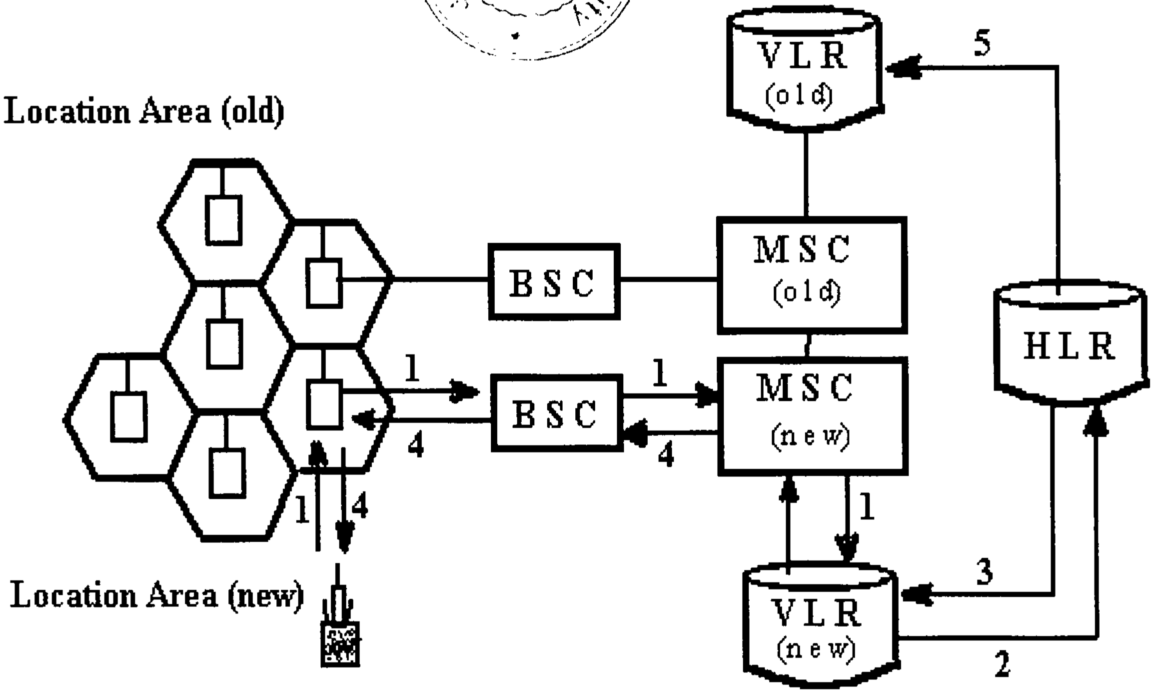


Figure 2.1 Location updating sequence in wireless communication

1. The MS sends a Location Update request to the VLR (new) via the BSS and MSC.
2. The VLR sends a Location Update message to the HLR serving the MS which includes the address of the VLR (new) and IMSI of the MS. This updating of the HLR is not required if the new LA is served by the same VLR as the old VLR.
3. The service and security related data for the MS is downloaded to the new VLR.
4. The MS is sent an acknowledgment of successful location update.

5. The HLR request the old VLR to delete data relating to relocated MS.

2.3.2 Dynamic Update Scheme

In the dynamic location update schemes, the update is based on the user activity. It does not employ any constraint defined by system. The mobile user makes the decision when and where to updates its location. The three schemes which falls under the dynamic update strategy is

(i) Distance-Based location update
(ii) Timer-based location update
(iii) Movement-based location update

In the distance-based location updates the system defines a threshold distance (say $D = 20$ miles). The users on the other hand compute the distance D_u. Whenever the user distance exceeds the distance threshold (i.e. $D_u \geq D$) it updates its location. The strategy is dynamic in nature as the distance threshold is computed from the system while taking the cells load in consideration. The user computes the distance from its last registration [4, 18]. In timer-based location updates, the threshold is time (say $\tau_m = 30$ minutes). In this scheme user updates its location whenever the user roaming time (τ) crosses the threshold (i.e. $\tau \geq \tau_m$)[9]. In movement-based location updates, the threshold is defined by the number of movement from one cell to another cell (say $M = 5$). User updates its location whenever the movement number (M_u) computed by user exceeds the threshold (i.e. $M \geq M_u$) [2].

In the work done by Bar, Noy, Sidi [2], the comparison between different dynamic location update strategy have given. It has been found that distance-based method performs best among these location update strategy. It is interesting to observe that both update and paging is complementary cost component. The total update cost is proportional to the number of times user updates its location, while the total cost of paging increases with the number of calls received over the certain threshold period. The complementary nature of the two cost component is evident form the fact that the more frequently user updates its location (increasing update cost), the less is paging attempts required to track him/her down. Several strategies have been proposed in literature which attempts to minimize either the total cost of location management, or the individual costs of paging and updates [10, 9, 4].

By looking at these strategies it seems that in location management, the location update is more fundamental than the mobility tracking. In all previous work, the main concentration was on location update schemes. Assuming few obvious probability distribution of user motion for tracking, the works have been done to optimize the total cost of location management or to obtain an optimal threshold. None of these work discusses on the probability distribution of real life user motion. In the present work we are looking at mobility tracking in location management while considering the user motion profile.

2.4 Previous works

Before going to the next section, a brief outline regarding the previous works are necessary. As mentioned earlier the location of a user must be known in advance to deliver the correctly. The wireless system provide free mobility to user so there should be an efficient method to track user in the system.

In the work proposed by A. Bar-Noy in [4] the tracking strategy is simple. System model consists a linear structure of service area (although two types of movement have been considered i.e., i.i.d.(independent and identically distributed) movement and Markovian movement) of ring cellular topology. The movement in i.i.d. model is considered as linear as the user in cell i can move to cell $i-1$ or in cell $i+1$. But in practice there can be more than two neighboring cells to each cell. Assuming that the time is slotted, user can move to cell $i-1$ or $i+1$ with probability p and therefore can stay in cell i with probability $1-2p$ $(0 < p < 1/2)$. In markovian model only three state of transition has taken into consideration viz.

(i) Stationary state (S)
(ii) The right move state (R)
(iii) The left move state (L)

Assuming that user in cell i, the 9 transition probabilities were defined as:

$$p_{R,R} = p_{L,L} = q, \quad p_{L,R} = p_{R,L} = v, \quad p_{S,R} = p_{S,L} = p,$$
$$p_{L,S} = p_{R,S} = 1-q-v, \quad p_{S,S} = 1-2p$$

Using these transition various update scheme for i.i.d. movement and markovian movement have been proposed. The comparison among the various update scheme were also carried out in [4]. In the work done by I. F. Akyildiz in [1], the one dimensional coverage area have been considered. Accordingly the search for user is linear search in two direction from the last known location.

A remarkable work is proposed by C. Rose and R. Yates in [9]. It does not take any assumption on network topology. It assumes that user is at location i with probability p_i and A_n is the location area. The probability of a user residing in location area A_n is then

$$q_n = \sum_{i \in A_n} p_i$$

and the number of location searched in order to track user in location area A_n is then

$$s_n = \sum_{j=1}^{n} k_j$$

Based on these the cost of paging, L, was defined as the number of location to be searched and the average cost of paging was defined as

$$E[L] = \sum_{j=1}^{\infty} s_n.q_n$$

This average cost of paging is minimized under the effect of delay-constraints. The average delay is defined as

$$E[D] = \sum_{n=1}^{\infty} n.q_n$$

In order to minimize $E[L]$, they proposed that the LAs should be paged in decreasing order of there steady state residential probability. Thus an optimization problem was formulated as

$$
\begin{aligned}
&minimize \;\; E[L] \\
&subject\ to \;\; s_n > 0 \\
&\qquad\qquad max_{\{s_n\}} \;\; E[D]
\end{aligned}
$$

Similar paging strategy was adopted by C. Rose in [10]. It proposes a time variant function which minimizes the sequential search of location in decreasing order of probability and the function is defined as

$$F_M(t) = \sum_{l=1}^{\infty} l.p_{q_l,m}(t)$$

where q_l is an ordering functions s.t. $p_{q_l,m} > p_{ql+1,m}$ and is the last known location of the user. Under a timer-based update and following the poisson call arrival, he proposes the cost of paging without registration as

$$C_M(\infty) = P \int_0^{\infty} F_m(\sigma) s_t(\sigma) d\sigma$$

where, P is cost of paging per location, and $s_t(t) = \lambda_p e^{-\lambda_p t}$, call arrival process. The cost paging and registration under the timer τ_m is defined as

$$C_m(\tau_m) = P \int_0^{\tau_m} F_m(\sigma) s_t(\sigma) d\sigma + (1 - S_t(\tau_m))$$

where $S_t(.)$ is cumulative distribution function of $s_t(.)$.

Looking at these works, it seems that location management problem is an optimization problem. In all previous works, the attention was given to cost of location management.

2.5 Mobility Tracking

In all the previous works the attention was given to location update and cost function was formulated as some static optimization problem with some probabilities values as input [10, 9]. Not enough attention was given on the mobility and calling profile of individual user. Since the mobility tracking is system side activity so there is need to consider the mobility pattern and calling profile of individual users. In the previous works, to track down users, a sequential search of decreasing order of steady state probabilities have taken in consideration. But what happen if network fails to track the user in that attempt. The call will drop and there will be increase in the load of paging channel. The more failure will cause more call drops and overloading paging channel. So there should be an efficient way to reduce the call drops and overloading of paging channels.

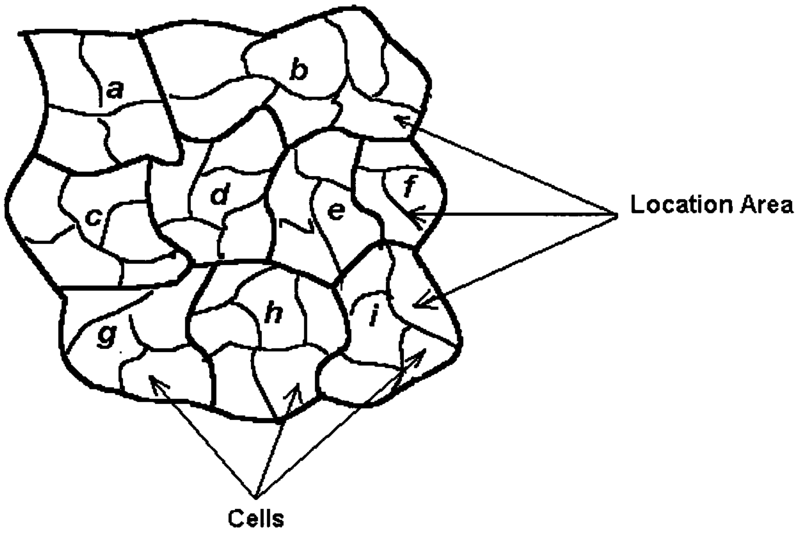
In the following work we are looking at the mobility tracking problem. In this we are taking the every individual users mobility profile. The users profile helps to track him/her whenever there is call for him/her. In our works we are not employing the sequential search while using the mobility profile of user, we are proposing a new tracking strategy. Based on the past user mobility pattern we are constructing the *Transition Probabilty Matrix* (TPM) which is stored in the system database for each user in the service area. Using the TPM the network will follow the search for users in the different location. Within the LA the networks page simultaneously. In the next chapter we are giving the system model and incorporation of the mobility pattern in the system.

Chapter 3

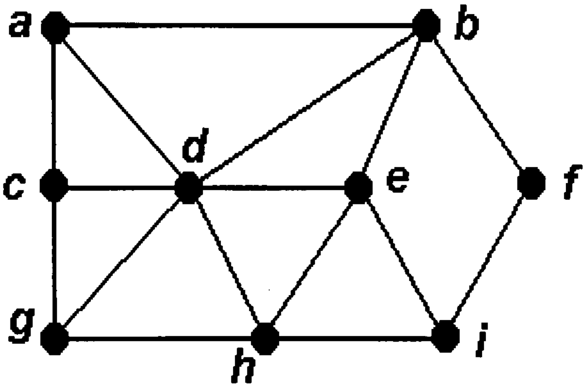
SYSTEM MODEL AND USER MOBILITY

3.1 Network Model

In solving location management problem, existing location management schemes use a structured graph to model the networks. For example, circular ,hexagonal or square ares are used to model the cells, whereas various regular graph topologies such as rings, trees, and one-or two dimensional grids are used to model the interaction between the cells. However, this model does not accurately represent the real cellular networks where the cell shapes can vary depending on the antenna radiation pattern of the base stations, and any cell can have an arbitrary (but bounded) number of neighbor. Although structured graphs help in the early stage of frequency planning, they over simplify the tracking problem [3]. The present system model does not impose any condition on the shape of the cell.



(a) Cell and location area plan in cellular system



(b) Network model showing interconnections of the location area

Figure 3.1 Modelling an actual cellular system

in the present work, we are not making any assumption about either the cellular geometry or the interconnections between the cells. However similar to model described in [6], we assume the existence of a zone or LA-based cellular mobile system. As a result, our network is represented by a bounded-degree, connected graph $G = (V, E)$ where the node-set V represents the

LAs and the edge-set E represents the access paths (roads, highways etc.) between pairs of LAs . Let $N = |V|$ be the numbers of the nodes or LAs in the network G. Figure 3.4 shows the service area with eight LAs, viz. a, b, c, d, e, f, g, h, i and the corresponding graph representation.

The general graph representation is ofcourse not restricted to LA-based cell planning. Some existing systems use paging strategies that work with a finer granularity, and choose the individual cells to be page next. In such cases this model would give rise to a graph with a larger node-set $V = \{a_1, a_2, ..., b_1, b_2, ..., c_1, c_2, ...\}$, where $a_1, a_2, ...$ are cells in LA a and so on. In the present model we are using a more general term *zone*. A *zone* can be an LA or a cell depending on the system.

3.2 Movement History

The present user mobility model utilizes the user movement history. The user profile is stored in the form of matrix. Actually system observes the user movement for the last 12 or 24 hours and generates a sequence of alphabets (i.e. zone's ID). The sequence generated by the system show the path taken by the user in daily routine. Based on this information we construct a Markov-chain which describes the user mobility during the past few hours[3].

Table 1: Zone sequence reported by various update

$Timer - based\ (T = 1hr)$	*aaaddcacccdeeehhdddbb...*
$Movement\ based\ (M = 2)$	*adacadacdbdehdhdbdc...*
$Time\ and\ movement\ based\ (T = 1/2hr,\ M = 1\ \ )$	*aaaaddacccadeeebbbdbedaaccccaad...*

The zone sequence generated by various updates schemes are given in the table 1. This sequence is useful to construct the user mobility pattern. The sequence of zone's id is represented by the letters of alphabets which also represents the different zones in the model. The zone sequence obtained in table 1 can be obtained through simulation. For the numerical illustration and comparison of models we will use the sequence "*aaaaddacccadeeebbbdbedaaccccaad*" in rest of the work.

Definition 1 *The movement history of a user is a string* "$v_1 v_2 v_3 \ldots$ *of symbols from the alphabet* V*, where* V *is the set of zone under the service area and* v_i *denotes the zone-id reported by ith update. Consequently* v_i'*s are not necessarily distinct.*

3.3 User Mobility Model

A simple model based on uniform distribution of vehicle locations is typically characterize user mobility, which neglects directional movements of vehicle or pedestrian traffic[17]. Another model for vehicular traffic is based on fluid flow, which assumes blocks of vehicle moving with equal speed[15]. Since our objective is to develop an optimal location management strategy on a per user basis, we use *random walk model* which very well characterizes the user traffic flow for PCS networks. We propose to use random walk on a connected graph G representing our network.

Definition 2 *The mobility model (random walk model) of a user is a stationary stochastic process* $V = \{V_i\}$*, such that* V_i *assumes the value* $v_i \in V$ *in the event of the* i^{th} *update reporting the user in zone* v_i*. The joint distribution of any subsequence* $V_i s$ *is invariant with respect to shifts in the time axis, i.e.,*

$$\begin{aligned}&Pr[V_1 = v_1, V_2 = v_2, \ldots, V_n = v_n]\\ =&Pr[V_{1+l} = v_1, V_{2+l} = v_2, \ldots, V_{n+l} = v_n]\end{aligned}$$

for every shifts l *and for* $v_i \in V$*. The movement history is a trajectory os simple path of* V*.*

3.3.1 Markov Model

The simplest possible Markov model assumes that the process is a time-invariant Markov chain, defined by

$$\begin{aligned}&Pr[V_k = v_k | V_1 = v_1, \ldots, V_{k-1} = v_{k-1}]\\ &=Pr[V_k = v_k | V_{k-l} = v_{k-1}]\\ &=Pr[V_i = v_i | V_{i-l} = v_{i-1}]\end{aligned}$$

for any arbitrary choice of k and i. This simply state the next state is independent of the previous states. The one-step transition probabilities is defined as:

$$P_{i,j} \;=\; Pr[V_k = v_j | V_{k-l} = v_i]$$

where v_i, $v_j \in V$ this is computed from the relative frequency count in the string which gives the user's routes within the network. The frequency count of a particular user may be defined in form of contingency matrix (each entry $n_{i,j}$is giving the frequency of transition from LA v_i to v_j . Using this we can construct the *Transition Probabilty Matrix* (TPM) and an $N \times N$

contingency matrix characterizing the user motion as:

$$\mathbf{P} = \begin{bmatrix} p_{00} & p_{01} & p_{02} & \cdots \\ p_{10} & p_{11} & p_{12} & \cdots \\ p_{20} & p_{21} & p_{22} & \cdots \\ \vdots & \vdots & \vdots & \ddots \\ p_{N0} & p_{N1} & p_{N2} & \cdots \end{bmatrix}_{N\times N}$$

$$\mathbf{S} = \begin{bmatrix} n_{00} & n_{01} & n_{02} & \cdots \\ n_{10} & n_{11} & n_{12} & \cdots \\ n_{20} & n_{21} & n_{22} & \cdots \\ \vdots & \vdots & \vdots & \ddots \\ p_{N0} & p_{N1} & p_{N2} & \cdots \end{bmatrix}_{N\times N}$$

3.3.2 Learning Markov Chain

In the Markov model user mobility have been characterized by markov chain which is generated by looking at the movement history of a user. The transition probability matrix was constructed on the basis of the relative counts of the symbol in the string of the zone-id. The series of alphabet (zone-id) can be summarized in $s \times s$ contingency table containing the frequencies of transition $n_{i,j}$ $=n(i \longrightarrow j)$. The frequency $n_{i,j}$ are used to estimate the transition probabilities $p_{i,j}$.

However, the observed transition frequencies $n_{i,j}$ may not be the only source of information about the user mobility. We may also have some background knowledge that can be represented in a series of markov chain of length $\alpha + 1$. The α transition are divided in $\alpha_{i,j}$ transition of type $i \longrightarrow j$. This background knowledge gives rise to a $s \times s$ contingency table homologous to the frequency table, containing these hypothetical transition $\alpha_{i,j}$ that we call *Hyper parameter*. By augmenting this hyper parameter $\alpha_{i,j}$ into the transition probability, the transition probability characterizing the user motion is given by

$$\hat{p}_{i,j} = \frac{\alpha_{i,j}+n_{i,j}}{\alpha_i+n_i}$$

using this transition, the probability matrix and contingency matrix for the hyper parameter will be

$$\hat{\mathbf{S}} = \begin{bmatrix} \alpha_{00} & \alpha_{01} & \alpha_{02} & \cdots \\ \alpha_{10} & \alpha_{11} & \alpha_{12} & \cdots \\ \alpha_{20} & \alpha_{21} & \alpha_{22} & \cdots \\ \vdots & \vdots & \vdots & \ddots \\ \alpha_{s0} & \alpha_{s1} & \alpha_{s2} & \cdots \end{bmatrix}_{s \times s}$$

$$\hat{\mathbf{P}} = \begin{bmatrix} p_{00} & p_{01} & p_{02} & \cdots \\ p_{10} & p_{11} & p_{12} & \cdots \\ p_{20} & p_{21} & p_{22} & \cdots \\ \vdots & \vdots & \vdots & \ddots \\ p_{N0} & p_{N1} & p_{N2} & \cdots \end{bmatrix}_{N \times N}$$

where $\alpha_i = \sum_j \alpha_{i,j}$ and $n_i = \sum_j n_{i,j}$. Thus α_i and n_i the number of times variable X visit the state i in the process consisting α and n transitions.

Assuming that there are N LAs in the system and i, the *ith* location area, there exists a unique stationary (or steady-state) probability distribution vector $\mathbf{\Pi} = (\Pi_1, \Pi_2, \ldots, \Pi_N)$ such that $\Pi_i > 0$ for $1 \leq i \leq N$. The steady-state probability Π_i of states i estimates the location probability of a user in LA i. Since the system knows the transition probability matrix $\hat{\mathbf{P}} = [P_{i,j}]_{N \times N}$ of each user characterizing its motion. The steady state location probability vector can be obtained simply by solving $\mathbf{\Pi} = \Pi\mathrm{P}$ for $\mathbf{\Pi}$

The *sojourn time* (in number of slots) of the user in state i is a discrete random variable T_i. It also follows from the Markovian nature of transitions that the sojourn time T_i within LA i is geometric random variable with parameter

$$p_i = \sum_{j=1,j\neq i}^{N} p_{i,j} = 1 - p_{i,i}$$

where p_i is the probability of a transition out of LA i happening within a slot.

3.4 Tracking Strategy

The transition matrix (TPM) is constructed using the relative counts of frequencies of zone's id (system keep in the database during the past few hours) and the hyper parameter α. The system utilizes this TPM to track user within the service area in contrast to earlier scheme which uses the steady-state residential probability in decreasing order of their value and search start in that sequence. Suppose the user is in the area which have very low residential probability then this tracking strategy will increase the cost of paging.

The proposed tracking strategy does not suffer from the increase in the paging cost. When a call comes for a user, the system pages the user in the last known location of user (say m). If user is not found there then system look at the m^th row of the TPM and ordered the probabilities in the decreasing order. Thus we get a vectorial form of probabilities as

$$\mathrm{M} = [p_{m,l_1}, p_{m,l_2}, p_{m,l_3}, \ldots, p_{m,l_N}] \tag{1}$$

and another ordered vectorial form of location areas as

$$\mathrm{A} = [l_1, l_2, l_3, \dots, l_N] \tag{2}$$

The search will begin in the above sequence of LA even if $\Pi_{l_i} < \Pi_{l_j}$ for some $i < j$. The ordering of probabilities in the decreasing order gives the next more probable location from the last known location.

If user is not found at the last known location then at the first step system will page the location area L_1 and in the second step it will page the location area L_2. Let N be the random variable representing the number of steps (i.e number of location area to be searched) in the service area. Since equation (1) representing discrete probability value in decreasing order of value. Therefore without loss of any generality we can rewrite equation (1) as

$$\mathrm{M} = [p_1, p_2, p_3, \dots, p_N] \tag{3}$$

where $p_1 = p_{m,l_1},\ p_{m,l_2},\ \dots p_{m,l_N}$.

As the search has to perform in the above sequence, the location area corresponding to these value can be numbered as

$$\mathrm{A} = [1, 2, 3, \dots, N] \tag{4}$$

where $1 = l_1,\ 2 = l_2,\ \dots,\ N = l_N$

Thus the average number search (i.e. the average number of location area to be searched in order to track the user) cab be defined as

$$E[N] \ = \ \textstyle\sum_{i=1}^{N} i.p_i \tag{5}$$

and the variance in the average search will be

$$\begin{aligned}\sigma &= E[N - E[N]]^2 \\ &= E[N^2] - \{E[N]\}^2\end{aligned}$$

$$\text{i.e.} \quad \sigma = \textstyle\sum_{i=1}^{N} i^2.p_i - [\ \sum_{i=1}^{N} i.p_i\ ]^2 \tag{6}$$

Ordering of probabilities are necessary in order to minimize the $E[N]$ and hence the paging cost. The following **theorem** illustrate that why ordering is necessary to decrease the $E[N]$.

Theorem: *To minimize $E[N]$, the more probable area from the last known location area of the user should be searched before less probable area form the last known location area of user. Formally if i and j are two location area in (4) with $p_i > p_j$, then the location area i must be searched before location area j even if $\Pi_i < \Pi_j$.*

Proof: Let $\{1, 2, 3, \ldots, N\}$ be an optimal sequence with $p_i > p_j$. But index j is appearing before index i in sequence i.e. sequence is $\{1, 2, 3, \ldots, j, i, \ldots, N\}$ optimal and corresponding order of probabilities is $\{p_1, p_2, \ldots, p_j, p_i, \ldots, p_N\}$. Let $\{1, 2, 3, \ldots, i, j, \ldots, N\}$ denotes the modified sequence in which index i and j are swapped. But the probability p_i and p_j are in the same order.The number of search for this new sequence will be

$$E'[N] = \textstyle\sum_{j=1}^{N} j.p_j$$

we claim that this is minimum. Therefore we compute $E[N] - E'[N]$

$$\begin{aligned}&E[N] - E'[N] \\ &= \textstyle\sum_{i=1}^{N} i.p_i - \sum_{j=1}^{N} j.p_j\end{aligned}$$

$$
\begin{aligned}
&= ip_i + jp_j - jp_i - ip_j \\
&= i(p_i - p_j) - j(p_i - p_j) \\
&= (i - j)(p_i - p_j) > 0
\end{aligned}
$$

which is contradiction that $E[n]$ is minimized by sequence $\{1, 2, 3, \ldots, j, i, \ldots, N\}$ with probability $p_i > p_j$. Hence theorem is correct.

Assume that C_j be the cost of paging within the location area j. The cost of paging within an LA will be different for different LA as it depends on the number of cells and cell loads in that location area. The total cost of paging when user is not found in the last known location, then can be defined as

$$C_P = \sum_{j=l}^{N} j.p_j.\Pi_j.C_j$$

where Π_j is the residential probability of user in LA j and C_j is the cost of paging within location area j.

Chapter 4

COMPARISON OF USER MOBILITY MODELS FOR TRACKING

In the previous section we given the system model characterizing the user mobility. In the present chapter, we are measuring the performance of system model by comparing it with existing system model. The comparison is performed quantitative as well as by measuring the entropies of the tracking strategies. Before giving the comparison of models, we are giving few definition related to entropy. We have defined user mobility earlier as a stochastic process $V = \{V_i\}$, where $V_i's$ form a sequence of random variables. We closely follow the definitions given in [3].

Definition: *The **entropy** $H_a(X)$ of a discrete random variable X, with probability mass function $p(x)$, $x \in X$, is defined by $H_a(X) = -\sum_{x \in X} p(x) \log_a p(x)$. We take $0 \log_a 0 = 0$. The base of the logarithm depends on the unit used. As* *we usually measure information in the terms of bits, using* $a = 2$ *we write*

$$H(X) = -\sum_{x \in X} p(x) \log p(x)$$

we observe that $H(X) \geq 0$ as $p(x) \in [0, 1]$,.

Definition: The **joint entropy** $H(X, Y)$ of a pair of discrete random variable X and Y with a joint distribution $p(x, y), x \in X, y \in Y$, is defined by

$$H(X, Y) = -\sum_{x \in X} \sum_{y \in Y} p(x, y) \log p(x, y).$$

Also the **conditional entropy** $H(Y|X)$ is defined as

$$\begin{aligned} H(Y|X) &= \sum_{x \in X} p(x) H(Y|X = x) \\ &= -\sum_{x \in X} p(x) \sum_{y \in Y} p(y|x) \log p(y|x) \\ &= -\sum_{x \in X} \sum_{y \in Y} p(x, y) \log p(y|x) \end{aligned}$$

Definition: The **per symbol entropy rate** $H(V)$ for a stochastic process $V = \{V_i\}$, is defined by

$$H(V) = \lim_{n \to \infty} \frac{1}{n} H(V_1, V_2, ..., V_n)$$

provided the limit in above exists. The conditional entropy rate $H'(V)$ for the same process is defined by

$$H'(V) = \lim_{n \to \infty} H(V_n | V_1, V_2, ..., V_{n-1})$$

provided the limit exists.

4.1 Quantitative Comparison

For the purpose of comparison, we consider the three mobility models based on I.I.D., Markov and Learning Markov models. The quantitative comparison is carried out on the basis of example. In quantitative comparison we take the example of string of alphabets $S =$ "*aaaaddacccadeeebbbdbedaaccccaad*" which is obtain through simulation and characterizing the past movement of user. The simplest model is ignorant model in which the steady state residential probabilities are equal i.e. system assign equal probabilities to each LA as given in figure 3.1 (a) of chapter 3. Hence in this case the residential probabilities will be

$\Pi_a = \Pi_b = \Pi_c = \Pi_d = \Pi_e = ... = \Pi_i = \frac{1}{9}$

4.1.1 I.I.D. Model

The independent identically distributed model assumes that each user mobility is independent of others. Using this relative counts of frequencies symbols in S. We calculate the steady-state residential probabilities as

$$\Pi_a = \frac{\text{No. of occurrence of } a \text{ in } S}{\text{Total no. of alphabets in } S} = \frac{10}{30} \simeq 0.3333$$

Similarly

$$\begin{aligned} \Pi_b &= \tfrac{4}{30} \simeq 0.1333 \\ \Pi_c &= \tfrac{7}{30} \simeq 0.2333 \\ \Pi_d &= \tfrac{5}{30} \simeq 0.1667 \\ \Pi_e &= \tfrac{4}{30} \simeq 0.1333 \\ \text{and } \Pi_f &= \Pi_g = \Pi_h = \Pi_i = 0 \end{aligned}$$

Here zero residential probabilities are showing that the user does not go to any of the location area f, g and i. Now when a call comes for a user, network starts searching user by paging the LAs in decreasing order of probabilities. Thus the page sequence of zone or LAs will be

$$a \longrightarrow c \longrightarrow d \longrightarrow e \longrightarrow b.$$

4.1.2 Markov Model

In markov model different location areas are assumed to form state space corresponding to$\{X_n\}$.

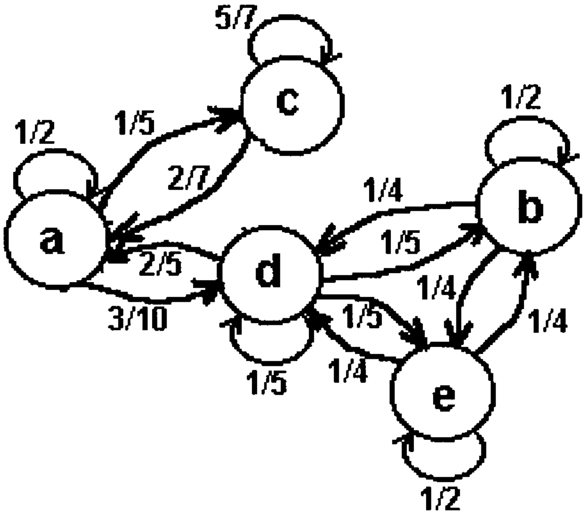


Figure (4.1) State transition diagram of user's movement

To calculate the transition probabilities we construct the contingency matrix for the frequency count of symbol. The contingency matrix for the string S

will be

$$S = \begin{bmatrix} 5 & 0 & 2 & 3 & 0 \\ 0 & 2 & 0 & 1 & 1 \\ 2 & 0 & 5 & 0 & 0 \\ 2 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 2 \end{bmatrix}$$

The transition probabilities are defined as

$p_{ij} = \frac{n_{ij}}{n_i}$, where n_{ij} is the number at i^{th} row and j^{th} column and n_i is the sum of the numbers in i^{th} row.

Hence we get the transition probability matrix as

$$P = \begin{bmatrix} 1/2 & 0 & 1/5 & 3/10 & 0 \\ 0 & 1/2 & 0 & 1/4 & 1/4 \\ 2/7 & 0 & 5/7 & 0 & 0 \\ 2/5 & 1/5 & 0 & 1/5 & 1/5 \\ 0 & 1/4 & 0 & 1/4 & 1/2 \end{bmatrix}$$

Let $\Pi = [\Pi_a, \Pi_b, \Pi_c, \Pi_d, \Pi_e]^T$ be the steady-state transition probabilities of the system. by solving $\Pi = \Pi \times P$ and using the condition $\Pi_a + \Pi_b + \Pi_c + \Pi_d + \Pi_e = 1$, we obtain

$$\begin{aligned} \Pi_a &= \tfrac{24}{83} \simeq 0.2892 \\ \Pi_b &= \tfrac{16}{83} \simeq 0.1927 \\ \Pi_c &= \tfrac{7}{83} \simeq 0.0843 \\ \Pi_d &= \tfrac{20}{83} \simeq 0.2409 \\ \Pi_e &= \tfrac{16}{83} \simeq 0.1927 \end{aligned}$$

4.1.3 Learning Markov-chain model

With the sequence obtained from movement history we have constructed the TPM. In the TPM there are few entries suggesting that no transition occurs in these set of location areas. For example there is no transition between a

and b as the transition probability from $a \longrightarrow b$ is zero. But the graphical model is depicting that b is neighboring location area of a. Therefore, we cannot ignore the possibility of user in that location.

The learning Markov chain uses the same idea as Markov model but it is more informative. As mentioned earlier that the frequency of symbols cannot be the only source of information for constructing TPM which is characterizing user mobility. Using the global precision $\alpha = 5$ and $\alpha_{ij} = 1/5$ in contingency matrix S as hyper-parameter, we construct the learning transition matrix $\hat{P}$ characterizing user's motion. The transition to state i to a state j is given by

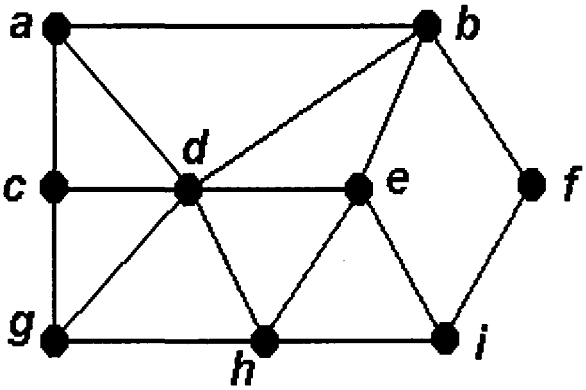


Figure (4.2) Graphical representation of location areas

$$\hat{p}_{ij} = \frac{\alpha_{ij} + n_{ij}}{\alpha_i + n_i}, \alpha_i = \sum_j \alpha_{ij} \text{ and } n_i = \sum_j n_{ij}$$

Using these prior information we construct the transition probability matrix which becomes

$$\hat{P} = \begin{bmatrix} 0.47 & 0.02 & 0.20 & 0.29 & 0.00 \\ 0.04 & 0.44 & 0.00 & 0.24 & 0.24 \\ 0.28 & 0.00 & 0.65 & 0.03 & 0.00 \\ 0.37 & 0.20 & 0.03 & 0.20 & 0.20 \\ 0.00 & 0.24 & 0.00 & 0.24 & 0.44 \end{bmatrix}$$

The zero values indicate that these two location areas are not neighboring LAs. Assuming $\Pi = [\Pi_a, \Pi_b, \Pi_c, \Pi_d, \Pi_e]^T$ is a steady state transition probabilities and solving $\Pi = \Pi \times \hat{P}$ and using $\Pi_a + \Pi_b + \Pi_c + \Pi_d + \Pi_e = 1$, we obtain $\Pi_a = 0.281$, $\Pi_b = 0.188$, $\Pi_c = 0.093$, $\Pi_d = 0.233$, $\Pi_e = 0.205$

Assume that the last known location of a user is LA b. Considering the I.I.D. model, the page sequence will follow the sequence $a \longrightarrow c \longrightarrow d \longrightarrow e \longrightarrow b$. But if we look at TPM P , we shall be knowing that from the location area b the next more probable areas are d and e. Thus, the search sequence will be $b \longrightarrow d \longrightarrow e$. In learning markov chain model the possibility of a user in LA a is not ignored as it is in the neighborhood of b. Therefore, the system pages that location area too.

The search is better in the sense that if user is not in the LA d and e then the search will not be terminated. For the comparison we compute entropy in each case.

4.2 Entropy Measurement

In this section we compare the three models (i.e. I.I.D., Markov, Learning Markov chain model using entropy rate $H(S)$. For comparison we calculate entropy, per location, in each model. Let $Pr[V_1 = v_1, V_2 = v_2, \ldots, V_n =$

$v_n] = p(v_1, v_2, \ldots, v_n) \ \forall \ v_i \in V$. In I.I.D. model V_i's are independent and identically distributed with distribution $p(v) = \Pi_v \ \forall \ v_i \in V$ and therefore

$$p(v_1, v_2, \ldots, v_n) = \Pi_{i=1}^{n} p(v_i) \qquad .$$

and hence the entropy is

$$H_i(V) = \ - \sum_{v \in V} p(v) \log p(v) = \ - \sum_{v \in V} \Pi_v \log \Pi_v \ \simeq \ 2.223 \text{ bit}$$

Let $|N|$ be the cardinality of the system model i.e. the number of location areas corresponding to probability distribution. In I.I.D model there are 5 location areas based on which entropy is calculated, therefore the entropy rate per location $\bar{H}_i(V)$ is

$$\bar{H}_i(V) \ = \ \tfrac{1}{|N|}[H(V)] \ = \ \tfrac{1}{5}[2.223] \ \simeq \ 0.446 \ \mathit{bit}$$

In Markov model entropy rate per location $\bar{H}_m(V)$ can be obtained as

$$\bar{H}_m(V) \ = \ \tfrac{1}{|N|} H(V)$$

In this case $|N|$ = no of non zeros in the matrix P, therefore

$$\begin{aligned} \bar{H}_m(V) \ &= \ \tfrac{1}{15}(\ - \ \textstyle\sum_i \sum_j p_{ij} \log p_{ij} \ ) \\ &= \tfrac{1}{15}[\ 7.2741 \ ] \ \simeq 0.485 \text{ bit} \end{aligned}$$

Similarly the entropy rate per location $\bar{H}_l(V)$ in Learning Markov chain model is

$$\begin{aligned} \bar{H}_l(V) \ &= \ \tfrac{1}{20}(\ - \ \textstyle\sum_i \sum_j p_{ij} \log p_{ij} \ ) \\ &= \tfrac{1}{20}[\ 7.9570 \ ] \ \simeq 0.398 \text{ bit} \end{aligned}$$

From the entropy per location we observe that Learning Markov model has the least uncertainty per location which implies that strategy based on Learning Markov chain model is performing better than I.I.D. and Markov model. Accordingly, Learning Markov model is more informative than Markov model as well as I.I.D. model.

Chapter 5

DISCUSSION AND CONCLUSION

We have discussed the user mobility pattern in location management problem. As opposed to earlier works, we have identified that user mobility does not have a fixed probability distribution. Consequently, there should be some efficient model which characterizes the user mobility. Based on the past movement of a user a Learning Markov chain model has been proposed which describes the user mobility in the service area. We have carried out the comparison between previous model in terms of average search to find the user. The system observes user's movement pattern and store in the database in the form location areas id. Based on these LA ids we construct the TPM which characterizes the user mobility pattern. However, the past movement cannot be the only data to be used in construction of TPM. Therefore, we have considered other data. Including a hypothetical hyper-parameter α in transition probability matrix, we have proposed Learning Markov Chain Model for tracking mobile users in wireless PCS networks.

The extension of this work may include that these transition probability may not be time invariant, but the transition may be time-dependent. For example rush hour congestion. An interesting issue will be to examine location update strategy in time dependent environment which is an area of future work. Another interesting issue may be to obtain average cost of paging and location update in location management problem.

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