CHAPTER 1

INTRODUCTION

1.1 WIRELESS MOBILITY

The basic obligation of a wireless system is to provide scope for maximum mobility (Mobile Terminal (MT)) while the system continues to provide the services at agreed levels of quality. The fundamental requirement for the system to support mobility is that it must be aware of the location where the MT resides at any point of time. Wireless systems require efficient mobility management procedures that would handle issues concerned with terminal's mobility. Mobility management is classified into a pair of complimentary operations namely handoff management and location management. Handoff management takes care of issues involved in maintaining a call-in-progress (in-session), as the MT changes its point of attachment to the network. On the other hand, when a mobile terminal is not engaged in a communication context (out-of-session), location management facilitates terminal's location information assimilation. This information is essential to route calls to the mobile terminal as it moves within and across networks.

Mobility prediction has been proposed in many areas of wireless cellular networks, as a means of enhancing the performance of the mobility management system. Mobility prediction can be defined as the prediction of a mobile user’s next movement, where the mobile user is traveling between the cells of a Global System for Mobile Communications (GSM) or Universal
Mobile Telecommunications System (UMTS) network. The predicted movement can then be used to increase the efficiency of the mobility management system. By using the predicted movement, the system can achieve improved resource allocation and reservations, better assignment of cells to location areas, more efficient paging, and call admission control. With the evolution of the cellular systems, mobility management is set to become an ever more difficult task as the volume of calls grows and the granularity of the network becomes smaller and smaller. Even though “mobility” is the common factor that influences both handoff management and location management tasks, works reported in the literature have dealt them separately. Yu et al (2005) proposed a framework for combining Quality of Service (QoS) provisioning and location management in wireless networks and have claimed performance enhancements. In future wireless networks, a unified framework for mobility management would be critical and beneficial. There has been a considerable amount of research on prediction schemes as applicable to handoff management (resource reservation, QoS etc). The focus of the thesis is on the intricacies of mobility prediction and its usage in location management and trajectory prediction.

1.2 MOBILITY PREDICTION IN WIRELESS NETWORKS

The fundamental requirement for the system to support mobility is that it must be aware of the location where the MT resides at any point in time. Mobility prediction is a dynamic strategy in which the system proactively estimates the MT’s location based on a user movement model. The importance of mobility prediction techniques can be seen at both the network and service levels. At the network level, there are several management tasks that are deeply influenced by the user’s mobility. These tasks include handoff management, flow control, resource allocation, congestion control, call admission control and quality of service (QoS)
provisioning. At the application level, the importance of mobility prediction techniques stems from the Mobile Location Services (MLS) which provide the users with enhanced wireless service based on a combination of their profile and their current or predicted location. Ability to determine the mobile’s future locations and access points as it moves inside the network while being connected can result in significant improvement in system efficiency and connection quality.

One way for the system to know the future position of the MT is to have a formal mechanism in place that allows the MT to indicate to the system, the MT’s intended destination and the duration of the connection. The system can combine this information with its knowledge of the geography of the terrain, and the location of the base stations within the terrain, to determine the path of the MT. Existing techniques for mobility prediction can be classified into two main categories. First category of techniques uses historical movement patterns pertinent to the users in order, to calculate their possible future locations (Quintero 2005), whilst the second category is based on contextual knowledge (Samaan and Kormouch 2005). Contextual knowledge based techniques uses environment and user contextual information such as real-world maps, user profile and preferences to predict the current and future expected locations of the MT. The availability of information to make realistic predictions, personal information and preferences in particular, could pose serious hiccups. The information required is huge and keeping information up to date is a difficult task. When the number of equivalent alternatives for a particular activity increases the error rate increases or the system would require more information sources to make accurate predictions.

Pattern based techniques exploit the basic fact that often moving objects have some degree of regularity in their motion. Regular pattern based
prediction techniques create user mobility patterns using time sequence in which the locations are visited over a period of time called the training phase. Based on the mobility pattern, users current and future expected locations are predicted. Even though the theoretical assumptions which form the basis for pattern based schemes are true to a large extent the pattern period and periodicity varies from one MT to another. In regular pattern based techniques no basic classification is made between MTs mobility behavior and a uniform rule is applied. Locations visited are included in the profile without considering the possible reasons for the visit and hence could be misleading. Further a restriction on the size of user’s history might cause loss of information. Unwinding history is a slow process, which has a negative impact on accuracy.

1.3 PERFORMANCE OF MOBILITY PREDICTION SYSTEMS

The real time performance of a prediction system depends on the following factors

- The mobility model assumed for the mobile nodes
- The network model
- Mobility characteristics of the user whose trajectories are to be predicted

1.3.1 Mobility model

The goal of the mobility model is to simulate the daily movement of cellular subscribers over a period of several days, in terms of cells crossed and time spent in each cell. Some of the popular cellular mobility models are
1. The Random walk model
2. Fluid flow mobility model
3. Trace based models

1.3.1.1 The Random walk model

The Random Walk Mobility Model is one of the most widely used mobility models because it describes individual movements relative to cells (Zonoozi and Dassanayake 1997). In this model, a node stays in a cell or moves to a neighbouring cell according to some given transition probabilities. These probabilities are often adjusted to practical observations of client behavior in cells. Since this model is memory-less, there is no such concept as a path or consecutive movement. Therefore, nodes stay in a vicinity of the starting cell for a rather long time.

1.3.1.2 Fluid flow mobility model

In this model the individual nodes are modeled on a macroscopic level. The behavior of the generated traffic is similar to a fluid flowing through a pipe. As a result, the Fluid-Flow Mobility Model represents traffic on highways very well for cellular networks (Kumar et al 2000). Fluid-Flow Mobility Model is insufficient for describing individual movements including stopping and starting.

1.3.1.3 Trace based models

Cellular phone companies have large records of mobility patterns of their users. These traces are a valuable source for the evaluation and
improvement of mobility management protocols (Capka and Boutaba 2005). The only drawback is that usually such data are not publicly available.

1.3.2 Cell Residence time

A very important parameter in modeling user mobility is the Cell Residence Time (CRT). In cellular wireless networks, the cell is the most atomic unit in the network topology. CRT is the period that a mobile device maintains a connection with a cell before moving into the control area of another cell. In a cellular network, the distribution of the cell residence time depends on many factors such as cell shape, cell radius, user mobility and the paths a user follows (Khan and Zeghlache 1997). In studies CRT is assumed to follow an exponential, uniform or a Gamma distribution. Due to the unavailability of real time data because of commercial and privacy related issues, statistical work to reveal insights into the nature of this parameter has not been carried out.

1.3.3 Network model

The network model describes the size and shape of the cell and deployment of the cellular network infrastructure. Local propagation conditions, traffic demand and physical layer issues determine the layout of a cell. One and two dimensional layout models are available in the literature. Mobility prediction studies use a simplified network model with uniform and regularly shaped cells or matrix of rectangular grids for performance evaluation (Jobin et al 2004). In reality the cells are irregular in shape and size. Simplification of the network model leads to a coarse mobility model, and has a significant bearing on the accuracy of the predictions made in real time.
1.3.4 User mobility Characteristics

Mobility characteristics of a user depict how widely a mobile terminal moves in the network. The objective here is to capture the trend for a mobile terminal to visit different locations and the time spent in each of the locations and other mobility parameters. In reality there exists a large difference in mobility behavior, from one user to another. Understanding user mobility is critical for planning network management tasks. A better understanding of mobility will help to make realistic simulation of mobile devices in a wireless network feasible. Based on mobility the users can be classified into high, average and low mobility classes. Classification breaks down users into groups that have common characteristics and thus might be modeled similarly. Since it is difficult and unrealistic to describe diverse user mobility behavior with a single model, classification of users is crucial. Currently, commonly used mobility models are simplistic, random independent and identically distributed models which do not reflect realistic mobility characteristics (Hsu et al 2007).

1.4 EVOLUTION OF LOCATION MANAGEMENT IN WIRELESS SYSTEMS

From being a predominantly voice based system (low data rate) in the 2\textsuperscript{nd} generation, digital cellular networks have evolved to support high speed data services from the 3\textsuperscript{rd} generation and beyond. Apart from the terrestrial wide area cellular systems, there are number of other wireless systems such as the global area satellite systems, Wireless Local Area Networks (WLAN), and Personal Area Networks (PAN). In future wireless networks, all these systems would co-exist and the users would demand high end multimedia services over these systems anytime and anywhere. As the
systems mentioned above are optimized for different ranges, there is a scope for co-operation amongst these systems in a complementary way.

In cellular wireless networks, the cell is the most atomic unit in the network topology and each cell is served by a base station (BS). The base stations are connected to a Mobile Switching Center (MSC). The MSC manages connection resources and provides mobility management support. The cellular system uses a two level database hierarchy formed by the Home Location Register (HLR) and Visitor Location Register (VLR) to gather and maintain location information. HLR is a Public Land Mobile Network (PLMN) wide database. Every MT authorized to use the services of PLMN has to be registered with the HLR. The records in the HLR database have a permanent part and a transient part. The permanent part maintains information such as the Mobile's Identification Number (MIN), subscription details, the quality of service requirements etc. and the transient part maintains information about the current location of the MT. Generally a VLR is associated with a MSC and it holds replications of users profile and the temporary identification number for the mobile terminals visiting the area controlled by the MSC. The cells in a PLMN are grouped into logical control areas referred as Location Areas (LA).

Location management process uses two operations, location update & paging, in unearthing the attachment point of a MT. Using the update operation (location registration) the mobile terminal keeps the network informed about changes in its point of attachment (associated with mobility), to enable the network to maintain its profile. If the information needs to be delivered to a MT, the network initiates a paging operation to discover the MT's current point of attachment, if the information available with the databases is not up-to-date. There is always a tradeoff between paging and location update operation (Akyildiz et al. 1996). The registration process
consumes MT's battery power, wireless bandwidth and other system resources. The call delivery process too consumes a significant amount of system resources. The total cost of a location management is the sum of the location update cost and the paging cost. Location management schemes strive to reduce the signaling load, cost and delay associated with the location management operations. Location management schemes can be classified as static or dynamic. A scheme is said to be static if the location update operation is performed at predetermined positions irrespective of the mobility of the terminal whereas in a dynamic scheme location update is performed based on the mobility of the terminal. The wireless cellular system is the most widely deployed mobile infrastructure and it is anticipated in the near future, various wireless applications will be mainly based on cellular networks which already have a good coverage (Fan and Zhang 2004).

1.4.1 Location management in 2G

Interim standard (IS-41) and GSM are two popular technologies in the 2nd generation of digital cellular evolution. The location management infrastructure in 2G is deployed as shown in Figure 1.1.

1.4.1.1 IS-41 and GSM basic HLR/VLR scheme

Under this scheme the permanent records of all the mobile terminals, authorized to use the services of the network is always available with HLR database. When a MT enters an area controlled by a MSC different from it’s serving MSC, the HLR is informed. The HLR sends a copy of the mobile terminal's profile to the VLR associated with the new MSC and a registration cancellation message to the old VLR. When a call is placed to a MT, the signaling network checks with the HLR to know the current VLR servicing the MT and a routing request is sent to the VLR. A connection
between the caller and the callee is setup using SS7 signaling network. A more detailed account of location update and call delivery procedures in 2G is available in Chen and Gu (2003).

![Figure 1.1 IS-41 Location management infrastructure](image)

**Figure 1.1 IS-41 Location management infrastructure**

### 1.4.2 Location management in 2.5 G

The popular 2.5 G cellular technologies are High Speed Circuit Switched Data (HSCSD), Enhanced Data Rate for Global Evolution (EDGE) and General Packet Radio Services (GPRS). GPRS is an enhancement over the GSM by adding some nodes into the network to provide the packet switched services. It provides higher data speeds and better spectrum efficiency. GPRPS provides the means to migrate towards 3G. Two new nodes, a serving GPRS support node (SGSN) and a Gateway GPRS support node (GGSN) are added to the GSM network to enable GPRS services. SGSN can be viewed as a packet switched MSC. GGSN acts as an interface to external IP networks. An illustration of the GPRS location management infrastructure is provided in Figure 1.2. Three different states exist in GPRS location management and different location information is available in each state. A Mobile station (MS) could be in READY, IDLE or in STANDBY state. A cell is the basic coverage area serviced by a Base Station (BS). Cells are
grouped into Location Areas (LA) and Routing Areas (RA) and a RA is a subset of a LA.

![GPRS Location management infrastructure](image)

**Figure 1.2 GPRS Location management infrastructure**

### 1.4.2.1 Location update & paging procedure in GPRS

Location update is done when the MS crosses a LA or RA boundary. When in READY state location update is done at cell crossings. In the STANDBY state, MS updates the location only when the MS moves to a new RA. When a MS moves to a new RA, it sends a routing_area_update request to the SGSN. Two different scenarios are possible. Intra-SGSN and Inter-SGSN routing area update. When the MS moves into a RA, assigned to the same SGSN as the old RA an Intra-SGSN update is performed, where other network elements need not be informed. When the MS moves to a RA assigned to a different SGSN the new SGSN may not be aware of the user profile of the MS and hence the SGSN contacts the old SGSN and obtains the necessary information and keeps the GGSN and HLR informed about the change. When in the Standby state, the network does not know the exact location of the MS and to provide a downlink transfer to the MS, paging is
done in the RA where the MS have last reported. Paging procedure causes the MS to move to the Ready state (Pal and Khati 2001).

1.4.3 Location management in 3G

The 3rd generation of cellular wireless technologies has paved the way for high speed access to internet from mobile handheld devices. UMTS is a very popular 3G cellular standard.

1.4.3.1 UMTS location management architecture

UMTS network architecture is divided into hierarchical boundaries to facilitate efficient location management. The UMTS location management infrastructure is given in Figure 1.3. It is divided into CS domain which handles voice calls and PS domain which handles data sessions. The basic building block is the cell identified by cell global identifier (CGI). Cells are grouped into location area (LA) for CS domain and routing area (RA) for PS domain, which is generally a subset of a LA. The RA is further partitioned into UTRAN registration areas (URA). The exact location of a User Equipment (UE) is known by the CGI of the cell where the UE is present. The current location of the UE is maintained and tracked by network elements in the Access Network (AN) and Core Network (CN). The HLR is common and the permanent store for all the information, including the location information about the subscriber. The HLR stores the MSC and the VLR in which the CS domain subscriber has registered and the SGSN where the PS domain subscriber has registered. The MSC/VLR and SGSN in turn store the current LA and RA respectively. At any instance the UE could be in detached, Idle or Connected state. For the UE in connected state the UMTS Terrestrial Radio Access Network (UTRAN) maintains the information about the current URA and cell in which the UE is available. When a call arrives and the mobile
station is in the idle state, the location information is not available at the cell level granularity as in the connected state. Hence paging is done in the LA/RA where the UE has last registered. In the connected state UE is required to carry out cell update on each cell change and URA update on each URA change. While in the ideal state the location information is available only at the LA/RA level maintained by the core network. Here the access network just relays the messages from UE to the core network. Different network elements are involved in maintaining the location information for CS and PS domain. The MSC/VLR and HLR forms a database hierarchy for the CS domain and the SGSN and HLR for PS domain.

1.4.4 Location management beyond 3G

Currently various wireless technologies and networks exist that cater to the multifarious needs of mobile users. Applications that demand high-data-rate can be supported by wireless LAN networks. Wide area

![Figure 1.3 UMTS location management infrastructure](image)
coverage can be by provided terrestrial networks and global coverage can be made feasible by satellite networks. These systems put together could provide a global infrastructure that could allow users to remain connected through the technology of their choice to meet their specific needs. Location management in a heterogeneous environment like the one envisaged would be a difficult task. The technology heterogeneities require a common infrastructure to interconnect the systems. Location management systems have to address issues like reduction of signaling overheads and service latency when intersystem roaming is attempted. The heterogeneous networks could be partially overlapping or completely overlapping networks. Link layer based and network layer based solutions are proposed for interoperation of different networks.

1.4.4.1 Link layer solutions

The link layer solutions address the critical issues of interoperation of different access networks and mobile application part by introducing additional entities and signaling information. The additional entities do not replace the existing systems, but modifications are required. In the case of partially overlapping networks, internetworking units like a Gateway Location Register (GLR) or a Boundary Location Register (BLR) is used. The GLR serves to convert the signaling and data formats from one form to other. The main drawback of GLR protocol is that it does not support ongoing call connection during intersystem roaming. To overcome the problem, in GLR protocol the concept of boundary location area (BLA) is used. The BLA is controlled by a boundary internetworking unit (BIU) that is connected to the MSCs of adjacent systems. Ongoing calls could be maintained in this scheme. The associated MAP protocol based on BLA/BLR is described in Wang W and Akyildiz (2001). In the case of completely overlapping networks, the MT is reachable via multiple networks. The location management infrastructure of
a wireless overlay network is shown in Figure 1.4. The objective is to integrate all the systems in various tiers to exploit their advantages. Since heterogeneous systems use different formats, it’s difficult to integrate all their HLRs into a single HLR. A tier manager based multitier HLR approach that connects all the HLRs is proposed in Lin and Chlamtac (1996).

**Figure 1.4  Location management infrastructure for wireless overlay networks**

Single or multiple registrations can be made by the MT. If only a single registration is made, the MT always registers and uses the services of the lowest tier available. On the other hand a MT could have multiple registrations with various tiers at the same time. The tier manager keeps track of the currently visited lower and higher tier VLRs. Registration traffic is minimized as the number of tier switching are minimized but call delivery is delayed.
1.4.4.2 Network layer solutions

Next generation wireless systems are envisioned to have an all IP-infrastructure to manage mobility. Some of the proposed network layer solutions are based on Mobile IP (MIP), an Internet Engineering Task Force (IETF) standard communications protocol that is designed to allow mobile device users to move from one network to another while maintaining a permanent IP address. In the basic Mobile IP protocol, IP packets destined to a mobile node that is outside its home network are routed through the home agent. However packets from the mobile node to the correspondent nodes are routed directly. This is known as triangle routing. This method may be inefficient in many cases. The drawbacks in the basic MIP, like triangular routing and packet loss that occurs when mobile node moves between subnets are addressed by route optimization (Wu et al 2002). In spite of various improvisations done to the basic MIP protocol it is not suitable for highly mobile terminals. A set of micro mobility protocols like Hierarchical IP, Cellular IP and Hawaii have been proposed to support highly mobile users within a same domain. All these schemes localize signaling traffic into one domain to reduce global signaling. Micro mobility is handled through tunnel based or routing based micro mobility schemes. Hierarchical IP uses a tunneling scheme that is scalable by introducing hierarchies, but could lead to additional costs and delays. Routing based schemes avoids the tunneling overhead, but has to incur heavy cost in propagating host specific routes in all routers within a domain and could also be single point failure. A comparative study of all micro mobility protocols is available in (Campbell et al 2002).

1.5 RELATED WORKS IN LITERATURE

Mobility modeling, user mobility characterization & classification, mobility prediction, and location management are the topics under which related works are available in literature.
Mobility models play a vital role in examining the performances of handoff management, resource allocation and location management systems. Different models based on individual and aggregate mobility behavior have been used to evaluate system performances. Synthetic modeling and trace modeling are the two methods of modeling the mobility of a single user or a group of users. Synthetic models artificially define the movement of mobile entities. Trace models are created by monitoring real life users in the wireless environment. They provide accurate network specific information on the mobility of user. Compositions on mobility modeling available in the literature depict the mobility of terminals in-session. These works demonstrate the mobility behavior of a user, as and when they are using the services of the network and they do not present a holistic view on how wide and far a user moves over a period of time. Such a study is possible only if real-time mobility traces are available.

Tabbane (1995) suggests that the mobile’s location may be determined based on its quasi deterministic mobility behavior represented as a set of movement patterns stored in a user profile. This method is further pursued by Liu and Maguire Jr (1995) in which a user’s mobility behavior is modeled as repetitions of some elementary movement patterns. The main drawback of these proposals is that they assume the existence of patterns in user movements and are very sensitive to random movements.

Liu et al (1998) suggest a pseudo stochastic movement model that integrates deterministic behavior with randomness in an attempt to mimic actual human behavior. The model is built as a two-level hierarchy in which the top level is the global mobility model (GMM) whose resolution is in terms of cells crossed by the mobile during the lifetime of the connection, and the bottom level is the local mobility model (LMM), whose resolution is in terms of a 3-tuple sample space (speed, direction, position) that varies with time.
The complete model is based on the assumption that the directional movements of the mobiles are not ad hoc.

Synthetic mobility models are generally non-realistic as they are based on assumptions. Mobility models assume straight line movements or constant speed which is not true. In general, works based on real time mobility traces are found to be more realistic, than those based on synthetic mobility models, in evaluating system performances (Wong and Leung 2000).

Mobility models based on real time traces are not available in the literature. The main reason for the same is the in-accessibility to real time cellular traces. Mobility modeling using real-time data are attempted in micro-cellular (WLAN) wireless network (Kim et al 2006).

To extract a mobility model from real time traces, first we need to understand the mobility characteristics from the traces of mobile users. Critical mobility parameter that characterizes the behavior of a user needs to be identified and extracted. Several works on characterizing mobility in microcellular wireless networks are reported in literature (Balazinska and Castro 2005; Thajchayapong and Peha 2006). There are a very few works available in literature that has attempted to characterize mobility in cellular networks. Emir Halepovic et al (2005) have attempted a characterization of user mobility and call activity using a weeklong trace obtained from a CDMA2000 network. This work has not clearly identified the parameters that determine the mobility behavior of the user and there is a clear need for such a work to be carried out.

Mobility prediction algorithms spell ways to predict as to where a user is likely to move based on mobility patterns, mobility models or other parameters. Mobility prediction schemes for QoS provisioning and bandwidth
reservation are widely available in the literature (Jayasuriya and Asenstorfer 2002; Shenbagaraman et al 2003). Aljadhai and Znati (2001) have proposed a scheme that integrates the mobility model into the service model, to achieve efficient network resource utilization and avoid severe network congestion. The mobility model uses a probabilistic approach to determine the most likely cluster to be visited by the mobile unit. Soh and Kim (2006) assume the availability of digital road maps and accurate device positioning capabilities to propose a prediction based scheme to reduce handoff dropping probability both for incoming and outgoing calls.

Akyildiz and Wang (2004) have proposed a user mobility profile framework for mobility management and enhancement of QoS in multimedia networks. The mobility model for the proposed scheme uses Gamma distribution for cell residence time for computational flexibility. Further the study assumes higher probability for movement along the MT’s current direction and considers uniform velocity increments. The assumptions on movement direction and velocity are unrealistic.

Chakraborty et al (2006) have proposed a movement prediction algorithm for reducing energy consumption in wireless communication. The scheme uses a variant of the random waypoint mobility model and a simplified network model (hexagonal, uniformly placed and equally sized cells) for performance evaluation. In real world cells are irregular in size and shape and user mobility is not random and hence the results may not hold true in actual networks.

Quintero (2005) has proposed a user pattern learning strategy for reducing the cost of location updates and call delivery in UMTS networks. Artificial neural networks are used to learn relationships in complex data set and to create and maintain user profiles. For performance evaluation, the MTs
are assumed to move with same velocity and to have a uniformly distributed movement direction.

To sum up mobility prediction algorithms proposed in the literature are based on several assumptions regarding speed, direction of movement, network models and infrastructure deployment etc and are validated only using synthetic user data. There is an apparent need for studies on development of mobility models and prediction techniques based on real time data.

Location management is one of the topics that has been extensively studied and reported in literature. A location update scheme can be classified as either static or dynamic. A location update scheme is static, if there is a predetermined set of cells at which location updates must be generated, by a mobile station regardless of its mobility. A scheme is dynamic if a location update can be generated by a mobile station in any cell depending on its mobility. Examples of dynamic schemes include Time-based, Movement based and Distance based schemes (Chakraborty et al 2002; Ma and Fang 2002; Senzaki et al 2004; Fan and Zhang 2004). Pattern learning strategies have been used for reducing location management costs in cellular networks (Quintero 2005). Distance based location management schemes and schemes that make use of user profile are found to produce good results when it comes to location management costs and signaling load (Kyamakya and Jobmann 2005). With the implementation of an innovative technique in CDMA 1X EV-DO (Evolution-Data Optimized) distance based LM schemes can be easily implemented.

This thesis proposes a dynamic distance location management strategy that exploits the predictable components of user’s movements to minimize location management costs.
1.6 RESEARCH MOTIVATION AND CONTRIBUTIONS OF THE THESIS

With the advent of pervasive computing and proliferation of handheld communication devices, more and more applications have started to go mobile. Predicting the user’s future location is often the key to developing smart pervasive devices. Predictive mobility tracking is also very important from the network infrastructure point of view (Sajal K Das et al 2003). All these are pushing the need for a realistic mobility prediction schemes to meet the demands of future wireless networks.

Works reported in the literature are found to have the following deficiencies:

- Some of the works have assumed the existence of prior known pattern with some regularity. No attempt has been made to identify the existence of such patterns due to unavailability of real-time mobility traces.

- Synthetic mobility models are inept at realistically modeling the mobility behavior of users. Assumptions regarding position, speed, direction of movement and the simplified network model over which their performances are evaluated make them very coarse and inapplicable in real-time environment.

- Prediction algorithms will not work the same way for all the users due to their heterogeneous mobility characteristics. Per-user schemes proposed in the literature are found to be complex and a group-based approach would be more practical. Parameters that could be used to quantify the
mobility behavior of a user and further to classify the users into homogeneous groups have not been clearly identified.

- One very important parameter in user mobility modeling is the cell residence time. Estimation of CRT using real-time mobility data has not been done. Statistical work can reveal insights into the nature of this parameter.

- Long-term mobility behaviors of users have not been studied. An understanding that could help to identify patterns, if any, which could be exploited by prediction algorithms.

- In Regular pattern based prediction techniques locations visited are included in the profile without considering the possible reasons for the visit and hence temporary changes in mobility pattern could mislead predictions. Further a restriction on the size of user’s history might cause loss of information. Unwinding history is a slow process which has a negative impact on accuracy.

Aiming to overcome the above deficiencies, this thesis has made the following contributions.

- Due to the difficulties in obtaining real time data mobility data, works reported in the literature have used synthetic models to define and validate proposals. Synthetic models are complex, computationally heavy and lack realism. This thesis uses real time trace data to characterize user mobility behavior. A study of the long term mobility behavior is made and the critical parameters that portray the mobility characteristics are identified.
• Estimation of cell residence time, a critical parameter in mobility modeling is made. Using empirical observations this thesis proposes a more realistic alternative for out-of-session CRT distribution.

• This thesis proposes a methodology for classifying users with heterogeneous mobility characteristics into homogeneous groups, based on mobility and predictability metrics. Users are first classified into three groups based on their mobility behavior (low, average, high) using the K-Means clustering algorithm. A further classification based on predictability of their mobility behavior is made using discriminant analysis.

• Based on the analysis of user behavior, a method to extract pragmatic mobility information from raw cell association data are devised. Using the pragmatic mobility data user profile is created. A dynamic distance based location management algorithm that uses profile to reduce location management costs is proposed and its performance is studied using real time traces. The proposed scheme helps to reduce the location management cost for users with fairly regular mobility behavior.

• An activity based mobility prediction framework is proposed in this thesis. User’s location activity behavior is modeled as a Markov chain and activity transition matrices are obtained; based on which the future user locations and trajectories are predicted. Activity transition is modeled as a semi-Markov process. This model can be used in future studies to make prediction of user locations at any particular instance of time.
1.7 ORGANIZATION OF THE THESIS

The rest of the thesis is organized as follows,

Chapter 2 opens with an account of the trace data used in this study followed by topics on the estimation of cell residence time for raw data, extraction of pragmatic mobility data and estimation of out-of-session CRT of pragmatic data. Chapter 3 deals with user classification and characterization. An analysis of individual user behavior is presented. A method to classify users into homogeneous groups based on mobility and predictability is proposed in this chapter. Chapter 4 describes the proposed dynamic distance based location update and paging strategy and presents the results obtained using real time traces. Chapter 5 explains the activity based mobility prediction strategy. The trajectory prediction results are presented. The chapter concludes with description of the semi-Markov model for activity transition, which can be, used in future studies.

The thesis concludes chapter 6 with the summary of work done and the scope for future work.