MOBILITY AND MOBILITY MANAGEMENT: A CONCEPTUAL FRAMEWORK

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ABSTRACT

The tremendous demands from social market are pushing the development of mobile communications faster than ever before, leading to plenty of new techniques emerging. Within those techniques, mobility management has widely been recognized as one of the most important problems for a seamless access to wireless networks and services. This paper proposes a conceptual framework for mobility and mobility management, with the emphasis on the key research issues involved in the effort of a graceful design of mobility management schemes. The effects of mobility on both architectures and protocols of networks and communications are presented. Diversity of the future mobile communication systems introduces new challenges, which lead to the definitions of mobility on various levels according to different granularities. Mobility management is defined as two complementary operations, i.e. location management and handoff management. The paper also describes the mobility management issues at the network layer. The processing stages of the two operations are introduced respectively, together with the analyses of key research issues and possible solutions. Finally, the issues about the performance evaluation of mobility management schemes are discussed.

1. INTRODUCTION

Various mobile devices, wider transmission bandwidth, manifold wireless and wired networks, and more powerful appliances' processing capability, together with advances in computing technology have brought more and more miscellaneous services to be delivered with more excellent quality. The mobile personal telecommunications and wireless computer networks are converging in the coming new generation of mobile communications. At present, 3G mobile communication systems are just beginning to be deployed, while research on the fourth-generation (4G) wireless networks has begun to pave the way for the future. In the near future, more and more Internet services can be smoothly accessed with various mobile devices through the wide deployed wireless networks. Next generation mobile systems need the support of all the advances on new theories, algorithms, architectures, standards, and protocols.

Mobility management has widely been recognized as one of the most important and challenging problems for a seamless access to wireless networks and mobile services. It is the fundamental technology used to automatically support mobile terminals enjoying their services while simultaneously roaming freely without the disruption of communications. Two main aspects need to be considered in mobility management, i.e. location management (e.g. addressing, location registration and update, tracking and paging, etc.) and handoff management (e.g. handoff trigger and initiation, connection routing, smoothing, etc.). Future mobile communication systems evolve with the trend of global connectivity through the internetworking and interoperability of heterogeneous wireless networks. Roaming in such network architectures is a very complex situation and it causes many new problems. The requirement of smooth and adaptive delivery of real-time and multimedia applications makes the design of mobility management scheme more severe a challenge that needs to be carefully and perfectly solved with more intensive efforts.

The goal of this paper is to study the basic concepts of mobility and mobility management, with the emphasis on the key research issues involved in the effort of a graceful design of mobility management schemes. An academic analysis of the effects of mobility on networks architectures and protocols is presented. Diversity is the key feature of the future mobile systems, which lead to the definitions of mobility of various granularities. Mobility management is defined as two complementary operations: location management and handoff management. The importance of network layer on the design of mobility management strategies is presented. The processing stages of the two operations are introduced, along with the discussions of key research issues and possible solutions. The performance evaluation of mobility management schemes is then discussed.

This paper is organized as follows. Section 2 provides an analysis of the impacts of mobility to both the architectures and the protocols of networks, followed by the diversity of mobile systems as the main feature of the future mobile communications, and various mobility according to different granularities. Section 3 defines two main operations of mobility management, and describes the mobility management issues at the network layer. Section 4 deeply discusses the two operations of mobility management, including location management and handoff management, in which the formal processing procedures are introduced and key research issues and promising solutions are proposed. Section 5 analyses some important issues involved in the performance evaluation of mobility management schemes. Finally, Section 6 concludes the paper.

2. MOBILITY FOR COMMUNICATIONS

2.1 Mobility effects on networks

Mobility affects mobile communications on all the components, including devices, networks, and services. To a mobile device, there are some requirements suitable to mobility scenario, e.g. weight, size, power, display, shape, user interface, etc. To a mobile service, the most important requirement is adaptation. A mobile service should be adaptive to different transmission links, different user mobile devices, and different using contexts.

Different mobility modes can be distinguished, resulting in different network architectures. The mobility modes can be

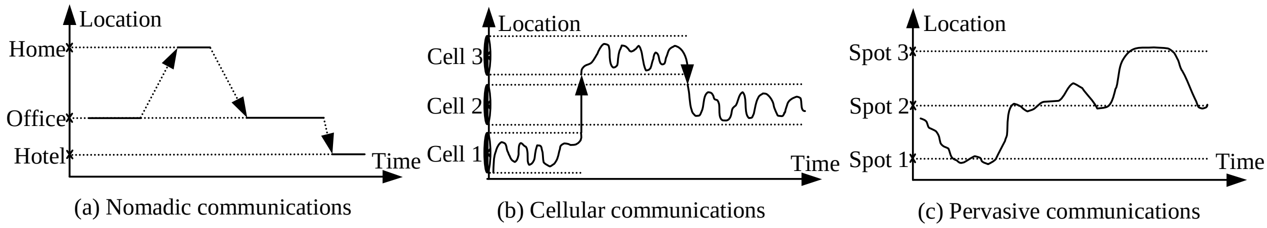

Fig. 1. Communications of three mobility modes

divided into three main classes according to the different spatial-temporal continuity, as curves illustrated in Fig. 1, including:

- *Nomadic or portable communications*, see Fig. 1(a), in which no network connection is needed during the movement. A new connection will be re-established only after the mobile node has arrived at its new location. Nomadic communications are not necessarily based on wireless networks.
- *Cellular communications*, see Fig. 1(b), in which the wireless network is organized as a cellular structure. Each cell encompasses a certain distance. Continuous connectivity should be provided when an on-served mobile node is moving from one cell into another (maybe either neighbouring or overlapping cell).
- *Pervasive communications*, see Fig. 1(c), in which the communications between mobile nodes are ubiquitous and invisible. The scenario is based on a dynamic on-the-fly set-up without using any pre-existing network infrastructure, known as mobile ad hoc networking.

The feature of mobility also affects the whole protocol stack.

- *At the physical layer*, mobility influences are remarkable since most mobile communications are based on wireless media. Resource reuse and interference avoidance are two important problems.
- *At the data link layer*, mobility based on wireless networks brings problems of bandwidth, security, and reliability. Other problems include fixed or dynamic channel allocation algorithms, collision detection and avoidance measures, QoS resource management, etc.
- *At the network layer*, mobility of mobile nodes means that new routing algorithms are needed to change the packets routing. To track a node's movement and to keep the moving node's connectivity are two basic issues. This in turn forms the two main operations of mobility management.
- *At the transport layer*, an end-to-end connection may mix both wired and wireless links. This makes congestion control a complex task due to the different network characteristics. Retransmission mechanism based on increasing interval may lead to an unnecessary drop in the date rate.
- *At the middleware and application layer*, mobility brings new requirements on middleware supports. Examples include service discovery schemes, QoS, and environment autoconfiguration. Mobility also brings new opportunities to applications. Context-aware applications are possibly based on the measures for sensing various context information of mobile end users.

2.2 Mobility in future mobile systems

Future mobile communication systems will base on the seamless integration of terminals, networks, and applications that employ adaptive management on diversity [1]. Diversity can exist in services, backbone networks, access networks, and terminals. One of the most important features of future mobile communications is that wireless networks are heading towards an architecture such as all-IP core with asymmetry accesses. Most mobile ad hoc networks also internetwork with other infrastructures like the Internet. From the cellular structure point of view, future mobile networks can be divided into different sizes of cellular coverage, as shown in Table 1. The basic idea behind this is to seamlessly integrate two categories of wireless network technologies together, i.e. those that can provide low-bandwidth over a wide geographic area and those that can provide a high bandwidth over a narrow geographic area. The various cellular techniques consequently cause the complex intercarrier and/or intersystem roaming of a mobile node in a heterogeneous and overlay wireless cellular environment. This is a big challenge to the design of mobility management schemes for the future mobile systems.

Mobile devices should be able to roam within a whole mobile system or between different systems as long as their networks are interconnected. Networks can firstly be classified according to different providers and/or technologies. Then one symmetric network can be further divided into domains, location areas, access point regions, zones of access points, and logical channels within one access point. Different mobility levels/granularities can then be defined accordingly, as follows.

- *Mega-mobility* is the mobility between the networks of different providers or technologies, e.g. satellite to UMTS to WLAN to Bluetooth, etc.

Table 1. Cellular coverage division

Cell name	Place	Coverage	Speed	Techniques
mega-cell	global	global coverage	>200km/h airplane	satellite
macro-cell	suburban, rural	1km-10km	20-200km/h vehicle/train	2G/3G PCS
micro-cell	urban	100m-1km	10-50km/h vehicle	PCS, WLAN, HiperLAN
pico-cell	in-building	10m-100m	<10km/h walk	WLAN, HomeRF, Bluetooth
nano-cell	personal area	1m-10m	nearly stationary	Bluetooth, IrDA

- *Macro-mobility* is the mobility between different "visited domains" but still within one network.
- *Micro-mobility* is the mobility between different "location areas" but still within one visited domain.
- *Mini-mobility* is the mobility between different "access point regions" but still within one location area.
- *Pico-mobility* is the mobility between different "access points" but still within one access point region.
- *Nano-mobility* is the mobility within the zone covered by one access point, where the cell zone can vary from mega-cell down to nano-cell, see Table 1. One access point may employ several logical channels.

The significance of this division is that different mobility granularities may have different effects on the corresponding mobility management schemes invoked. For example, nano-mobility, pico-mobility and mini-mobility often do not need the joint of location update; micro-mobility in a certain domain can limit the location updates into the domain and leave the other domains uninfluenced and unaware; vertical handoff and location management strategies must be involved in case of mobility at mega level, in order to treat network structures and protocols with the asymmetry.

This division does not mean any direct correspondence with either the cellular division based on cellular size, or the moving speed or range of a mobile device. Instead, the division is totally based on the mobility granularity from the network point of view. For example for a spot in overlay cells of heterogeneous networks, mega-mobility may happen from cell A (e.g. pico-cell) to cell B (e.g. macro-cell) without necessarily moving out of the coverage area of cell A, or it can even be stationary. This is also known as vertical handoff. Pico-mobility handoff may occur in the area overlapped by two contiguous access points. Nano-mobility a logical handoff may happen between different logical channels in one physical zone.

3. MOBILITY MANAGEMENT

3.1 Mobility management concept

Mobility management is the essential technology that supports roaming users with mobile terminals to enjoy their services through wireless networks when they are moving into a new service area. Fig. 2 shows a simple model to illustrate the basic scenario of mobile communication. The serving networks can be of any type, e.g. the Internet or intranet, mobile ad hoc networks, personal communications systems (PCS), or the mix of these networks. The mobile node can freely change its point of attachment to the networks. The main function of mobility management is then to efficiently support the seamless roaming of the mobile users and/or devices within the whole serving networks. From the viewpoint of functionality, mobility management mainly enables communication networks to:

- Locate roaming terminals in order to deliver data packets, i.e. function for static scenario.
- Maintain connections with terminals moving into new areas, i.e. function for dynamic scenario.

According to the concept above, mobility management contains two distinct but related components: location management and handoff management. The former concerns how to locate a

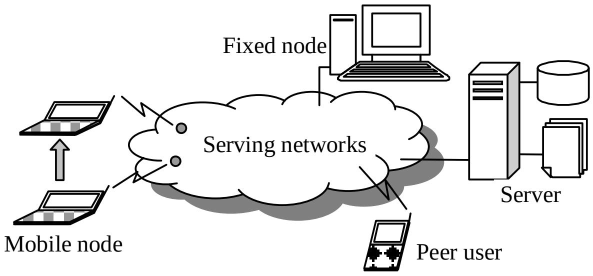

Fig. 2. Basic model for mobile communications

mobile node, track its movement, and update the location information, while the latter focuses mostly on the control of the change of a mobile node's access point during active data transmission. One usage scenario may invoke either one or both of the two managements.

There are still many other aspects concerning the network management of mobility, e.g. mobile QoS and resource management, mobile security and privacy, billing, power management, etc. In this paper we focus mainly on issues in location and handoff management, since these two are the kernel techniques to support seamless roaming of mobile nodes and form the basis of mobile applications. Section 5 discusses the key research issues of the two management types for the future mobile systems in more detail.

3.2 Mobility management at network layer

Network layer offers routing for packets from one network to another through independent links according to the destination address. The physical location of a mobile unit can no longer decide its address in a network. Since mobility, modelled as changing node's point of attachment to the network in Fig. 2, is essentially an address translation problem, it is naturally best solved at the network layer by changing the routing of datagrams destined to the mobile node to arrive at the new point of attachment [2]. To implement mobility management at network layer may also shield the upper-level protocols from the nature of the physical medium and make mobility transparent to applications and higher-level protocols.

Currently mobility management at the network layer is mainly addressed in two different communities: the PCS community and the Internet community. The works in the PCS community focus on the effort on location and handoff management of a cellular phone [3-5]. Also many works have been done in the field of wireless ATM [6, 7]. The works in the Internet community focus mostly on the standardization of Mobile IP aiming towards extending IP with the capabilities of dealing with mobility [8]. Besides, many efforts have also been made for the routing strategies of mobile ad-hoc networks in the Internet community [9]. Generally speaking, the PCS community concerns mainly location management research, while the Internet community focuses mostly on handoff management research. The reason of this difference is that handoff is more important to data service than to voice service. There are also other works focusing on the mobility management at the transport layer, e.g. TCP/UDP protocols over wireless link [10].

4. MOBILITY MANAGEMENT OPERATIONS

In Section 4.1 the operation of mobility management is divided into two related parts, location management and handoff management. The following in this section discusses the main processes and key research issues included in the two techniques. No specific design scheme in any specific mobile communication system is introduced here. A survey on different mobility management schemes for PLMN (PCS), wireless ATM, wireless Internet (Mobile IP), and satellite networks can be found in [11].

4.1 Location management

Location management equals locating roaming terminals in order to deliver data packets to them despite the fact that their locations may change from time to time. The essence of location management is constituted by the mechanisms for mapping the name of a mobile node to its address. Operations of location management include:

- *Location registration*, also know as location update or tracking, i.e. the procedure that the mobile node informs the network and other nodes of its new location through special messages by updating the corresponding location information entries stored in some databases in the networks.
- *Location paging*, also know as locating or searching. In most cases location information stored in databases is only the approximate position of a mobile device. Location paging is then the procedure that, when calls/packets need to be delivered to the target mobile device, the network tries to find the mobile device's exact locality.

Some key research issues for location management include:

- *Addressing*, i.e. how to represent and assign address information to mobile nodes. The problem is becoming more severe since the future mobile communication systems will be based on the internetworking and interoperability of diverse and heterogeneous networks of different operators and/or technologies. A global addressing scheme is needed, e.g. IPv6 address, to locate the roaming nodes.
- *Database structure*, i.e. how to organize the storage and distribution of the location information of mobile nodes. Database structure can be either centralized or distributed, or the hybrid of these two schemes. Tradeoff is needed between access speed, storage overhead, and traffic overhead due to the access to the related databases. Caching is also an important technique for the improvement of access performance.
- *Location update time*, i.e. when a mobile node should update its location info by renewing its entries in corresponding databases. Schemes for location update can be either static or dynamic. In a static scheme location update is triggered by some fixed conditions like time period or network topology change. A dynamic scheme is more personalized and adaptive, and based on some situations such as counter, distance, timer, personal profile, or even predicted factors.
- *Paging scheme*, i.e. how to determine the exact location of a mobile node within a limited time. Obviously an adequate tradeoff is needed between time overhead and bandwidth overhead. There are also both static and dynamic schemes for location paging. In static cases paging is simply done to the whole certain area where the mobile node must be in. For a dynamic method, the main problem is to firstly organize the paging areas into groups and then recognize the best sequence of the separated areas for paging, based on information like distance, probability, moving velocity, etc.

4.2 Handoff management

Handoff management equals controlling the change of a mobile node's attachment point to a network in order to maintain connection with the moving node during active data transmission. Operations of handoff management include:

- *Handoff triggering*, i.e. to initiate handoff process according to some conditions. Possible conditions may include e.g. signal strength deterioration, workload overload, bandwidth decrease or insufficiency, new better connection available, cost and quality tradeoff, flow stream characteristic, network topology change, etc. Triggering may even happen according to a user's explicit control or heuristic advice from local monitor software.
- *Connection re-establishing*, i.e. the process to generate new connection between the mobile node and the new attachment point and/or link channel. The main task of the operation relates to the discovery and assignment of new connection resource. This behaviour may be based on either network-active or mobile-active procedure, depending on which is needed to find the new resource essential to the new establishment of connection.
- *Packet routing*, i.e. to change the delivering route of the succeeding data to the new connection path after the new connection has been successfully established.

As discussed in Section 3.1, the diversity feature of future mobile communication systems, especially that of the miscellaneous wireless network technologies, causes new challenges to handoff management. Wireless networks vary widely in both service capabilities and technological aspects, so no single wireless network technology can fulfil the different requirements on latency, coverage, data rate, and cost. An efficient strategy is necessary for the management of such a wireless overlay architecture and mobility within the framework. In homogeneous environments, traditional horizontal handoff can be employed for intra-technology mobility. In heterogeneous environments, vertical handoff should be used for inter-technology mobility. Vertical handoff may be occur either upward (i.e. to a larger cell size and lower bandwidth) or downward (i.e. to a smaller cell size and higher bandwidth), and the mobile device does not necessarily move out of the coverage area of the original cell. Some packet-level QoS parameters become more important to real-time multimedia services, including packet latency, packet loss rate, throughput, signalling bandwidth overhead, and device power consumption.

Besides the basic functions that implement the goal of handoff management, there are many other requirements on performance and packet-level QoS that should be carefully taken into account when trying to design or select a handoff management scheme, including

- *Fast handoff*, i.e. the handoff operations should be quick enough in order to ensure that the mobile node can receive data packets at its new location within a reasonable time interval and so reduce the packet delay as much as possible. This is extremely important to real-time services.
- *Seamless handoff*, i.e. the handoff algorithm should minimize the packet loss rate into zero or near zero. Fast handoff and seamless handoff together are sometimes referred to as smooth handoff. While the former concerns mainly packet delay, the latter focuses more on packet loss.
- *Routing efficiency*, i.e. the routing path between corresponding node and mobile node should be optimised in order to exclude possible redundant transfer or bypass path as e.g. triangle routing.

Some distinct but complementary techniques exist for handoff management to achieve its performance and QoS requirements above, including:

- *Buffering and forwarding*, i.e. the old attachment point can cache packets during the MN in handoff procedure, and then forward to the new attachment point after the operation of connection re-establishing of mobile node's handoff.
- *Movement detection and prediction*, i.e. mobile node's movement between different access points can be detected and predicted so that the next network that will soon be visited is able to prepare in advance and packets can even be delivered there before and/or during handoff simultaneously to the old attachment point.
- *Handoff control*, i.e. to adopt different mechanisms for the handoff control. Typical examples include e.g. layer two or layer three triggered handoff, hard or soft handoff, mobile-controlled or network-controlled handoff, etc.
- *Domain-based mobility management*, i.e. to divide the mobility into intra-domain mobility and inter-domain mobility according to whether the mobile host's movement happens within one domain or between different domains.

5. EVALUATION OF MOBILITY MANAGEMENT SCHEMES

5.1 Simulation-based evaluation method

The performance evaluation of the mobility management schemes of the future mobile communication systems is becoming more and more difficult and complex a task. Future mobile communication systems evolve with the trend of global connectivity through the internetworking and interoperability of heterogeneous wireless networks. Roaming in such a network architectures is very complex a situation and causes many new problems. The future mobile systems should support a huge number of subscriber population with diverse movement modes. The complexity in future mobile networks brings the performance evaluation many new challenges under studied.

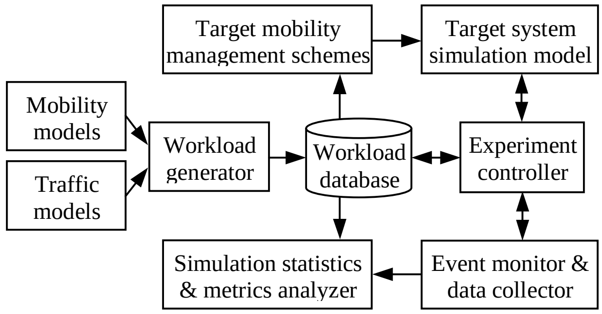

Fig. 3. Simulation-based performance evaluation

To current study simulation-based method has gained more attentions and acted as the kernel technique under the assistances of analytical and measurement-based methods. In simulation-based method, simulation model of the target mobile communication system is used for the evaluation. Models for characterizing workload attributes can also be analytical as used in analytical methods, but other simulation descriptions exist to describe the workload in a more detailed manner. Evaluation process consists of many well-organized experiments, in which different events are simulated and related data are collected for further analysis. Fig. 3 illustrates the main processes of simulation-based method.

The main challenge of simulation-based method is that to what details the simulation should be made. The complexity in detailed modeling both target mobile system and workload characteristics can make experiments unfeasible due to the experiment time burst and massive computing power needed. Another problem may be that it's difficult to generalize the results from a series of experiments in one specific mobile system in order to predict the performance parameters of other related mobile systems.

5.2 Simulation modeling issues

The performance of mobility management schemes strongly depends on workload characteristics. Consequently, accurate workload models are needed to specify the different behaviors of subscribers in terms of both user mobility patterns and communication traffic patterns, as illustrated in Fig. 3. Two user patterns need to be simulated for evaluation experiments, including mobility and traffic patterns. Mobility models characterize user movement patterns. Traffic models describe the condition of mobile services. The combinations between user units (individual or group) with user behavior patterns (mobility and traffic) lead to different models that are finally used for various evaluation purposes.

There are many literatures concerning user behavior modeling for various specific scenarios. In [12] a hierarchical user mobility model is developed and a hierarchical location prediction algorithm is generated for advance resource reservation and advance optimal route establishment in wireless ATM networks. In [13] three basic types of mobility models are proposed for the analysis of the full range of mobile communications' design issues, including the City Area Model, the Area Zone Model, and the Street Unit Model. [14] presents a realistic teletraffic modeling framework for personal communications services. The framework captures complex human behaviors and has been validated through analysis of actual call and mobility data. In [15] a mathematical formulation is developed for systematic tracking of the random movement of a mobile station in a cellular environment, which is used to characterize different mobility-related traffic parameters. [16] extends the previous mobility modeling from one or two-dimensional space to three-dimensional indoor building environments by considering the proper boundary conditions on each floor and analytically modeling mobility in multi-storey buildings.

For mobility modelling, both analytical and simulation models can be employed to describe the activity of user's movement. Analytical mobility models base on simplifying assumptions regarding the movement behaviors of subscribers and can provide performance parameters for simple cases through mathematical calculations. Simulation models consider more detailed and realistic mobility scenario and then can derive valuable solutions for more complex cases. Typical mobility models include Brownian model, random walk model, random waypoint model, random Gauss-Markov model, Markovian model, incremental model, mobility vector model, reference point group model, pursue model, nomadic community model, column model, fluid flow model, exponential correlated random model, etc.

Traffic models need to be studied from both macro and micro points of view. Descriptions of available services are especially important for the future mobile systems where applications can be other data services besides voice call. Micro traffic models are used to characterize incoming and outgoing traffic of subscribers, i.e. frequency of individual users accessing a certain service, duration of each service using, and transmitting packet size. New models are needed to describe the impacts of mobility on traffic models, i.e. the derivations of mobility-related traffic parameters that usually include e.g. handoff rate parameter, cell residence time, channel holding time.

6. CONCLUSIONS

Mobility management has widely been recognized as one of the most important and challenging problems for a seamless access to wireless networks and mobile services. This paper makes a general framework for the study of the basic concepts of mobility and mobility management. The impacts of mobility to networks are analysed. Features of the future mobile systems are introduced and mobility of various granularities is discussed. Two main operations of mobility management are defined as location and handoff managements and the processing stages of the two operations are introduced respectively, together with the discussions of key research issues and possible solutions. Some important issues involved in the performance evaluation of mobility management scheme are discussed. The conceptual framework constructed forms a clear layout to outline the research area of mobility management for mobile communications and can direct systematic research on mobility management issues for the future mobile systems.

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