

# Managing Mobility in Beyond-3G Environments

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**Abstract.** Beyond 3G (B3G) environments typically consist of multi-homed terminals and wireless overlay networks. This paper presents a categorization of IP-level mobility management solutions for B3G environments. Closely observing the mobility requirements of a wide range of possible applications, the paper also motivates the consideration of a new mobility management approach in B3G environments, whereby location management (i.e., reaching mobile end-users at the IP-level for session invitations) is decoupled from handover management (i.e., switching ongoing sessions, collectively or individually, to another access network whenever appropriate). For example, one can use cellular GPRS/UMTS networks for location management and Wi-Fi™ or cellular networks for handover management. The paper elaborates upon the merits of such so-called context-aware mobility solutions, which are attained from an optimum use of the mobility management features embedded in the underlying infrastructure.

## 1 Introduction

B3G environments are typically characterized as environments that integrate different wireless and fixed access network technologies, using sophisticated terminals with multiple network interfaces. B3G environments provide mobile end-users with direct Internet access and end-to-end IP connectivity to (third party) services over such heterogeneous networks. Enabling the communication of mobile users via different networks leads to localization and connectivity issues that are addressed by the so-called Mobility Management system functionality. Until recently, telephony and Internet communities had pursued Mobility Management research separately in response to the need of making telephone and Internet services mobile. Providing end-to-end IP connectivity over heterogeneous networks, which has resulted in adopting the so-called All-IP network architecture, has brought telephony and Internet communities together. A key challenge here is how the Mobility Management solutions of the telephony and Internet communities can be converged, integrated and at the same time exploited to their maximum potentials to deal with user and terminal mobility, i.e., movement of users between and with terminals, respectively.

This paper investigates the problem of IP-level Mobility Management in B3G environments. In addition to standalone IP mobility protocols, e.g., [3][4][13][21][15], many composite mobility solutions have recently been introduced that use a

combination of different mobility protocols to cope with the diversity of application requirements, e.g., [2][4][6][7][8][9]. We believe that, in addition to taking into account the requirements of applications, a Mobility Management solution for B3G environments should consider the available mobility enabling features embedded in the constituent networks, and accordingly make use of these features to their full extent. Despite the fact that most efforts have been made so far to come up with link-layer independent Mobility Management mechanisms, we believe ignoring these mobility features brings inefficiency and redundancy to IP-mobility solutions.

This paper addresses the issue of Mobility Management in B3G environments at conceptual and state-of-the-art levels. Specifically, the paper elaborates on: (1) a state-of-the-art categorization of different Mobility Management solutions applicable for B3G environments and (2) the motivations for context-aware Mobility Management solutions that exploit the mobility features embedded in B3G environments. Such a context-aware Mobility Management solution, e.g., in the context of Wi-Fi™ and cellular GPRS/UMTS networks, can benefit from the always-on feature, the wide-area reach and the efficient paging mechanism of cellular networks for reaching mobile end-users. This may obsolete the necessity of introducing any paging feature at the IP layer, as required in existing Mobility Management solutions.

The rest of this paper first lays down the problem context and provides some prerequisite information for a self-contained presentation of the topic in Section 2. Section 3 discusses the related work. Section 4 describes our vision and motivations for a new Mobility Management approach. Finally, Section 5 briefly discusses our conclusions and future work.

## **2 Problem description**

To elucidate the problem context, this section describes a typical B3G-environment and the relevant mobility types, and formulates the functionality of Mobility Management in such environments.

### **2.1 Beyond 3G environments**

The term B3G in network technology generally refers to a conceptual framework to address future needs of heterogeneous wireless networks that will interoperate seamlessly with wire-line backbone networks. Since there are no standards under development, a precise and unique definition of B3G cannot be given at this moment. This section, therefore, presents a definition of B3G as adopted throughout this paper.

A B3G environment consists of B3G networks, including Wireless Wide Area Networks (WWANs) such as GPRS and UMTS cellular networks, and Wireless Local Area Networks (WLANs) such as Wi-Fi™, HiperLAN/2 and HomeRF networks; next generation terminals; and services provisioned across these heterogeneous networks and terminals. Motivated by the current trend of Wi-Fi™ and GPRS/UMTS integration, we consider GPRS/UMTS and Wi-Fi™ as two indispensable types of

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future wireless overlay networks. Compared to Wi-Fi™, GPRS/UMTS provides a lower bandwidth per unit area connection over a larger geographic area. Next generation terminals will have, in addition to a run-time environment for applications, multiple network interfaces that enable end-users to access the Internet via different access networks. This situation is referred to as “end-host multi-homing” [18][19] (or “multi-homing” in short). Motivations for using devices with multiple active network interfaces are: having smoother hand-offs, offering better QoS (due to accessing multiple networks), exploiting access networks with link asymmetry (e.g., satellite systems), reducing cost, and improving privacy and security [7].

We are moving towards an era where “always-on” multi-homed devices will provide communication anywhere, anytime and with any kind of service, by being reachable (simultaneously) through several topological paths. Mobile end-users can also use a multi-homed terminal as a personal device for identifying themselves or being reachable by other users. Mobile users may occasionally transfer some of their (running) service sessions from their personal devices to a nearby device with better and more suitable capabilities and features.

### 2.2 Mobility types in B3G environments

Mobility patterns of end-users in B3G environments are technically realized in systems supporting *user mobility* and *terminal mobility*, both of which deal with and realize *service mobility* and *session mobility*. We consider a session as the instantiation of a service.

Terminal mobility is defined as the ability of a terminal, while perhaps in motion, to access services from different points of attachment to the access networks, to maintain ongoing service sessions, and the capability of the system to identify and locate that terminal. User mobility is similarly defined as the ability of an end-user to access services, to maintain ongoing service sessions at any terminal on the basis of a personal identifier, and the capability of the whole system to provide those services in accordance with the user’s profile. Note that unlike us some authors don’t include “maintaining of ongoing sessions” in their definition of user mobility, e.g. see [20]. User mobility involves the system capability to locate the terminal associated with the end-user for the purposes of addressing, routing, and charging of the end-user.

### 2.3 Mobility Management functionality

Similarly to [1], we define Mobility Management in B3G environments as a functional component that firstly keeps track of the IP-addresses of mobile end-users, and secondly modifies the IP routes of the ongoing sessions of mobile end-users. Additionally, our definition of Mobility Management includes the function of detecting mobility and selecting a new access network.

*Location Management* keeps track of (or discovers) the current attachment point(s) of a mobile end-user, thus enabling other end-users to initiate new sessions towards the mobile end-user. Generally, IP mobility solutions dynamically keep the IP address(es) of the mobile end-user in a registrar, generally referred to as *Location*

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*Registrar*, which binds between the identification of the mobile end-user and her/his current IP address(es). Every other session initiator is aware of the location of or knows how to reach the Location Registrar, based on the mobile end-user's identification (that, in turn, depends on the mechanism used). The session initiator contacts the Location Registrar that either returns the current IP address of the mobile end-user to the initiator or forwards the session initiation request towards the mobile end-user's current IP address. Location Management encompasses the following sub-functions: Address Update (to dynamically maintain mobile end-users' IP addresses), Session Invitation Handling (to associate a suitable IP address of the mobile end-user, i.e., the called party, with the invitation), and Paging (to find the exact location of a mobile end-user).

*Handover Management* maintains an mobile end-user's ongoing session(s) as her/his corresponding IP-address(es) changes (change). The sessions of a mobile end-user can be handed over collectively or separately. Handover Management encompasses two sub-functions: Session Route Regeneration (to find and reserve the resources for the new session path) and Data Flow Control (to maintain the delivery of the data from the old session path to the new session path, in accordance with the session requirements).

*Network Access* deals with mobility detection, access network selection and new IP address acquisition, thus enabling a mobile end-user's terminal to send and receive IP traffic (i.e., to have IP connectivity) within an Intranet and/or the Internet. Network Access sub-functions are: Access Network Detection, Access Network Selection, and Terminal Interface Configuration. Note that Network Access sub-functions are prerequisite functions to the Location Management and Handover Management.

### **3 Related work**

Many solutions have been proposed to address the issue user and terminal mobility. These solutions have evolved with the developments in the areas of applications and infrastructures, as well as with the extensions in the scope of mobility. This section provides an overview of some Mobility Management solutions/protocols grouped into flat, hierarchical, application-dependent categories. This presentation emphasizes the dimensions along the evolutionary path of Mobility Management solutions to cope with their deployment context. By positioning another category at the end of the section, which reflects our main vision in this paper, a new dimension along the evolutionary path of Mobility Management solutions is recognized.

#### **3.1 Flat and hierarchical Mobility Management**

Mobile IP [3][13] and the SIP based mobility support [4] are two examples of flat structured mobility solutions, operating at the network and application layer, respectively. While Mobile IP supports terminal mobility, SIP also provides a solution for user mobility. Flat structured mobility mechanisms suffer from high latency and large global signaling load. Therefore, hierarchical IP-based protocols are proposed to alleviate the problem by grouping IP subnets into mobility domains and minimize the

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scope (and latency) of most updates by localizing them within the domain [2] [10] [14]. By managing local route and address changes within the domain, nodes outside the domain are not aware of these changes. Cellular IP [21], HAWAII [22], Mobile IP Regional Registration (MIP-RR) mechanism [15] [16] and Dynamic Mobility Agent (DMA) architecture [2] are examples of hierarchical Mobility Management solutions for IP-based networks. Hierarchical Mobility Management solutions allow paging functionality that enables a mobile terminal to save power by not performing IP-address configuration and binding updates when the terminal is in an idle mode and moves inside the domain lowest in the hierarchy, see for example [2].

### 3.2 Application dependent mobility management

To meet the requirements of applications and to deal with harsh networking environments, application-dependent Mobility Management solutions are proposed. This section reviews some of such Mobility Management approaches in more detail, relative to those presented in Subsection 3.1.

In the context of Mobile IP, authors of [7] and [9] introduced two Mobility Management mechanisms for multi-homed devices to make use of active network interfaces simultaneously or sequentially, based on a trade-off among coverage, performance and price. The first mechanism supports opting multiple packet delivery methods, for example, choosing whether to use regular IP (for short-lived connections such as Web browsing) or Mobile IP (for long-lived connection-oriented traffic or for traffic initiated by correspondent hosts such as ftp file transfer). When using Mobile IP, the mobile host can further choose between regular Mobile IP and Mobile IP with bi-directional tunneling. The second mechanism proposed in [7] addresses the ability of using different interfaces in a terminal based on the types of the traffic flows (even if all flows are for communicating with the same host). For the second mechanism Mobile IP is extended to allow a mobile terminal to have multiple active Care-of-Addresses (CoAs) simultaneously and to update these flow CoAs in a so-called Flow-to-Interface binding table at the Home Agent. The Flow-to-Interface binding associates a particular flow with a given CoA for the mobile host. The Home Agent sends all packets of a flow destined to the mobile host to the appropriate CoA. In this way Mobile IP becomes application aware.

When introducing SIP mobility support for personal and terminal mobility, the authors of [4] suggested to use Mobile IP for long-lived TCP connections, e.g., telnet, ftp, irc, etc., and SIP for other (real-time) connections. The IST project EVOLUTE uses a domain-based approach to support transparent Internet mobility in All-IP networks. According to the EVOLUTE project, Cellular IP is used for micro-mobility to support fast handoff and paging within an administrative domain [6]. For inter-domain mobility Mobile IP and SIP are used complementarily to each other [6], where domain edge routers separate traffic from/to a mobile host based on traffic type. More specifically, real-time traffic uses SIP signaling and non-real-time traffic uses Mobile IP. The authors in [2] considered similar application-centric approaches for choosing appropriate IP-mobility protocols, believing that no single approach to IP mobility applies across different applications. Approach of [2] uses DMA [2] protocol to manage intra-domain mobility and it uses SIP and Mobile IPv4/6 for

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global binding mechanisms in VoIP and in mobile server scenarios, respectively. As another example, an application dependent Mobility Management architecture is proposed in [8] for survivable military networks, where a derivative protocol of Cellular IP and HAWAII is used for intra-domain mobility. For inter-domain mobility, instead, SIP for real-time applications (i.e., RTP/UDP traffic) and Mobile IP with Location Registrar [17] for non-real-time applications (i.e., TCP/IP traffic) are proposed.

### **3.3 Towards Context-Aware Mobility Management**

Taking into account the topological characteristics of network nodes and the requirements of applications, as done in the above-mentioned solutions, can be regarded as steps towards context-awareness in Mobility Management. As another step in the same direction, we propose here to exploit the Mobility Management features of the underlying access networks. Thus, the term context-aware used in this paper accommodates two properties of being application-centric and infrastructure-aware for a Mobility Management solution.

The approach mentioned here is against most efforts made so far to come up with link-layer independent Mobility Management mechanisms operating at or above the network-layer. A Mobility Management mechanism is link-layer dependent if it is designed only for a particular access network type. Such link-layer independency for Mobility Management is beneficial if a (multi-interface) mobile terminal switches sequentially in time between its network interfaces. In this paper we focus on multi-homed terminals that are in control of using appropriate inter-domain mobility mechanisms based on their running applications. In multi-homed terminals, where multiple network interfaces are active simultaneously, a totally layer 2 independent Mobility Management means overlooking the versatile mobility features of, for example, GPRS/UMTS networks. Ignoring the link-layer mobility features of GPRS/UMTS and the extent of its countrywide coverage on the one hand has brought complications to the existing IP-mobility solutions, e.g., by re-introducing paging features in their architectures, and on the other hand has introduced redundancy in the whole system, e.g., by doing similar things in the link-layer and in the layers above.

## **4 Context-aware mobility management**

As the main contribution of this paper, this section motivates considering context-aware Mobility Management solutions in B3G environments.

### **4.1 Motivations**

The concept of context-aware Mobility Management proposed in this paper relies on two characteristics of B3G environments, explained in the following paragraphs.

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**Application Requirements.** Here we investigate the requirements of applications running on a multi-homed terminal of a mobile end-user with respect to Location Management and Handover Management functions. The figure below categorizes applications according to the following criteria:

- Whether the mobile end-user should be reachable for a session via the IP network
- Whether the mobile end-user’s IP-address changes during a session.

These criteria determine whether Location Management and Handover Management are needed for these applications, respectively. As the figure suggests, many applications don’t basically require both Location Management and Handover Management. Those applications that need both of these functions can be classified in two groups according to whether the separation of Location Management and Handover Management is feasible or not. These two groups of applications are encapsulated in grayed boxes in the figure. By separation we mean to allow location bindings for maintaining reachability and those for maintaining ongoing sessions to follow separate courses. Note that these bindings concern the Address Update and Session Route Regeneration sub-functions mentioned in Subsection 2.3, respectively.

	the mobile end-user need not be reachable	the mobile end-user should be reachable (Location Management)
an IP-address change does not occur in mid-sessions	Web browsing (short lived TCP sessions)	
IP-address change occurs in mid-sessions (Handover Mgmt.)	FTP client (long-lived TCP sessions)	VoIP & multimedia conferencing
	video/audio streaming	mobile server

**Fig. 1.** A categorization of applications/services from the mobility management viewpoint

Applications like mobile servers do not allow any attempt to decouple Location Management and Handover Management due to inflicting scalability problems. Relying on mechanisms like Mobile IP, Location Update in these applications actually realizes also the regeneration of all sessions and thereby obsoletes the necessity of sending location bindings to all correspondent hosts, i.e., to the clients of the mobile server. Applications that require a mobile end-user’s terminal to act as a mobile server are less likely to occur in B3G environments. We envision that terminals acting as servers will be static and most-probably be connected to the Internet backbone via wired access networks.

From the arguments presented here we can conclude that separation of Location Management and Handover Management is possible for applications capable of running on mobile end-users’ multi-homed terminals. Interesting to know is the fact that session handover for such applications can be coped with at the application level independently of the address at which the Mobile end-user’s terminal is reachable.

**Below IP-layer Mobility Management of UMTS.** Although this section investigates the below-IP layer mobility features of UMTS, comparable features exist for GPRS networks and other 3G evolution branches (e.g., 3GPP2). Three levels of mobility can be distinguished in the architecture of UMTS [11] (based on the UMTS reference architecture outlined in 3GPP TS 23.002):

- Access mobility: to ensure uninterrupted communication as a mobile node changes its point of attachment to the network, i.e., changes the access points, within the scope of a single Radio Network Controller (RNC),
- Macro-mobility: to allow uninterrupted communication when the change of the access points occurs out of the scope of a given Gateway GPRS Support Node (GGSN), via which a mobile node communicates with the Internet.
- Micro-mobility: to support intermediate mobility scenarios whereby the access point change occurs out of the scope of a RNC but within the scope of a GGSN.

In the UMTS reference model mentioned above, the GGSN plays an Access Router role with DHCP capabilities, i.e., it is a globally IP-reachable node within the core network of UMTS. There are new proposals for the UMTS network architecture, where this globally IP-reachable node is shifted towards the edge nodes of UMTS (i.e., towards the RNCs). For example, in 3GPP TR 23.922 an integrated GSN (IGSN) is introduced, which combines the functions of the SGSN and GGSN, and directly communicates with the RNC. In another proposal [11], a 3G-Access Router (3G-AR) is introduced by collocating the IGSN with RNC. In these scenarios of UMTS evolution, GGSN, IGSN and 3G-AR serve as the globally IP-reachable nodes from the outside Internet world. This implies that the scope of the below IP-layer mobility support in UMTS corresponds to the scope of the GGSN, IGSN or 3G-AR serving the mobile node, respectively. Considering these scenarios, we conclude that below IP-layer mobility support of UMTS covers a large geographical area (at least the scope of an RNC, which corresponds to a few UMTS cells). Within this area no IP-layer mobility support is needed such as CoA acquisition, IP address update at a Location Registrar, etc.

Another important property of mobility support features in UMTS is its link-layer location update and paging procedures, designed to reduce the net costs of location update and paging. These costs are associated with signaling overhead (consuming bandwidth) and mobile device power. The scope of the link-layer paging in UMTS, which corresponds to at least a number of UMTS cells (depending on the state of the mobile device), covers large spatial areas as compared to the paging areas in the schemes applied to WLANs.

## 4.2 Rationale for context-aware Mobility Management

As foreseen in composite Mobility Management schemes of Subsection 3.2, different mobility protocols can be used on the basis of the requirements of the applications running on the terminal. As another dimension of application dependency, one may

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take into account the requirements of applications for Location Management and Handover Management, as outlined before. Such an observation leads us to propose an infrastructure-aware mobility management for multi-homed terminals, whereby IP level Location Management is realized only via the UMTS (in general, WWAN) interface and Handover Management via both Wi-Fi™ (in general WLAN) and UMTS interfaces.

After locating a mobile end-user with the help of Location Management function, the Handover Management function maintains a session via the UMTS interface or another appropriate Wi-Fi™ interface on the basis of application requirements, user preferences, availability of the Wi-Fi™ network, etc. When the session falls into an idle phase, a handover can be triggered to the UMTS interface in order to make use of its inherit link-layer standby features. Such IP-level handover that depends on the state of the session can be based on a state diagram similar to that used for link layer paging/location-updates in current 2-3G networks, see for example [11] and [12]. The here proposed state diagram determines the interface through which the IP traffic of the session should flow.

Although such decoupling of Location Management and Handover Management is the opposite of the way that has been done in the existing mobility support protocols, the proposed context-aware Mobility Management approach has the following advantages in the context of B3G environments:

- Globally reaching the MEUs by relying on the UMTS for Location Management (the globe is promoted as the scope of the UMTS),
- Power saving at the mobile terminal by relying on the sophisticated and efficient paging and location-update procedures of UMTS,
- No need for provisioning any paging feature at the IP level by relying on the link layer paging of UMTS,
- Lower network load by eliminating and reducing IP level location updates within the large area of UMTS's below IP layer coverage,
- Utilizing the best access network for on going sessions.

The main assumptions that we have made here is that every mobile end-user operates a personal device with multiple network interfaces, i.e., a multi-homed terminal, among which are WWAN and WLAN interfaces. Via its WWAN interface the mobile end-user is (always) reachable for other end-users. The proposed Location Management assumes that the WWAN interface of the terminals is always ready to receive invitations for new sessions. This assumption is in accordance with the advocated always-on feature of 2.5/3G networks. The proposed approach also relies on the assumption that the UMTS infrastructure provides IP addresses that are globally routable, which may not be the case in currently available UMTS trials.

A detailed description of such context-aware Mobility Management architecture and its implementation is out of our scope in this paper and will appear in a subsequent publication shortly.

## 5 Conclusions and future work

The key benefit of an IP-based mobility solution is its independence of the underlying link and physical layers. In this contribution we proposed to consider an IP-based Mobility Management strategy for B3G environments that keeps track of the IP-address(es) of a mobile end-user via the WWAN interface of a multi-homed terminal and changes the IP-routes of the mobile end-user's ongoing sessions to other WLAN/WWAN interfaces whenever a session handover is possible and necessary. This approach, derived from observing the requirements of different applications, makes optimal use of the features embedded in the existing technologies. For example, in this way the paging feature and the wide coverage property of WWAN networks are fully explored in locating mobile end-users. Moreover, it provides an IP-based Mobility Management without unnecessarily complicating the existing IP mobility protocols with any paging capability or similar enhancements.

For this idea to work, the coupling between Location Management and Handover Management as exists in traditional IP Mobility Management solutions and protocols should be loosened. Currently we have designed and implemented our Mobility Management strategy in a distributed testbed, using SIP and Mobile IP solutions. The Mobility Management system mainly relies on the intelligence in a multi-homed terminal for choosing the appropriate network interface. The detailed overview of our activities will appear in a separate paper shortly.

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