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Seamless Roaming: Developments and Challenges

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Abstract.
The paper reports on recent developments and challenges focused on seamless handover. These are subject for the research projects MOBICOME and PERIMETER, recently granted by the EU EUREKA and EU STREP FP7, respectively. The research projects are considering the recently advanced IP Multimedia Subsystem (IMS), which is a set of technology standards put forth by the Internet Engineering Task Force (IETF) and two Third Generation Partnership Project groups, namely 3GPP and 3GPP2.
The foundation of seamless handover is provided by several components, the most important ones being the handover, mobility management, connectivity management and Internet mobility. The paper provides an intensive analysis of these components.

1 Introduction

The paper is about recent developments and challenges related to seamless handover. There are many types of handover systems existing today, which can be partitioned in different ways. Several dimensions can be used in partitioning the handover systems. These are, e.g., regarding the domain, the system, the overlay and the technology [1].

For instance, handover systems can be partitioned with reference to technology, which can be similar or different. In the first case we have homogeneous handovers and in the second case we have heterogeneous handovers. Handover systems can be also partitioned with reference to the place of the access points, which can be within the same network or in different ones. The first case refers to horizontal handover and the second case to vertical handover. The vertical handover can in turn be of two classes, which are the upward handover and the downward handover.

Another dimension is the domain. Handover systems can in this case be of two classes, namely intra-domain handover and inter-domain handover. Intra-domain handover means that the mobile node can roam within the same network domain. Inter-domain handover means that the mobile node can cross from one domain to another one.

Finally, the last dimension is the system. An inter-system handover refers to the case that a mobile node hands off between two independent systems controlled by different operators. An intra-system handover refers to the situation where the both domains are deserved by the same system.

The IETF document RFC 3753 on "Mobility Related Terminology" is perhaps one of the best documents that defines terms for mobility related terminology [2]. The document covers specific terminology used in handover as well as in mobile ad-hoc networking. All types of handover are considered to facilitate seamless roaming in a heterogeneous environment formed by highly-coupled and heterogeneous networks.

There are three possibilities to handle movement: at the link layer (L2), network layer (L3) and application layer (L5) in the TCP/IP protocol stack. The complexity of handover is large and demands for solving problems of different nature. Accordingly, a number of standard bodies have been working on handover, e.g., IEEE, 3GPP, 3GPP2, WiMAX, IETF.

L2 mobility across different access technologies is covered by 3GPP, 3GPP2 and WiMAX in a number of documents, e.g., TS23.402 and TS23.228 (3GPP), A.S0023, X.P0058 and X.S0013 (3GPP2), NWG_R1_V1.2-Stage-3-3GPP-Interworking, NWG_R1_V1.2-Stage-3-3GPP2-Interworking, NWG_R1_V1.2-Stage-2-3GPP-WiMAX-Interworking, and NWG_R1_V1.2-Stage-2-3GPP2-WiMAX-Interworking (WiMAX Forum). L3 mobility is addressed by IETF. Therefore, the IP Multimedia Subsystem (IMS), which is acting as a service layer, does not need to cover mobility issues related to access but other mobility issues.

The rest of the paper is as follows. Section II briefly overviews the main characteristics and most important technologies of the fourth generation mobile communication systems. Section III is about seamless handover and the solutions existent today with a particular focus on their limitations. Section IV describes the main elements involved in mobility management. Section V shortly describes the algorithms that can be used for connectivity management in connection with mobility. Section VI is about Internet mobility and the most important solutions used to solve this. Sections VII and VIII present short overviews of the network layer mobility and application layer mobility, respectively. Finally, section IX concludes the paper.

2 Vision

Future mobile networks are expected to be all-IP-based heterogeneous networks that allow users to use any system anytime and anywhere. They consist of a layered combination of different access technologies, e.g., UMTS, WLAN, WiMAX, WPAN, which are connected via a common IP-based core network to provide interworking. These networks are expected to provide high usability (anytime, anywhere, any technology), support for multimedia services, and personalization. Key features are user friendliness and personalization as well as terminal and network heterogeneity [3].

User friendliness refers to the way the user interacts with the terminal, which must be simple and friendly. User personalization refers to the way users configure the operational mode of the terminal based on personal preferences. Given the large spectrum of existent users with different preferences, experiences and background, the consequence is that user friendliness and personalization should be able to offer a high degree of granularity such as the huge amount of information is selected in an appropriate way.

Terminal heterogeneity refers to the different types of terminals existent today and expected to appear in the future. This heterogeneity refers to, e.g., energy consumption, bandwidth, display size, weight, portability, complexity. On the other hand, network heterogeneity refers to the increasing heterogeneity of networks, e.g., UMTS, WLAN, WiMAX and Bluetooth. This heterogeneity mainly refers to technology, coverage area, data rate, latency, and loss rate. One of the biggest challenges is therefore to provide communication services with the best QoS and the best price irrespective of the type of terminal and network involved in the communication process.

The most important technologies of the future mobile networks are multicarrier modulation, use of smart antenna techniques, use of OFDM-MIMO techniques, use of adaptive modulation and coding with time-slot scheduler, use of cooperative communication services and local/triangular retransmissions, software-defined radio and cognitive radio [4].

With reference to handover, the main requirements are in terms of service continuity, provision of horizontal and vertical handover, provision of security, policy-based handover, flexibility, making the heterogeneous network transparent to user and design of system architecture such as it is independent of the (wireless) access technology. Connected to this, particular focus must be given to mobility management aspects (e.g., access network location, paging and registration) as well as provision of QoS, user and network security [5].

3 Seamless Handover - Situation Today

There are three possibilities to handle movement, namely at the link layer (L2), network layer (L3) and application layer (L5). Most of the existent solutions attempt to solve the handover at L2 (access and switching) and L3 (IP) with particular consideration given to L4 (transport). Some of the most important requirements are on seamless handover, efficient network selection, security, flexibility, transparence with reference to access technologies and provision of QoS.

Typically, the handover process involves the following phases:

- Handover initiation
- Network and resource discovery
- Network selection
- Network attachment
- Configuration (identifier configuration; registration; authentication and authorization; security association; encryption)
- Media redirection (binding update; media rerouting)

The basic idea of L2/L3 handover is using Link Event Triggers (LET) fired at Media Access Control (MAC) layer, and sent to a handover management functional module such as L3 Mobile IP (MIP) or L3 Fast MIP (FMIP) or IEEE 802.21 Information Server (IS). LET is used to report on changes with regard to L2 or L1 conditions, and to provide indications regarding the status of the radio channel. The purpose of these triggers is to assist IP in handover preparation and execution.

The type of handover (horizontal or vertical) as well as the time needed to perform it can be determined with the help of neighbor information provided by the Base Station (BS) or Access Point (AP) or the IEEE 802.21 Media Independent Handover Function (MIHF) Information Server (IS).

Based on the type of handover, one or more layers may be involved in the handover procedure, as shown in table 1. This table shows an example on how the basic handover functions are handled at the layers L2, L3 and L5 in an IP-based handover environment [6].

Given the extreme diversity of the access networks, the initial model was focused on developing common standards across IEEE 802 media and defining L2 triggers to make Fast Mobile IP (FMIP) work well. Connected with this, media independent information needs to be defined to enable mobile nodes to effectively detect and select networks. Furthermore, appropriate ways need to be defined to transport the media independent information and the triggers over all 802 media.

In reality, however, the situation is much more challenging. This is because of the extreme diversity existent today with reference to access networks, standard bodies and standards as well as architectural solutions [7]. Other problems are because of the lack of standards for handover interfaces, lack of interoperability between different types of vendor equipment, lack of techniques to measure and assess the performance (including security), incorrect network selection, increasing number of interfaces on devices and the presence of different fast handover mechanisms in

Handover operation	**L2**	**L3**	**L5**
Discovery	Scanning	Router advertisement	Domain advertisement
Authentication	EAPoL	IKE, PANA	S/MIME
Security association	802.11i	IPSEC	TLS SRTP
Configuration	ESSID	DHCP stateless	URI
Address uniqueness	MAC address	ARP DAD	SIP registration
Binding update	Cache update	Update CN, HA	SIP re-invite
Media routing	IAPP	Encapsulation tunneling	Direct media routing

Table 1. Handover operations at L2, L3 and L5 [6]

IETF, e.g., MIPv4, Fast MIPv6 (FMIPv6), Hierarchical MIPv6 (HMIPv6), Fast Hierarchical MIPv6 (FHMIPv6).

IETF anticipated L2 solutions in standardized form (in the form of triggers, events, etc), but today the situation is that we have no standards and no media independent form [7]. Other problems are related to the use of L2 predictive trigger mechanisms, which are dependent of L1 and L2 parameters. Altogether, the consequence is in form of complexity of the existent solutions and dependence on the limitations of L1, L2 and L3. The existent solutions are simply not yet working properly, which may result in service disruptions. Because of this, it is important to develop cross-layer architectural solutions where cooperation is established between L2 and L3 to assist the IP handover process and to improve the performance. Even better would be to develop architectural solutions where IP has control over specific L2 handover-related actions.

Today, user mobility across different wireless networks is mainly user centric, thus not allowing operators a reasonable control and management of inherently dynamic users. This is the reason for why the IEEE 802.21 Working Group is doing an effort to ratify the Media Independent Handover (MIH) standard, to enhance the user centric mobility handovers and enable network controlled handovers across heterogeneous networks [8]. In parallel to this, IETF addresses the IP level support for mobile heterogeneous access like, e.g., the Working Group (WG) on "The Mobility for IP: Performance, Signaling and Handoff Optimization (MISHOP)". This WG regards the delivery of information for MIH services at L3 or above. The L3 discovery component is also defined. The target is to enable MIH services even in the absence of the corresponding L2 support. The security issue is addressed as well.

IEEE 802.21 defines a framework to support information exchange regarding mobility decisions, which is irrespective of media. The goal is to facilitate handovers among heterogeneous access networks. Handover decisions are taken based on information collected from both mobile nodes and network, e.g., link type, link identifier, link availability, link quality.

The core of the IEEE 802.21 framework is the Media Independent Handover Function (MIHF), which provides abstracted services to higher layers by means of a unified interface. This unified interface provides service primitives that are independent of the access technology. This interface is called Service Access Point (SAP).

IEEE 802.21 MIH is targeted at optimizing L3 and above handovers. It acts across 802 networks and extends to cellular networks like 802.3, 802.11, 802.16. 802.21 MIHF Information Server (IS) has information about location of PoA, list of available networks, cost, L2 information (neighbor maps), higher layer services (e.g., ISP, MMS) and others. Key benefits are optimum network selection, seamless roaming and low power operation for multi-radio devices.

Furthermore, it is important to point out that the traditional TCP/IP protocol stack was not designed for mobility but for fixed computer networks. This is particularly shown by the fact that the responsibility of individual layers is ill-defined with reference to mobility. The main consequence is that problems in lower layers related to mobility may create bigger problems in higher layers. Higher layer mobility schemes are therefore expected to better suit Internet mobility.

Better prediction mechanisms and especially some form of movement prediction would definitely improve the handover performance in the sense that this could compensate for errors connected with delay in the handover process and the associated service disruptions. One should also keep in mind that this kind of solutions opens up for research and development of new architectural solutions for handover based on movement, possibly implemented at L5 in the protocol stack like, e.g., the application layer architecture developed by the Blekinge Institute of Technology (BTH) research group [9].

4 Mobility Management

Mobility management refers to the problem of managing the mobility of users in the context of diverse computing and networking environments. Considerations must be given in this case to elements like location-aware services, system capacity and application demands.

There are two major elements involved in mobility management, i.e., handover management and location management [5]. Handover management refers to the way the network acts to keep mobile users connected when they move and change their position and access points in the network. For instance, in the case of UMTS, there are two types of handover: intra-cell handover and inter-cell handover. Intra-cell handover refers to the situation when the mobile user changes the communication channel to one with a better signal strength at the same Base Station (BS). Inter-cell handover occurs when a user moves from one cell to another. In this case, another BS takes over the control of the user connection.

As a general rule, the procedure for intra-cell and inter-cell handovers is as follows:

- The user initiates a handover procedure
- The network or the mobile unit provides necessary information
- The routing operation associated with the handover is performed
- All subsequent calls to the user are transferred from the former connection to the later one

Location management refers to the process used by a network to find out the current attachment point of a mobile user and provide call delivery. There are two phases involved in location management, namely location registration or update and paging. Location registration means that the mobile user periodically notifies the network about the new access point and the network uses this information to authenticate users and to update the location profile. Paging means that the network is queried for the user location profile so that the current position is found.

The standard solution existent today for Location Area (LA) based location update does not allow adaptation to the mobility characteristics of the mobile node. Many research efforts have therefore been done over the last years to improve the performance by designing dynamic location update mechanisms and paging algorithms. The basic idea is that these mechanisms take into consideration user mobility and accordingly optimize the signaling cost associated with location update and paging. The goal is to reduce the costs associated with these mechanisms to a minimum. Examples of such algorithms are [5]:

– Distance-based location update approach
– Time-based location update approach
– Movement-based location update approach
– Movement threshold scheme
– Information theoretic approach

A very important research issue is therefore regarding location modeling and mobility modeling and prediction. Location modeling refers to how to describe the position of a mobile user, whether it is a one-dimension or two-dimension or three-dimension system. Different methods can be used for location modeling, which depend upon the specific network infrastructure. Usually, the position of a mobile user can be specified at three levels: location area, cell ID and the position inside the cell. Furthermore, one should also mention that a more precise location modeling (i.e., within a cell or a WLAN rather than finding the residing cell) may demand for solving a so-called geo-location problem.

Mobility modeling and prediction strongly influences the choice and performance of other resource management elements like call admission control, routing and handover. A precise model for mobility offers the possibility of improving the performance of mobility prediction, with positive effects on performance. Diverse criteria can be used for mobility modeling like, e.g., dimension, scale, randomness, geographical constraints and change of parameters. The most popular models are [5]:

– Fluid-flow models
– Random-walk models and derivatives
– Random-waypoint models and derivatives
– Smooth random-mobility models
– Gaussian-Markov models
– Geographic-based models
– Group-mobility models
– Kinematic mobility models

These models have specific advantages and drawbacks, and each of them is usually used in specific cases only.

5 Connectivity Management

The extreme heterogeneity existing today with reference to access networks and network technologies has had as a consequence that the problem of mobility management has now become more complex. The fact that a handover procedure is not directly related to physical parameters like coverage and movement speed has had as a consequence that the mobility has now become a logical concept rather than a physical one. This means that today mobility refers not only to the user geographic position but also to the change of a logical location with respect to network access points. The consequence is that mobility management becomes more of a connectivity management procedure.

There are two aspects that must be considered in vertical handover. These are regarding handover at device level and handover at flow level [10]. Device level handover refers to the situation when data transfers are switched over from one network interface to another within the same mobile node. On the other hand, flow level handover refers to the situation when the network interface is selected based on the specific traffic flow and every individual traffic flow takes own handover decisions. Multi-homing handover is possible in this case when multiple network connections are simultaneously used.

There are two general classes of algorithms used in the vertical handover, which are based on [10]:

- Traditional algorithms, and
- Context based algorithms

Traditional algorithms are typically used in horizontal handover and focus mainly on L1 and L2 parameters like link quality conditions, e.g., Received Signal Strength Indicator (RSSI), Signal to Noise Ratio (SNR), frame error rate and base station workload. These parameters can be used in vertical handover as well. The target in this case is to minimize the number of unnecessary handovers while maintaining throughput and latency constraints.

Context based algorithms target at always providing best possible QoS and user-perceived Quality of Experience (QoE). High level information like user preferences, cost, application features, device capacity, bandwidth, security are considered in this case. The target is to provide the so-called "Always Best Connected (ABC)" paradigm in the handover procedure.

There are three categories of context based algorithms [10]:

- Traffic flow based algorithms
- Simple Additive Weighting (SAW) algorithms, and
- Advanced Multiple Criteria Decision Making (MCDM) algorithms

Traffic flow algorithms classify the packets based on their traffic class field, IP address, port number and protocol. Different network interfaces are assigned to different traffic flows based on the characteristics of applications, e.g., real-time and non-real-time services.

SAW-based algorithms use weights assigned to parameters considered relevant for a specific handover mechanism. Weighted sums are computed based on all normalized factor values for the specific parameters. Based on this, individual scores are computed and the network interfaces are ranked based on the scores resulted from the evaluation [11].

MCDM-based algorithms are quite sophisticated. The handover decision is treated in this case as a MCDM problem, which is solved using classical MCDM methods and including techniques like Analytic Hierarchy Process (ARP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Grey Relation Analysis (GRA) [10].

It is important to mention that, in the handover decision making algorithm, the evaluation and decision are processes that can be local or distributed. Especially the case of distributed algorithms is very challenging, given that it is not only the decision making algorithm itself that must be solved but also other control mechanisms that are typical for distributed algorithms, e.g., synchronization, causality. The target in this case is to come to an optimal global decision with reference to a set of local and distributed requirements.

6 Internet Mobility

Internet mobility refers to providing support for communication continuity when an IP-based mobile node moves to different networks and it changes the point of attachment. There are in this case several basic requirements on the TCP/IP protocol stack and networks. These requirements refer to handover and location management, support for multihoming, support for current services and applications as well as security. Other important requirements related to mobility refer to minimum changes to applications, avoidance of using third-party for routing and security purposes as well as easy integration in the existent infrastructure.

The traditional TCP/IP protocol stack and networks have been designed and developed for fixed computer networks. This means that a number of limitations must be solved when further developing the system to provide support for mobility. The main limitations are particularly because of physical and link layer, IP layer, lack of cross-layer awareness and cooperation, transport layer and applications [12].

Today, wireless access techniques are typically providing mobility of homogeneous networks at link layer only. On the other hand, Internet mobility across heterogeneous networks demands for mobility support provided in higher layers as well. Furthermore, radio channels typically show limitations when compared to fixed networks. They are characterized by lower bandwidth, higher bit error rates, faded and interfered signal. These limitations degrade the performance of transport protocols.

The main limitation related to IP layer is because IP addresses play the roles of both locator and identifier. In a mobile environment the IP address of a mobile node must be changed when moving to another network to reflect the change of the point of attachment. This feature is in conflict with the situation at fixed networks, where the IP addresses never change.

Other important limitations are because of the lack of cross-layer awareness and cooperation. For instance, the congestion control mechanism of TCP is not able to distinguish packet losses due to link properties from those due to handover. Because of this, TCP does not perform well for seamless roaming. In a similar way, the lack of L2/L3 cross-layer interaction further deteriorates the performance. Another fundamental limitation of transport protocols is because they can not deal with mobility on their own.

Limitations due to improper design of applications for mobile environments are important as well. For instance, applications like Domain Name System (DNS) and Session Initiation Protocol (SIP) have characteristics that are not favorable for mobility. The best example is given by DNS, where the Fully Qualified Domain Name (FQDN) is usually statically bound to an IP address of a node. This is not favorable in the case of mobility, where mobile nodes change IP addresses. Further, the main limitation of SIP is because of the relatively large delays associated with SIP transactions.

A number of solutions have been suggested and developed to solve the problem of Internet mobility. They can be partitioned into four classes:

- Mobility support at L3, e.g., MIPv4, MIPv6, Location Independent Network Architecture for IPv6 (LIN6)
- Mobility support at L4 of type improving TCP performance for mobility (e.g., Mobile TCP - MTCP) or mobility extension to TCP (e.g., MSOCK, Mobile UDP - MUDP, Mobile SCTP - MSCTP)
- New layer between L3 and L4, where the Internet mobility is deployed, e.g., Host Identity Protocol (HIP), Multiple Address Service for Transport (MAST)
- Mobility support at L5, e.g., Dynamic Updates to DNS (DDNS), Session Initiation Protocol (SIP), MOBIKE

Detailed description of these protocols, together with their limitations, is provided in [12].

Table 2 presents an example of functions provided by different solutions existent for Internet mobility at L3, L4, new layer between L3 and L4, and L5. The following functions (needed for mobility) have been considered:

- Handover management (HO)
- Location management (LO)
- Multihoming (MH)
- Support for current services and applications (APP)
- Security protection (SEC)

It is observed that none of the available solutions fulfills all requirements for mobility. For instance, the network layer solutions do not support multihoming, the transport layer solutions do not support location management, application layer solutions are only appropriate for specific applications and so on.

	L3		**L4**			**New layer**		**L5**
	MIP	LIN6	TCP	UDP	SCTP	HIP	MAST	SIP
HO	$\star$	$\star$	$\star$	$\star$	$\star$	$\star$	$\star$	
LO	$\star$	$\star$				$\star$	$\star$	$\star$
MH					$\star$	$\star$	$\star$	$\star$
APP	$\star$	$\star$	$\star$	$\star$	$\star$			
SEC	$\star$	$\star$	$\star$		$\star$	$\star$	$\star$	$\star$

Table 2. Internet mobility and limitations [12]

7 Network Layer Mobility

L3 mobility means that the network layer handles mobility and it can be either mobile controlled or network controlled. In the first case, the mobile node is equipped with a mobility stack and interacts with remote entities like Home Agent (HA). Network controlled mobility means that there are networking units in the network that interact with HA and perform handover related functions. It is important to mention that, even in the case of network controlled mobility, the mobile node still assists the mobility function by providing information about, e.g., signal-to-noise ratio and other specific measurement related information.

In the case of mobile controlled mobility done with, e.g., the Client MIPv6 (CMIPv6), the mobility stack in the mobile node sets up a tunnel between the Mobile Node (MN) and HA. The mobile node sends a binding update to the HA and the Correspondent Node (CN), which maps the new Care-of-Address (CoA) for the mobile node with its own home address. With the help of some route optimization procedure, the CN updates its own cache and sends traffic directly to MN instead of via HA.

Network controlled mobility avoids the overhead associated with tunneling. The price is in different forms, e.g., limited mobility domain (like in the case of cellular IP, HAWAII), use of proxies in the network like the so-called Proxy Mobile Agents (PMA) [13]. The solution with limited mobility domain still does require a mobility stack in MN. On the other hand, PMA does not demand for mobility stack in MN but rather uses the proxies on the edge routers to help performing mobility functions like binding updates to HA.

The Proxy MIPv6 (PMIPv6) based mobility is preferred when mobility is confined within a domain and also when avoiding overload of mobile nodes by setting up tunnels between MN and HA. Mobile overload means that extra processing is added and bandwidth constraints are set to the wireless hop.

8 Application Layer Mobility

Application layer mobility refers to using the application protocol Session Initiation Protocol (SIP) [13, 14]. This solution offers the advantage of eliminating the need for mobility stack in mobile nodes and also does not demands for any other mobility elements in the network. Simple

IP is used in this case together with a SIP protocol stack. No additional elements are needed to support application layer mobility. This solution is very suitable for applications like VoIP.

SIP-based handover has several drawbacks. These are mainly because SIP is an application protocol and therefore involves large delays in handover, due to application layer processing. There are several solutions to reduce the handover delays in this case, and one of the most efficient is to develop a tight-coupled interworking architecture like, e.g., in the case where the WLAN Access Points are integrated into the UMTS network architecture [4].

Another drawback is that this solution is not suitable for non SIP-based applications like FTP and Telnet based applications. SIP can be used to support RTP and TCP based applications. Furthermore, another drawback is because the TCP connection must be kept alive even when the underlying IP address is changed. This means that better solutions must be used in this case for TCP, like TCP Migrate [5, 12]. Furthermore, it is very important that prediction is used in this case to reduce the negative effects of changing the IP address.

It is important to mention that things may become quite complicated when the mobile node and the network have different mobility protocols. The mobile node may for instance support simple IP without any mobility stack or it can be equipped with SIP or, alternatively, it can be equipped with a MIPv6 protocol stack. The network in this case needs to complement the mobile node protocol. In the case of IP protocol in the mobile node, the network does not need any other protocol. In the case of MIPv6 in the mobile node, then the network must have this protocol stack as well.

9 Conclusions

The paper has reported on several important developments and challenges related to seamless handover. These are regarding L2/L3 handover, mobility management, connectivity management, Internet mobility, network layer mobility and application layer mobility.

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