

◆ Global Roaming and Personal Mobility with COPS Architecture in SuperDHLR

Ramana Isukapalli, Triantafyllos Alexiou,
and Kazutaka Murakami

Personal mobility removes the fixed association between a terminal and a user (a characteristic of traditional fixed and mobile networks), thereby adding one more degree of mobility on top of terminal mobility. Global roaming allows a user to roam in communication networks of different technologies. These two mobility options provide users with ubiquitous services across networks of different types. This paper identifies the technical challenges to achieving global roaming and personal mobility. We propose common operations (COPS) architecture to allow effective multiprotocol support and efficient protocol interworking among disparate networks and compare it with other approaches. SuperDHLR embodies the COPS architecture. It keeps track of user location, manages user profiles for multiple networks, and incorporates service logic for global roaming. It serves as a home location register (HLR) for wireless networks and a mobility management server for Internet protocol (IP) networks. SuperDHLR enables terminal and user mobility and facilitates seamless roaming across circuit and packet switched wireless networks, the Internet and wireline networks.
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Introduction

The introduction of mobile wireless networks endowed the terminal with mobility—hence the realization of mobile terminal. However, terminal mobility does not meet the needs of subscribers for personal mobility. They prefer that their services not be restricted in the coverage area of their wireless network alone. The concept of personal mobility has been introduced [3, 5, 8, 10, 12], allowing a user to move from one terminal to another while receiving the same service. Some of the proposed approaches, however, assume mobility in the same type of network [5], and others rely on the introduction of a new protocol suite for realizing personal mobility

[3, 10]. Furthermore, most proposals realize personal mobility by mapping a personal address to a terminal address in a way that requires an additional home location register (HLR) interrogation to map it to the roaming location.

Global roaming is also gaining much attention in today's disparate wireless networks. It is mobility with an emphasis on roaming between networks of different types [11]. Global roaming brings new issues to several components in a mobile network. Accommodation of multiple air interfaces is one of the major issues if the same terminal is used for roaming. From the viewpoint of an HLR, however,

the main issue is protocol conversion between mobility management protocols. Recent activity in this area includes the standardization of the signal translation mechanism between today's two predominant wireless protocols, Global System for Mobile Communications (GSM) and American National Standards Institute-41 (ANSI-41) [6]. However, the proposed approach is based on a one-to-one protocol mapping between these two wireless protocols, and as discussed in "Existing Approaches" below, the architecture is not designed to accommodate new protocols such as session initiation protocol (SIP), which has attracted much attention from the telecommunications community.

SIP is being used more and more as part of various mobility solutions. It supports personal mobility over Internet protocol (IP) networks, as well as public switched telephone networks (PSTNs). The wireless telecommunications community is also considering it as the signaling protocol for its future all-IP wireless networks. They have started the standardization activity at 3rd Generation Partnership Project (3GPP) and 3rd Generation Partnership Project 2 (3GPP2), and are considering converging approaches [9]. Although IP telephony protocols have been gaining momentum, a single-type global all-IP network with common Internet-centric signaling is still far in the future. Traditional telephone networks, whether wireless or wired, of different technologies will have to coexist and interoperate for many years.

This paper proposes SuperDHLR supporting personal mobility and global roaming across networks, including telecommunications networks (both wired and wireless) and the Internet. SuperDHLR provides full support for each of the different protocols separately or in combinations, and allows for interworking between them so that users can retain their services while roaming to networks of different types. It directly terminates mobility management protocols such as ANSI-41, GSM Mobile Application Part (MAP), and SIP, and does not require any new protocol suite to achieve this goal. Common operations (COPS) architecture is introduced in this paper and selected to realize protocol interworking effectively. COPS has an extensible structure so that it can integrate support for

Panel 1. Abbreviations, Acronyms, and Terms

2G—second generation
 3G—third generation
 3GPP—3rd Generation Partnership Project
 3GPP2—3rd Generation Partnership Project 2
 4G—fourth generation
 AAA—authentication, authorization, and accounting
 ANSI-41—American National Standards Institute-41
 CDS—core database server
 CLS—core logic server
 COPS—common operations
 DHLR—distributed home location register
 DN—directory number
 G-MSC—gateway MSC
 GSM—Global System for Mobile Communications
 IAM—initial address message
 IN—intelligent network
 IP—Internet protocol
 ISDN—integrated services digital network
 ISO—International Standards Organization
 ISUP—ISDN user part
 LAN—local area network
 MAP—mobile application part
 MPA—mobile people architecture
 MSC—mobile services switching center
 MS—mobile station
 MSRN—mobile station routing number
 OSI—open systems interconnect
 PDLS—protocol dependent logic server
 PLMN—public land mobile network
 PSTN—public switched telephone network
 QoS—quality of service
 SCP—service control point
 SIM—subscriber identity module
 SIP—session initiation protocol
 S-MSC—serving MSC
 TLDN—temporary local directory number
 UMTS—Universal Mobile Telecommunications System
 UPT—universal personal telecommunication
 URI—universal resource identifier
 URL—universal resource locator
 VLR—visitor location register
 VoIP—voice over IP

future all-IP wireless networks and provide a migration path from circuit switched wireless networks to all-IP networks. It has an evolutionary view of all-IP wireless networks and does not consider them as overlay networks.

SuperDHLR has an integrated user profile database with a single provisioning system to reduce operating costs for providers, enable them to extend their services to multiple domains, and help them avoid the proliferation of heterogeneous database systems. It extends the individual protocol subscriber profiles with user- or provider-configurable options and preferences for call handling and interworking. The database introduces the concept of a *user*, to which multiple *terminals* can belong, allowing personal mobility. It manages the location of all participating terminals for a user. Thus, a location request can be directly translated into a device location leading to efficient global roaming.

This paper is organized as follows. The section on “Existing Approaches” reviews the existing approaches to global roaming and personal mobility and discusses their limitations. “COPS Architecture and SuperDHLR” explains our vision of global roaming and proposes COPS architecture as a means to achieving it. It also explains how it is used in SuperDHLR. “Global Roaming Approach with SuperDHLR/COPS” illustrates the usage of personal mobility in SuperDHLR to enhance the scope of global roaming to multiple terminals operating in several disparate networks. “Benefits of SuperDHLR with COPS Architecture” summarizes the benefits of SuperDHLR and COPS architecture, followed by our “Conclusion.”

Existing Approaches

Current wireless networks allow users to roam and to get service in a visiting network that possibly belongs to a different provider, but uses the same signaling protocol (e.g., ANSI-41, GSM MAP) to handle call sessions. In the GSM world, roaming was facilitated by a subscriber identity module (SIM) card—a smart card—that helps the network to identify the subscriber and locate the service profile. Personal mobility, backed by a SIM card, spanning from wireless to wireline networks was thought possible, if

wireline terminals could support SIM cards. However, the latter never happened.

The idea of an intelligent network (IN) was introduced to provide enhanced personal communication services (such as personalized voice, data, image, and video communication), as well as the necessary networking functions that would allow the cooperation of networks of various types, whether wireless or wireline. IN supports personal mobility by means of a universal personal telecommunications (UPT) number associated with a person. Reference [5] discusses IN in detail. Applications of IN showed some limitations—it was mainly applied to PSTN. To the best of our knowledge, there is no IN implementation that can act as a user location server tracking user and terminal registrations from wireless and Internet protocols. Regarding UPT numbers, a provider uses a directory service to map them to mobile or PSTN phone numbers. However, in the case of mobile phones, after the provider’s service control point (SCP) obtains a mapped mobile phone number, an additional number translation is necessary. Namely, HLR must be interrogated to obtain a routing number from the mobile phone number in order to offer a call to the user’s serving mobile services switching center (MSC). SuperDHLR, however, could dynamically map such a UPT number directly to the proper routing number. The *follow-me* service of GSM and Universal Mobile Telecommunications System (UMTS) also provides personal mobility in a similar fashion [1], but with the same shortcoming.

SIP also provides personal mobility over the Internet. It allows for call delivery between the Internet and wireless networks through SIP/PSTN gateways. A SIP user can register a mobile phone number as a contact address with a SIP registrar. When a call is placed to the SIP user, the SIP proxy server sends an INVITE message with the mobile phone number to the SIP/PSTN gateway. This gateway contacts the gateway MSC (G-MSC) if the network is a GSM network, or the home-MSC if the network is an ANSI-41 network. The G-MSC or the serving MSC (S-MSC) then interrogates the HLR using a *send routing information* or *location request* message, respectively, in GSM and ANSI-41 networks to retrieve a routing number

toward the S-MSC. Therefore, the signaling and media path goes from the gateway to the G-MSC and then to the S-MSC. SuperDHLR can reduce this path by having the SIP/PSTN gateway directly contact the S-MSC, avoiding the G-MSC.

The GSM/ANSI-136 Interoperability Team (GAIT) defined a new functionality called interworking and interoperable functionality (IIF) that is used to support global roaming between GSM and ANSI wireless networks [6]. In this model, an intermediary agent called an IIF translates signaling messages between the two protocols. However, this approach may require two separate databases, each one keeping subscriber profiles for one protocol. The complexity of scaling this approach of one-to-one IIF agents for n protocols is $O(n^2)$. It makes deployment of services among new protocols difficult, since several different IIF modules would have to be modified. Such a system would inflate the operational and maintenance costs. An IIF implementation exists for ANSI-41 and GSM networks. Adding the SIP protocol would require two new IIF modules to route calls or share registration/deregistration events.

There are several research prototypes realizing personal mobility. One such example is the mobile people architecture (MPA) [8] that introduces the new concept of *person layer* on top of the application layer of the International Standards Organization (ISO) open systems interconnect (OSI) model to facilitate personal mobility with an MPA identity. A personal proxy is introduced that can interact with many types of networks for session initiation at a *person layer*. Since it can run outside of any network, it does not benefit from the mobility features of wireless protocols. It cannot directly receive mobile location information via wireless registration and deregistration messages. MPA also leads to inefficient media routing since a call session must always go through a personal proxy. The latter is similar to the inefficient triangular route created in GSM, when the subscriber roams in a foreign country's Public Land Mobile Network (PLMN), and a PSTN call to the subscriber originates from the same foreign country [4]. In addition, specific call flows with signaling protocols have not been considered.

ICEBERG architecture [10] integrates data and voice, supports networks with diverse access technologies, and facilitates personal mobility among them. ICEBERG architecture, aiming at operation in a wide area, requires deployment of ICEBERG points of presence, creation of provider/administrative domains. It also requires service-level agreements among the providers. It introduces an ad hoc signaling protocol, and requires an ICEBERG unique user ID. The approach is revolutionary. Any existing wireless/PSTN network beyond its access system is replaced with an ICEBERG network plane. On the other hand, SuperDHLR has well-defined interactions with the popular signaling protocols ANSI-41, GSM/UMTS, and SIP, benefits from these protocols, and does not intervene in session/conference control or network and quality of service (QoS) management. SuperDHLR also depends on the per network user and terminal identities.

COPS Architecture and SuperDHLR

SuperDHLR performs mobility management, user profile management, and authentication functions for users of different network types. These functions are required in traditional cellular networks (e.g., GSM, ANSI-41), third-generation wireless networks (e.g., UMTS, CDMA2000*), and the Internet (e.g., SIP), and are deployed over separate functional entities including ANSI-41 HLR, GSM/UMTS HLR, SIP servers, authentication, authorization, accounting (AAA) and remote authentication dial-in user service (RADIUS) servers, and so on. SuperDHLR realizes the functions of these different entities in one entity by supporting multiple standard protocol interfaces. By adopting the COPS architecture, SuperDHLR can further provide interworking capability and support global roaming across diverse networks.

The role of SuperDHLR in supporting global roaming across second-generation (2G), third-generation (3G), and all-IP fourth-generation (4G) networks is illustrated in **Figure 1**. The various networks and protocols SuperDHLR supports are shown around it. It acts as a traditional HLR for wireless networks (GSM, ANSI-41, UMTS) and a location and authentication manager for IP networks (SIP or Radius/

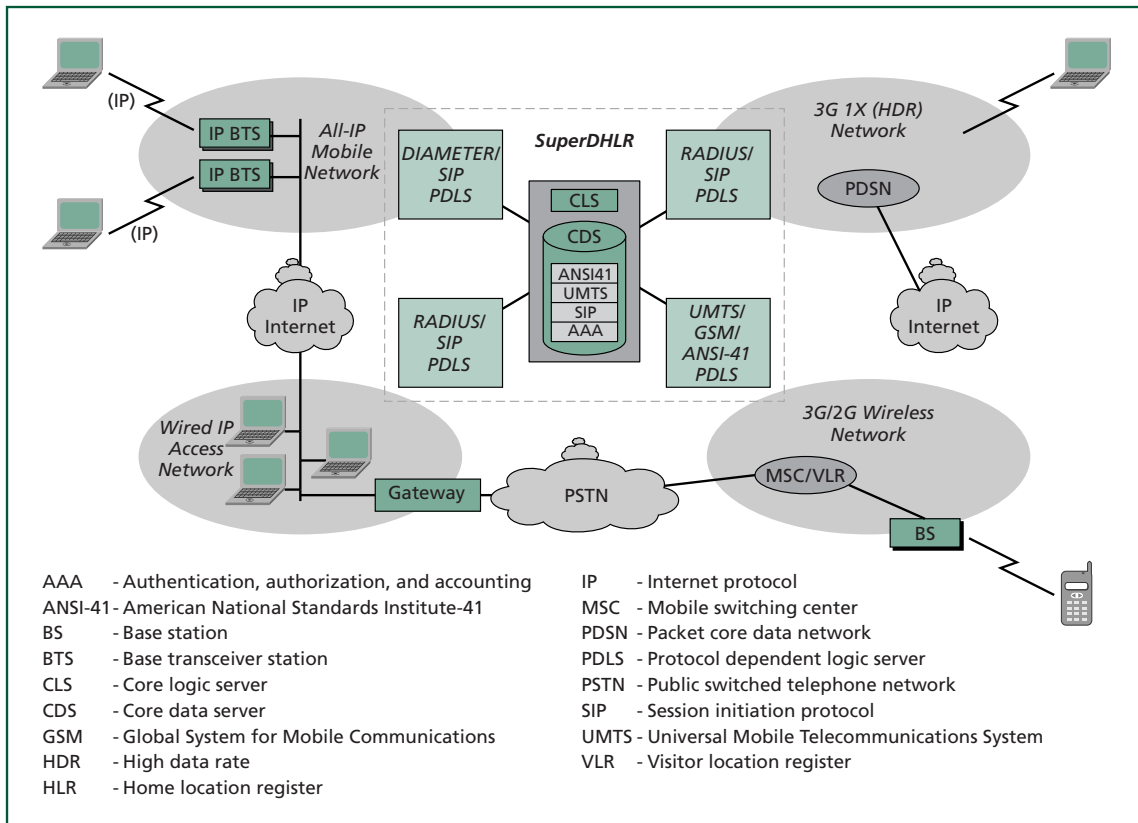


Figure 1.
SuperDHLR with COPS architecture to support global roaming.

Diameter). SuperDHLR embodies our vision of next-generation global roaming, providing ubiquitous service to a user that transcends the realms and boundaries of any protocol-specific networks. This can potentially involve multiple mobile and even fixed terminals. A subscriber will be able to have seamless roaming globally and still receive services everywhere uniformly, ranging from today's wireline PSTN networks, 2G wireless networks, and IP networks to tomorrow's 3G networks, 802.11 wireless local area network (LAN), and all-IP mobile networks. An end user, who wants to access a subscriber, needs to know only the subscriber's personal address, and of course does not have to know the network where the subscriber is currently roaming. Services such as authentication, authorization, registration, call delivery, and

message delivery may span any of the various protocols supported by these networks. A subscriber roaming in a UMTS network may receive calls addressed to the subscriber's SIP universal resource locator (URL) on the UMTS terminal. Similarly, the subscriber may register on a GSM cell phone in a GSM network and receive short messages that are stored in various message centers of an ANSI-41 network.

Support for such a rich feature set demands network elements that are sophisticated and cannot only understand the various protocols they need to support, but also translate the messages of any feature to messages of the different protocols they support. They need to communicate with various other network elements using protocol-specific messages. The overall architecture should be scalable, able to support

new protocols easily, and should not suffer from duplication of subscriber data. SuperDHLR with COPS architecture addresses with these issues. They will be discussed in this section.

COPS Architecture

This paper proposes COPS architecture to effectively achieve protocol interworking. Protocol interworking arises when a request from a network of a certain type must be fulfilled by issuing another request to a network using a different communication protocol. This capability is especially required to achieve global roaming. In wireless networks, for example, a location request is sent to a HLR from a certain network, such as UMTS, in order to deliver a call to a roaming wireless terminal. The response must include a temporary routing number that is used to deliver the call to the serving system. In order to obtain the routing number, HLR sends a routing number request message to a visitor location register (VLR). If a user roams to a network (e.g., an ANSI-41-based network) other than the network issuing a location request (here UMTS), protocol translation and interworking is required between the two protocols.

Figure 2 illustrates a system based on the COPS architecture. The major components are the core logic servers (CLSs), protocol dependent logic servers (PDLs), and the COPS interface that is defined between these two components. The system can

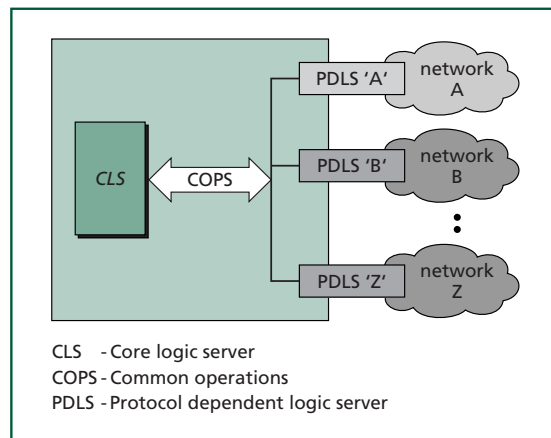


Figure 2.
COPS architecture.

support multiple types of networks with different protocols. Corresponding to each network type, a specific type of PDL is defined, which terminates the network specific protocol.

PDLs implement protocol-specific service logic. If it receives a request for a service that does not require interworking with another network, it provides the service directly, independent of CLS and COPS. However, if the service requested may require interworking with another network, PDL invokes the COPS interface to access CLS. The COPS interface defines the protocol-independent messages that are used as a means of communication between a CLS and a PDL of any type. The underlying principle in the usage of the COPS interface is interworking, that is, it embodies COPS for all features that can potentially involve interworking.

CLS provides some protocol-independent service and determines if interworking is necessary. If required, it then uses the COPS interface to communicate with the appropriate PDL of a target protocol to accomplish protocol interworking. In the event that there is no interworking, CLS still uses the same COPS message to achieve the service, but it is sent to a PDL of the same protocol type as the originating network.

An important feature of the COPS architecture is that PDL of any protocol A must know only protocol A and protocol-independent COPS interface and nothing else. No knowledge of protocols other than A is necessary for PDL. Multiprotocol handling and decisions on interworking are performed only by CLS. This ensures the ease of introduction of new protocols and will not cause any changes to the existing PDLs. This reduces the interworking complexity down to $O(n)$, where n is the number of protocols that need to be supported. This is a significant improvement over the $O(n^2)$ complexity for architectures that require separate interworking functions among all potential protocol pairs.

SuperDHLR Components

Figure 3 shows the high-level structure of SuperDHLR based on the COPS architecture. The core database server (CDS) is a front-end server to an integrated user profile database. This database is a

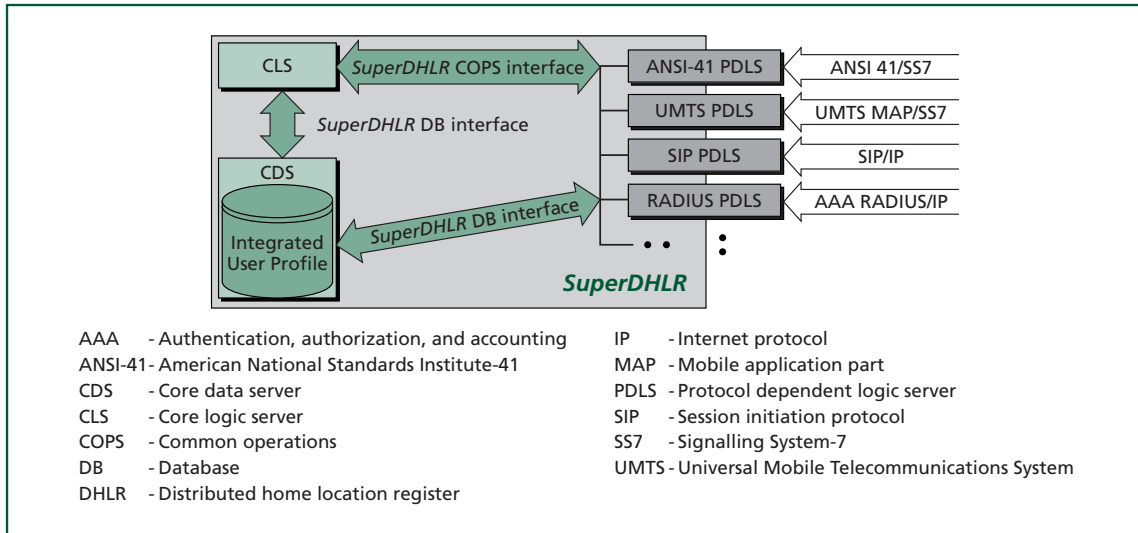


Figure 3.
High level architecture of SuperDHLR.

central repository of the user profile for all protocols to which they subscribe. SuperDHLR database interface provides a remote access mechanism to the profile database and is defined between CDS and CLS, as well as CDS and PDLS. One type of PDLS exists for each protocol: ANSI-41 PDLS, UMTS PDLS, SIP PDLS, AAA/RADIUS PDLS, and so on. More than one instance of CDS, CLS, and PDLS of a specific type can be deployed to achieve system scalability. Defined between PDLS and CLS is SuperDHLR COPS interface. The COPS interface provides various types of PDLSs with a common interface to support core mobility management operations. It sets clear functional separation between PDLS and CLS so that PDLS can use the functions provided by COPS interface as a black box to build its own service logic.

CLS provides the core mobility management services across multiple protocols. As discussed in the previous subsection, multiprotocol handling and decisions regarding interworking are only performed at CLS. When a PDLS receives any request that can potentially involve protocol interworking, it encodes the request in a protocol-independent COPS message and sends it to CLS over SuperDHLR COPS interface. CLS has the logic to communicate with the PDLSs of

various protocols to provide the service. Such COPS cover the core part of mobility management operations performed by HLR, namely call routing and delivery, terminal registration, message routing and delivery, and terminal status update for message service.

All other service procedures, which are confined to a single protocol, are handled totally by PDLS, with direct access to CDS for database lookup and update. Examples include mobile terminal deregistration procedure (e.g., UMTS purge mobile station [MS]) supplementary service management (activation, deactivation, registration, erasure, and password management), subscriber data management, and so on. Although core mobility management operations are handled by CLS, the majority of the request message types fall into this category, suggesting that a relatively small set of SuperDHLR COPS messages are necessary to achieve protocol interworking while supporting a full set of features for a certain protocol.

SuperDHLR COPS Interface

Table I summarizes the list of COPS messages corresponding to key mobility management features. It also lists the equivalent messages in ANSI-41,

Table I. COPS messages and the equivalent messages in various protocols.

Feature Name	COPS Message	ANSI-41 Message	GSM/UMTS MAP Message	SIP Message
Location Registration	Register Terminal	Registration Notification	Update Location	REGISTER
	Cancel Terminal Registration	Registration Cancellation	Cancel Location	N/A
Call Routing and Delivery	Request Location	Location Request	Send Routing Information	INVITE
	Request Route Information	Routing Request	Provide Roaming Number	ALLOCATE

ANSI-41—American National Standards Institute-41
 COPS—Common operations
 GSM—Global System for Mobile Communications

MAP—Mobile applications part
 SIP—Session initiation protocol
 UMTS—Universal mobile telecommunications system

GSM/UMTS MAP as well as SIP. Note that SIP ALLOCATE [2] is a SIP extension proposed for supporting interworking between traditional wireless networks with voice over IP (VoIP) networks based on signaling protocol such as SIP, as will be discussed in the next subsection.

Interworking Flow Examples

Call delivery procedures in wireless and IP networks can potentially involve interworking between networks of different protocols. Global roaming with a personal mobility feature as described in “Global Roaming Approach with SuperDHLR/COPS” could enable this type of protocol interworking. Interworking between GSM/UMTS and ANSI-41 networks is possible in the case of global roaming with a dual-mode phone supporting both air interfaces. The rest of this section illustrates two such interworking cases, one for wireless (UMTS) to wireless (ANSI-41), and another for wireless (UMTS) to IP (SIP). As shown in Table I, call routing and delivery uses two COPS messages, request location (RL) and request route information (RRI). A location request from any protocol is translated into an RL COPS message, which will be sent to a CLS. An RRI COPS message, on the other hand, is sent from a CLS and received at a PDL. It is then translated to a temporary routing number request message of the target protocol, which is sent to the serving system (e.g., VLR).

Wireless interworking scenario. Figure 4 shows the message flow for call delivery from a UMTS to an ANSI-41 network. Note that the caller can use any phone including a non-UMTS phone, but dials a UMTS phone number assigned to a callee. Interworking arises when the callee happens to roam to an ANSI-41 network. When the caller places a call using a UMTS directory number, an ISDN user part (ISUP) initial address message (IAM) is sent to an appropriate UMTS gateway MSC, which issues a location request message (UMTS send routing information [SRI]) to the SuperDHLR. Note that the SuperDHLR can be viewed just as a UMTS HLR from a UMTS network, and the UMTS PDL is the entity accepting UMTS requests. Upon receipt of the SRI request, the UMTS PDL rationalizes the service, translates this UMTS protocol message to a protocol-independent RL COPS message, and sends the message to a CLS. CLS first accesses a user database to find the location where the user is currently roaming. After determining that it is an ANSI-41 network, the CLS sends an RRI request to an ANSI-41 PDL, which translates the message to an ANSI-41 specific RRI message, namely an ANSI-41 ROUTEREQ message, and sends it to the serving VLR/MSC. The response with a temporary routing number is sent all the way back to the gateway MSC in the reverse direction, and the ISUP IAM message is finally relayed to the ANSI-41 serving MSC using the routing number just obtained.

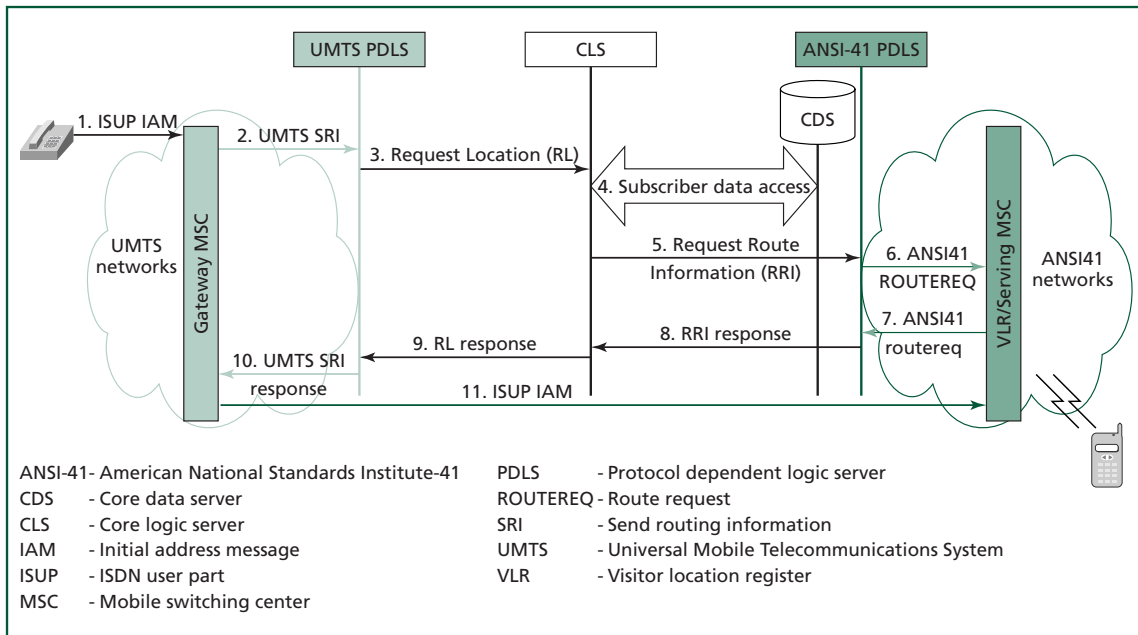


Figure 4.
Call delivery procedures from a UMTS to an ANSI-41 network.

Wireless and IP interworking scenario. Figure 5 shows the message flow for call delivery from a UMTS to a SIP network. The key difference from the previous scenario is that a PSTN-to-IP gateway is necessary for signal and media translation. The equivalent of a temporary routing number of wireless networks in SIP is the user's contact address itself. However, that cannot be returned directly to the originating (wireless) system to complete the call. In other words, it is necessary to emulate the temporary number allocation process to deliver a call from a gateway MSC to a PSTN/IP-SIP gateway. The SIP ALLOCATE method is proposed as an extension to SIP to accomplish this goal [2]. PSTN/IP-SIP gateway has a pool of temporary routing numbers as in VLR. Upon receiving a SIP ALLOCATE message, it allocates one available temporary number and saves its association with the SIP contact universal resource identifiers (URIs). The routing number is sent back to the SIP PDLS, and is eventually delivered back to the gateway MSC. Then the gateway MSC sends an ISUP IAM using the number, which reaches the PSTN/IP-SIP gateway that assigned the routing number. By checking temporary

mapping table from the number to contact-URI, it can send a SIP INVITE message to an appropriate SIP user agent to complete the call delivery.

Global Roaming Approach with SuperDHLR/COPS

In this section we illustrate how the usage of personal mobility in SuperDHLR can extend the scope of global roaming to multiple terminals operating in several disparate networks. We first clarify the concepts of "user" and "terminal," explain briefly how the data is organized in the SuperDHLR, and then show how this is used to enable personal mobility.

Concept of User and Terminal

SuperDHLR distinguishes a user from a terminal and provides a mechanism to reach a user on any available terminal that has been registered. To support such a feature, SuperDHLR provides a *personal address* that is a pseudo-telephone number (directory number) or a SIP URL that gets dynamically mapped to any mobile terminal, or a SIP phone belonging to the user, or even to a fixed telephone in the wireline network. In case multiple terminals (such as a cell phone and a SIP terminal) are registered and are

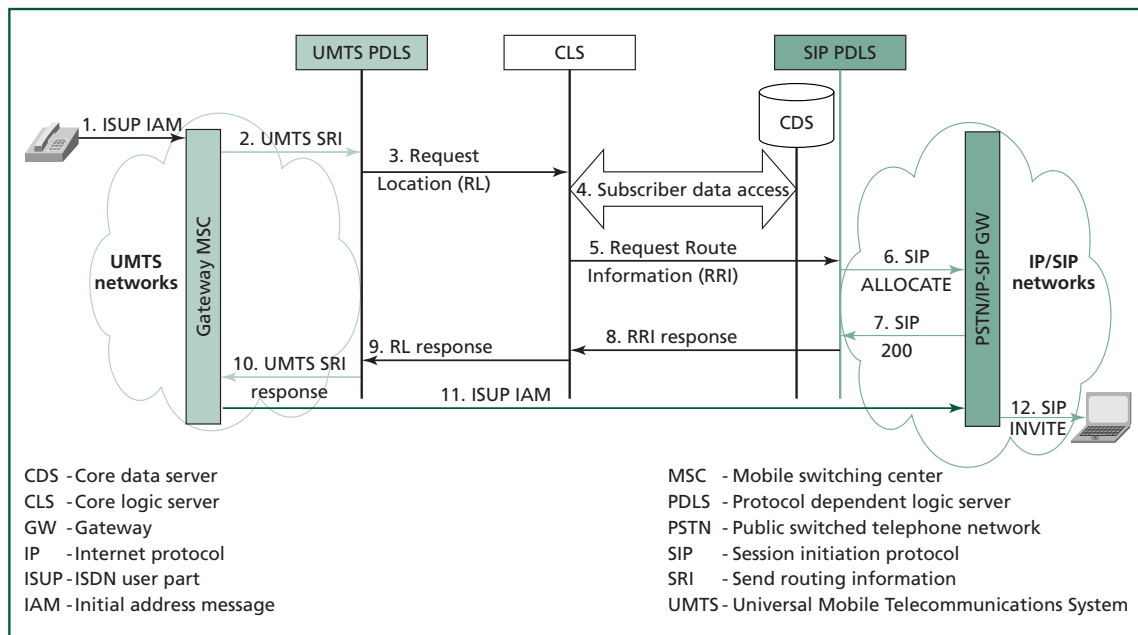


Figure 5.
 Call delivery procedures from a UMTS to a SIP network.

available simultaneously, the user can specify preference, that is, the order in which the terminals need to be alerted to access the user.

To provide such a rich set of features, the system should have the intelligence to associate a personal address to a terminal (or perhaps even multiple terminals), remember the various terminals that are currently registered and available, and locate them. An integrated user profile database in CDS manages user data and profile data for a set of terminals belonging to the user and maintains the association between them. **Figure 6** illustrates the logical view of the user profile database for a single user. The salient point to be noted here is the distinction between the “user” and “terminal” information.

User information has data concerned with the user—such as the name, address, and other relevant information. A personal address forms the key to every user record. A user can have multiple personal addresses and can have selective call delivery for each of them. For example, a user can have a personal address for business purposes and another for family

members. The former could include all office terminals, but not a home phone. Figure 6 shows two personal addresses for a user, a directory number (DN) and a SIP URL. Each of these has a *destination selection policy* associated with it. It specifies the order of terminals where the user prefers to receive calls. As an example, some users may prefer to receive calls on their SIP terminal first. If that fails, they may prefer to receive calls on their UMTS telephone. Similarly, they can specify different destination selection policies for each of their personal addresses. In the example above, they may specify to block all calls addressed to the second personal address (SIP URL), while they may accept the calls on the first one (DN). This can be modified dynamically, for example, based on the time of day or weekend.

Terminal information stores the data related to the various terminals of the user. Terminal address forms the key to each terminal record. A user may have terminals of different protocols, as well as multiple terminals of each protocol as shown in the figure. Each terminal record stores the terminal specific

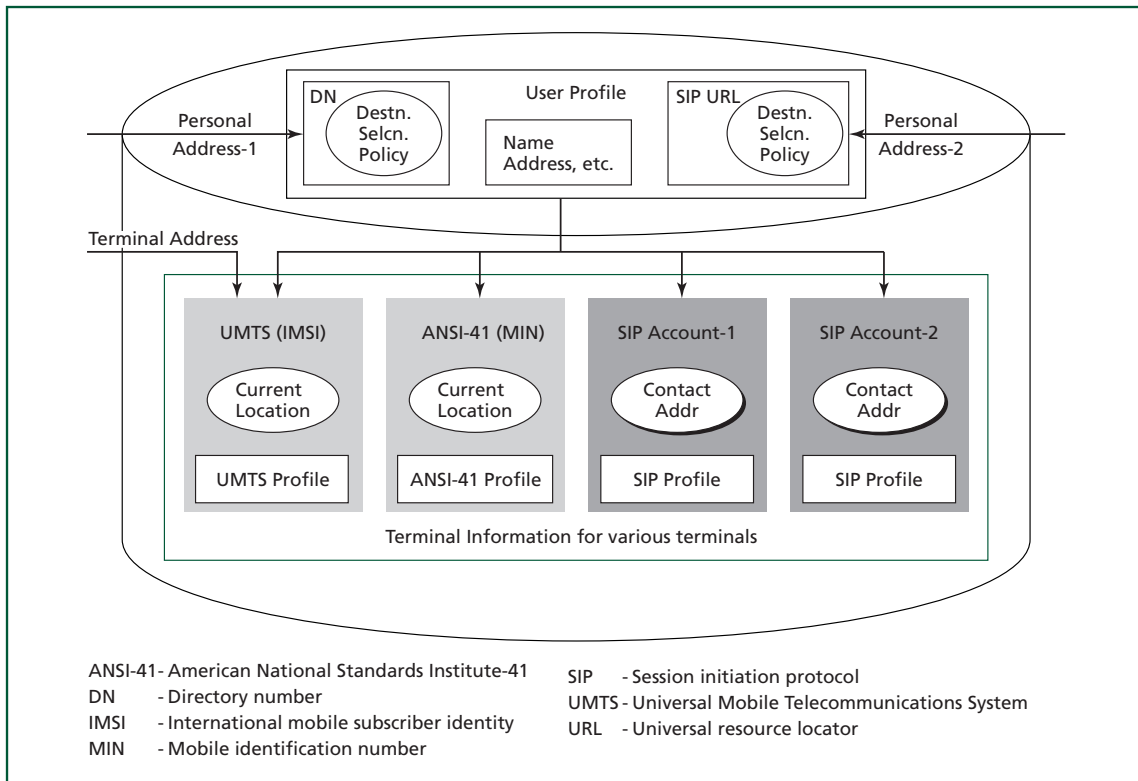


Figure 6.
User profile and terminal information storage in SuperDHLR.

profile (i.e., the terminal identifier or the protocols it supports) and the current location information. This terminal profile typically corresponds to the subscriber profile of each protocol. Using the personal address, the associated terminals and the other relevant information of any user can be retrieved, which in turn is used to reach a terminal where the user is accessible. Of course, it is also possible to reach the user at a *specific terminal* by using the terminal address.

A salient feature of this logical view of user and terminal data is that the database acts as a central repository for the location information of all the terminals associated with any user. With such a view, all the registered terminals of a user (who is called by a personal address) can be retrieved efficiently. This is a significant improvement over the current approach where the location information is distributed across

different HLRs of different protocols for each mobile terminal that the user owns. With such a distribution, every HLR needs to be contacted separately, which adds significantly to the signaling overhead.

Finally, with personal address in SuperDHLR, it is possible to call multiple registered terminals of a user simultaneously or sequentially until one terminal is reached. These features are better known in ANSI-41 protocol as *flexible alerting* and *multiple access hunting*. In SIP, the latter is known as *forking*. Different from the existing approaches, however, SuperDHLR can support these features across networks with different protocols in an effective manner. When CLS downloads the user profile and the profile of all the terminals for any subscriber, it has the knowledge of the location of each of these terminals. It can retrieve the routing numbers for any or all of them. It can then forward

these routing numbers sequentially or all at once to the requesting network element (such as a SIP proxy or a home MSC of ANSI-41), which in turn can try to deliver the call to them. The examples in the next subsection clarify these issues.

Examples

We present a couple of examples to illustrate personal mobility in SuperDHLR. In the first example, a user is called on his personal address, which is a UMTS directory number. The user has active registrations in a UMTS network, as well as an ANSI-41 network. In the second example, the user is called on a personal address, which is a SIP URL. The user has active registrations in UMTS, ANSI-41, and SIP networks. We show how the call is delivered to the user in both examples. The first example given below is similar to the first example given in “Interworking Flow Examples.” The emphasis there was on global roaming with terminal mobility using a dual-mode phone. Here we demonstrate it with personal mobility by delivering a call addressed to a UMTS directory number to an ANSI-41 telephone. To distinguish between UMTS,

ANSI-41, SIP and COPS messages, we use different colors in Figures 7 and 8 for different messages.

Personal mobility based on UMTS directory number.

Figure 7 illustrates this example. The user is assumed to have active registrations in UMTS and ANSI-41 networks, but not in SIP networks. CLS has knowledge of these registrations once it downloads the data from CDS (step 4). We assume that the destination selection policy (as shown in the figure) requires the SIP terminal to be alerted first, followed by the UMTS terminal and the ANSI-41 terminal, respectively. In addition, we assume that the UMTS terminal is not currently reachable, although its registration in SuperDHLR is still active.

CLS first realizes that the first destination candidate, SIP, is not registered. So it moves to the second candidate (i.e., UMTS terminal), and it tries to retrieve the routing number by sending a COPS RRI message to a UMTS PDLS (step 5). However, it fails because the terminal is not active in the VLR record. Then it tries to retrieve the ANSI-41 terminal routing number (step 5', 6'), which it forwards to the gateway MSC, and

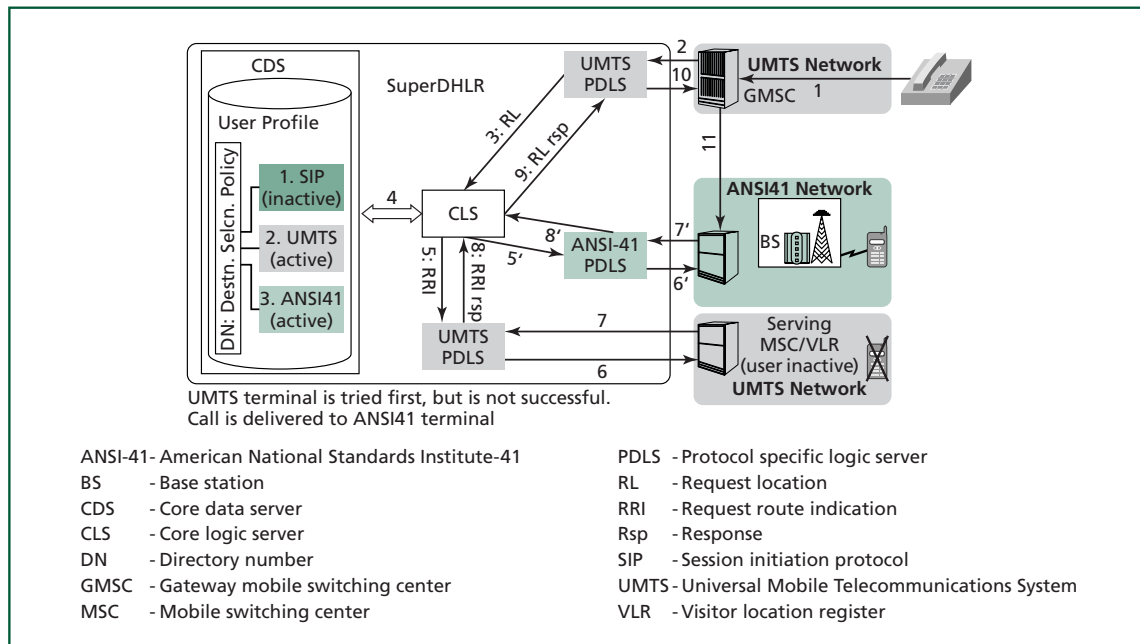


Figure 7.
Delivery of a call addressed to a UMTS directory number.

the call is completed. This example clarifies two features of personal mobility as supported by SuperDHLR. First, a call addressed to a UMTS directory number is delivered to a terminal in an ANSI-41 network. Second, CLS has the knowledge of all the active registrations and is capable of retrieving routing numbers for any or all of them as dictated by the destination selection policy and enabling call delivery.

Personal mobility based on SIP URL. In the second example, illustrated in **Figure 8**, we assume the user is called on an SIP URL personal address and that the user has active registrations in UMTS, ANSI-41, and SIP networks. The requesting network is SIP and it is capable of calling all the active terminals in parallel (forking). Destination selection policy is assumed to indicate *try all in parallel*.

CLS has the knowledge of all the active registrations after it downloads the data from the CDS (step 4). It is capable of retrieving the routing numbers *simultaneously* for both the ANSI-41 terminal and the UMTS terminal (as shown by step 5, RRI COP message) that are sent simultaneously to a UMTS PDLs, as well as to an ANSI-41 PDLs. For the UMTS terminal, the MS routing number (MSRN) retrieval is shown in the figure by steps 6 and 7 originating from the UMTS PDLs. Similarly for the ANSI-41 terminal, steps 6' and 7' indicate the routing number or temporary local directory number (TLDN) retrieval from the ANSI-41 PDLs. CLS eventually retrieves both the routing numbers (step 8 arriving from the UMTS PDLs and ANSI-41 PDLs). For the registered SIP terminal, the locally stored contact address can be used. CLS

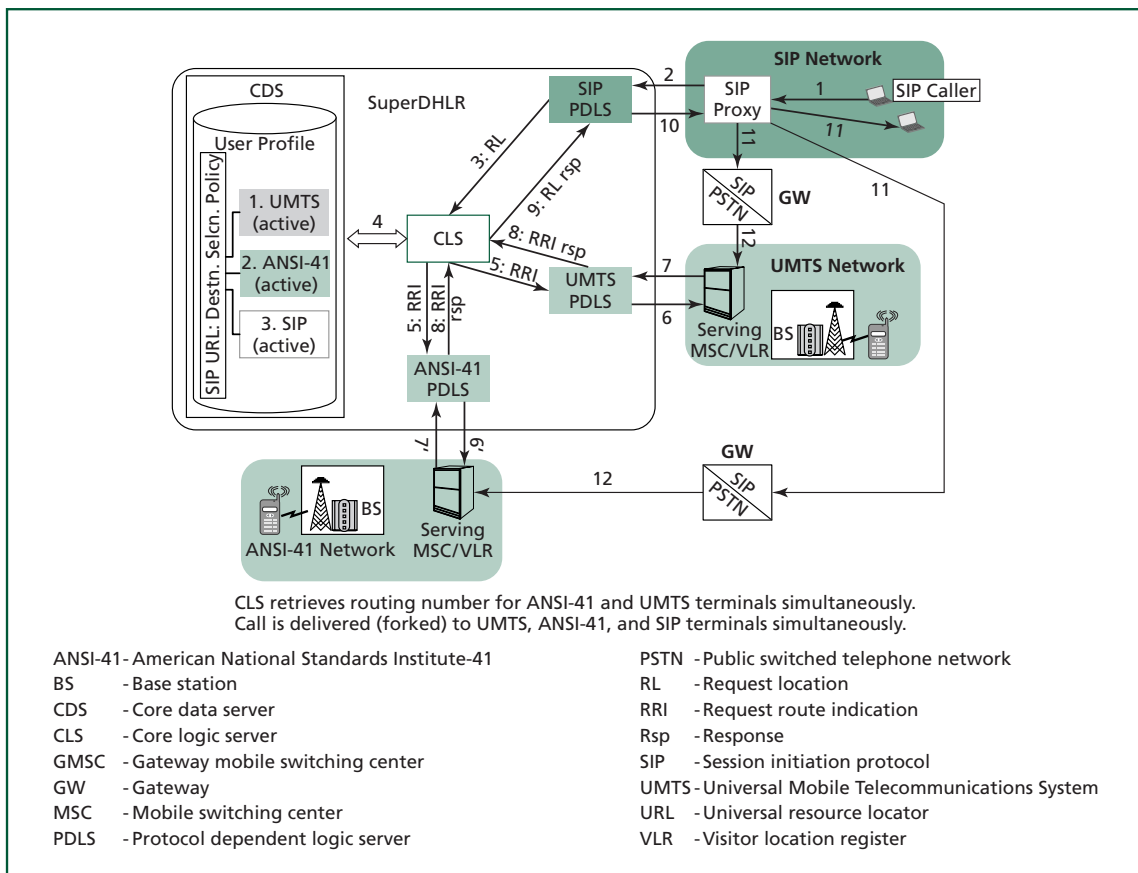


Figure 8.
Delivery of a call addressed to a SIP URL.

forwards the TLDN, MSRN, and the SIP contact address to the requesting SIP PDLs (step 9 of the figure). They are then forwarded to the SIP proxy (step 10).

The call delivery from a SIP terminal to a UMTS terminal or an ANSI-41 terminal requires the services of an intermediary *SIP-to-PSTN gateway*. SIP PDLs, which has the knowledge of the network topology and also the location of the gateways, is capable of selecting an appropriate gateway, based on some selection criteria (such as route optimization or maximizing the packet switched leg of the call). It forwards the address of the gateway so selected to the SIP proxy along with the MSRN as shown in the figure by step 10. The SIP proxy contacts the gateway (step 11) with the MSRN it received from the SIP PDLs and the call is delivered normally after that (step 12 and beyond). To deliver the call to the SIP terminal, the SIP proxy sends the INVITE message directly to the contact address it received from the CLS, without going through the SIP/PSTN gateway. A call can be delivered to multiple terminals as explained, but the call will actually be established to, at most one terminal, most likely to the one that responded first.

As demonstrated in this example, a SIP-PSTN gateway must be involved in case of call setup between the SIP and wireless networks. An important issue is the selection of an optimal gateway based on certain selection criteria. The most plausible criterion would be minimizing the circuit switched leg of the call and maximizing the packet switched leg, so as to minimize the cost of the entire call. In the case of a mobile terminal, it is typically impossible to accomplish this optimization since the only available information for gateway selection is a mobile phone number, not the location of the mobile terminal. However, using SuperDHLR, the location of the destination mobile terminal (which is obtained during registration of the mobile terminal and stored in the database) can be obtained at step 4. Using the location information so obtained, it is possible to select the most appropriate gateway.

Benefits of SuperDHLR with COPS Architecture

The benefits of SuperDHLR with COPS architecture include:

- *Less deployment complexity.* This is the inherent benefit of COPS architecture as discussed before. The

complexity of protocol interworking deployment goes down to $O(n)$ where n is the number of protocols to be supported.

- *Protocol extensibility.* COPS architecture promotes the easy introduction of new protocol with interworking capability without any major modification of the system. Confinement of any protocol-specific logic to a protocol-specific PDLs, and the usage of protocol-independent COPS interface for inter-protocol communication, facilitates the ease of extension of SuperDHLR to multiple protocols. Support for a new protocol (by the addition of the protocol-specific PDLs) does not affect the existing service logic. This feature will be especially important in the future since mobile networks will shift toward an IP-based environment. In contrast to the telecommunication environment, new protocols have been and will be introduced in IP-based environments with great regularity.
- *System customization.* SuperDHLR supports multiple protocols. However, a service provider may not need all the protocols it supports. COPS architecture allows SuperDHLR to configure itself by selectively introducing and deploying PDLs of only those protocols that need to be supported.
- *Smooth evolution toward all-IP based wireless networks.* With the multiprotocol support, SuperDHLR can facilitate seamless evolution from today's 1G/2G wireless networks based on HLR, to next-generation wireless networks based on HLR/IP server complex, and to future all-IP based wireless networks.
- *Integrated database for a user.* Besides multiple protocol support, a key difference of the SuperDHLR from a traditional HLR is that SuperDHLR manages profile information for a *user*, not just a single wireless *terminal*. The integrated user profile database must be able to maintain profile information for a user who could subscribe to the services of more than one network type. SuperDHLR database access interface can give a consolidated view of user information where common information across protocols is effectively shared. The unified service profile management also has a better position to avoid the data inconsistency issue.

SuperDHLR could work further as a central repository of user information, including the data of applications other than its supported protocols.

- *Personal mobility support across protocols.* With the introduction of user concept, SuperDHLR can provide personal mobility not just within a single network such as SIP, but also across different networks including wireless and wireline telecommunication networks as well as the Internet. Furthermore, by having a unified database across protocols, it can easily provide ubiquitous services for a user beyond network boundaries. For example, the activation of some service from one network (e.g., call forwarding activation from UMTS phone) can be easily propagated to other types of networks subscribed to by this user (e.g., SIP and/or ANSI-41 phones). SuperDHLR conforms to the existing protocols and does not need any new ones to enable personal mobility.
- *Efficient wireless/VoIP interworking.* There are several alternative approaches on protocol interworking for registration and call delivery between wireless and VoIP networks as described in [7]. However, the approach taken by SuperDHLR eliminates unnecessary additional signaling messages for registration and routing number lookup by centrally managing user location information for multiple protocols. As reported in [7], our proposed approach can save signaling load by 15 to 30% compared to other alternatives.
- *Efficient PSTN/IP gateway selection.* As discussed, in the case of wireless/IP interworking, SuperDHLR can obtain the location information of the destination device before selecting PSTN/IP gateway. This allows devising an effective gateway selection mechanism based on a certain policy, such as minimizing circuit switch path, maintaining QoS requirements on VoIP path, and so on.

Conclusion

In this paper we presented the COPS architecture and showed how it can be used to achieve global roaming. We distinguished between the concepts of a *user* and a *terminal* and explained how the two can be associated in a logical view. We explained our vision of global roaming across disparate networks in order to

achieve seamless roaming for a user among such networks and provide the same service ubiquitously using user mobility and terminal mobility. We then discussed SuperDHLR, which is based on the COPS architecture, and its components and principles in detail, explaining how it supports personal mobility as well as terminal mobility across different networks to provide global roaming. We compared our approaches to other approaches used for global roaming, wherever applicable and clarified our concepts using examples.

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*Trademarks

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RAMANA ISUKAPALLI is a member of technical staff in the Advanced Mobile Networking Department of the Wireless Advanced Technology Laboratory at Lucent Technologies, Holmdel, New Jersey. He works on the SuperDHLR project and is



responsible for the design and development of the CLS module and interworking among different protocols. His professional interests include wireless networks, interworking among heterogeneous protocols, and efficient data distribution to mobile terminals. He has research experience in other areas such as robot navigation, machine vision, and face recognition and has published papers in IEEE, AAAI, and IJCAI conferences in these areas. He holds a B.Tech. degree from the Indian Institute of Technology in Madras, an M.E. degree from the Indian Institute of Science in Bangalore, both in metallurgy, and an M.S. degree in computer science from Oregon State University.

TRIANTAFYLLOS ALEXIOU is a member of technical staff in the Wireless Advanced Technology Lab, Mobility Solutions, at Lucent Technologies in Holmdel, New Jersey, where he contributes to the definition, development, and support of COPS



interface and SIP extension for SuperDHLR. His professional interests include call processing in mobile networks and the Internet, applications of encryption and authentication algorithms, and software engineering. He holds a Diploma in electrical engineering from the Aristotle University in Thessaloniki, Greece, and an M.Sc. degree in electrical engineering from Columbia University in New York City.

KAZUTAKA MURAKAMI is a distinguished member of technical staff in the Mobile Networking Research Department at Lucent Technologies in Holmdel, New Jersey. He holds a B.Eng. degree and an M. Eng. degree in electrical engineering from The



University of Tokyo in Japan, and a Ph.D. degree in electrical and computer engineering from Carnegie Mellon University in Pittsburgh, Pennsylvania. Dr. Murakami has worked on highly available distributed call processing systems for wired and wireless telecommunications networks and a unified mobility/security/profile management system for mobile cellular/IP networks. His research interests are in network optimization, survivable network management, routing control, call-processing systems, distributed object-oriented systems, fault-tolerant systems, and multi-protocol interworking. He has served as feature editor (Japanese and other Asian literature) of IEEE Communications Magazine and served on the program committee for IEEE ICON '99. ♦