Quality-of-Service Signaling for Next-Generation IP-Based Mobile Networks

Joachim Hillebrand and Christian Prehofer, DoCoMo Communications Laboratories Europe

Roland Bless and Martina Zitterbart, University of Karlsruhe

Abstract

We present a novel end-to-end QoS architecture that enables seamless services over heterogeneous wireless access networks. We discuss the main architectural approaches and design issues of mobility-aware QoS signaling in IP networks. Then we introduce a QoS signaling architecture that integrates resource management with mobility management. It is based on a domain resource manager concept and nicely supports various handover types in an integrated approach. In particular, we support anticipated handover with pre-reservation of resources over the old network before the mobile node is attached to the new access point.

Introduction

Next-generation mobile networks will support heterogeneous radio access and will offer seamless services between different wireless access technologies. For different scenarios and applications, various radio access systems will complement each other. For instance, wireless LANs will offer high-speed data services with restricted mobility support for hot spots, while some cellular networks can provide real-time services. To support heterogeneous networks, mobile networks are moving toward "all-IP" networks, based on Internet protocols.

In this article we present an end-to-end quality of service (QoS) architecture that enables QoS for seamless services over different wireless access networks. In heterogeneous, overlapping networks, a handover to a more suitable access point offering more capabilities may be needed to enable additional services. For instance, when passing by a wireless hot spot, one can perform a handover to this access point for a short period of time to facilitate some demanding service, such as download of bulk data or video conferencing. However, in many cases the availability of resources at the potential access point is not known before handover is performed. For QoS, this means that the resources at the new access point should be allocated before attaching to the new network. This is often called *anticipated* or *planned handover*. This kind of handover mainly offers two advantages. First, it reduces handover latency, because most signaling to set up resources in the new path is carried out in advance. Second, it avoids unsuccessful handovers or unnecessary periods of QoS degradation, because handovers should only be performed if the resources are actually available.

Our QoS signaling architecture integrates resource management with mobility and location management. *Mobility management* protocols like Mobile IP [1] ensure that a mobile device is reachable by a home address, although the local IP address may change during handover. Further micromobility protocols [2] aim to reduce handover disruptions by handling handover signaling and packet forwarding locally if possible.

Our QoS signaling protocol supports a variety of handover types. In addition to anticipated handover, the main ones are *hard handover*, where the attachment to the new network takes place after leaving the old one, and *soft handover*, where the mobile node is attached to two networks at the same time. Note that soft handover is only suitable if the node has two radio interfaces, or the radio mode, such as wideband code-division multiple access (WCDMA), supports this on the link layer. While most other approaches consider the handover cases individually, our new integrated handover model allows switching dynamically between these cases during a handover process.

In addition to QoS signaling, *resource management* has to take care of admission control, allotment, and release of requested resources. To ensure QoS on the data path, there are several techniques such as differentiated services [3] or integrated services [4]. Integrated services is based on per-flow resource reservation. Differentiated services (DiffServ) is a recent approach defined by the Internet Engineering Task Force (IETF). Instead of manipulating per-flow state at each router in a network, QoS preferences or guarantees are assigned to traffic aggregates,

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which are composed at the network edges. This requires the marking of packets in a special field in the IP header, the DS field. While IntServ defined Resource Reservation Protocol (RSVP) [5] as a related end-to-end signaling protocol, the DiffServ standard lacks a control plane.

Our architecture is based on a resource manager approach, which fulfills the main requirements of future mobile networks. First, it is flexible regarding heterogeneous networks with different QoS capabilities (e.g., DiffServ, IntServ) and mobility models. We support pre-reservation of resources before attaching to the new network, triggered by either the mobile node or some network intelligence (e.g., movement prediction). Furthermore, we present an integrated handover model that can dynamically change between handover cases, covering new cases not considered before. A detailed discussion of the different approaches for QoS architectures, such as centralized vs. decentralized resource management, is presented in the next section.

The article is organized as follows. We present our mobility-aware QoS signaling architecture based on a resource manager concept and address architectural issues. We describe the signaling protocol and also discuss several design issues related to IP networks. We then introduce and explain the integrated handover model.

A Mobility-Aware QoS Signaling Architecture

Before we present our architecture, based on Mobility-Aware Reservation Signaling Protocol (MARSP), we discuss requirements and different architectural approaches to QoS signaling.

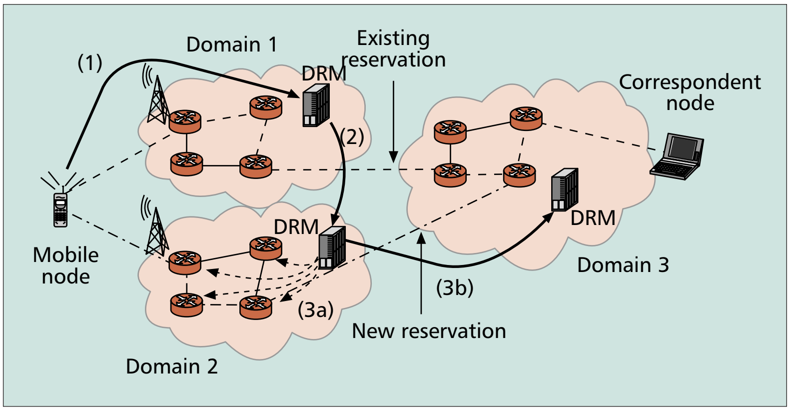
Requirements and Architectural Approaches

The main requirements for a QoS signaling architecture in future mobile IP-based networks are:

- Independence of a particular QoS technique for provisioning of QoS on the data path (e.g., IntServ and DiffServ)
- Independence of specific radio access technologies
- Interworking with different mobility concepts, including micromobility [2], for seamless handovers
- Support for interdomain handovers, when a mobile node (MN) changes its point of attachment to a network that is administered by another organization

In the following, we compare the main QoS approaches for their applicability in IP-based mobile networks. The many approaches to QoS in IP networks can be classified along the following two criteria.

The first criterion is whether signaling messages follow in the data path or not, often called *on-path vs. off-path* signaling. The RSVP protocol [5] is the current Internet standard for on-path QoS signaling and is used for other signaling purposes as well. But, as explained later, RSVP is not very well suited to future



■ **Figure 1.** *QoS signaling for anticipated handover between domains.*

mobile networks. The IETF is currently working on an on-path general-purpose signaling protocol in the NSIS working group, which may also replace RSVP. An advantage of on-path signaling is that failures affect both the signaling and data path, and may be handled locally. For off-path signaling, resource requests are sent to a dedicated entity, which is then responsible for admission control and QoS setup along the data path.

Second, resources can be managed centrally by one entity (in each network domain) or decentrally in each router. For local resource control, each router manages the resources of the outgoing links.

In the centralized QoS architecture, a *domain resource manager* (*DRM*) (also called a *bandwidth broker*) handles the resources for one domain. The DRM maintains an up-to-date image of resources and reservations in its domain (Fig. 1). The DRM may request resources from DRMs in adjacent domains in order to provide end-to-end reservations. The central approach is flexible with respect to different QoS models (e.g., IntServ or DiffServ).

Typically, on-path signaling is used with local resource management, as in IntServ with RSVP. Central resource management suits off-path signaling, but can also be used with on-path signaling if the central resource manager is contacted by routers using additional protocols. Many approaches [6–8], use central resource management with off-path signaling together with DiffServ, because a DiffServ control plane may not require fine-grained resource control for each flow. Since the central approach has a single control point, the integration with different mobility schemes and location management is more flexible, as discussed below.

In our approach, we use a central DRM for each domain with off-path inter-DRM signaling. Our main motivation to use a central approach is the support for anticipated handover with pre-reservations, as shown in Fig. 1. With the DRM approach, a DRM can determine the route and reserve resources for a new access point within its domain or by contacting a neighboring DRM. This is illustrated in Fig. 1, steps 1–3. After an anticipated handover request (step 1), the old DRM requests resources in a new domain (step 2). After a successful reservation (steps 3a and

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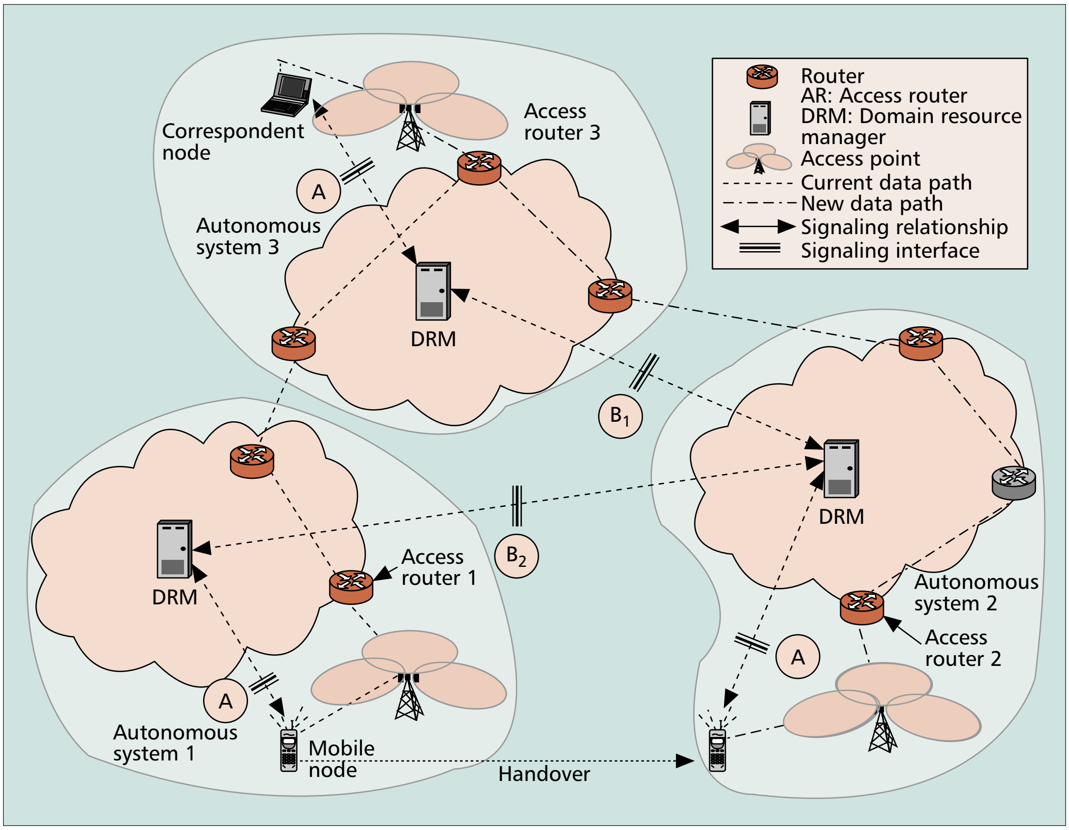

Figure 2. *A QoS signaling architecture for autonomous systems.*

3b), the handover can take place. Note that off-path signaling is needed to reserve resources in the new domain. In this way, a handover only takes place if resources are available. It is important that the resource reservation may also be triggered by some network service, such as a mobility scheme that uses location prediction to find the next suitable access point.

We argue that the anticipated handover is difficult to implement with on-path signaling such as RSVP. Current RSVP is not mobility-aware and, for instance, does not support changing of IP addresses. An overview of current research on RSVP extensions for mobility can be found in [9]. The extension of RSVP presented in [10] uses so-called *proxy agents* (e.g., in the access routers) to set up a reservation on behalf of the mobile node. The proxy agent for a new prospective access point has to be discovered and triggered by additional protocols. Potential access router discovery protocols are currently being discussed in the seamoby IETF working group, for example. However, this access router lookup and triggering from the wireless node can take considerable overhead and time. The signaling for discovery and pre-reservation over the wireless link can be avoided, as only one request is sent to the local DRM, even for several access points. Since a DRM takes care of many reservations, it is also suitable for the DRM to maintain longer-term signaling sessions with adjacent DRMs, which decreases reservation setup latency. If a receiver intends to change its access routers, it is even more difficult for an on-path router-based scheme to discover the involved upstream routers on the new reservation path within a domain, as discussed later. Many other approaches for on-path signaling (e.g., [9, 11]) do not use network-assisted pre-reservation.

MARSP Resource Manager Architecture

Our QoS architecture is based on a resource manager approach (Fig. 2). *Access routers* (*ARs*) provide IP connectivity to an MN within a domain. An AR can be connected to multiple *access points* (*APs*) that provide link layer connectivity. Each domain has a DRM that controls all resources at the IP level within this domain.

For resource management, the DRM needs to maintain an image of the resources available in its domain and should monitor routing protocols such as Open Shortest Path First (OSPF) and Border Gateway Protocol (BGP). With resource and reservation information, it can perform admission control for the current data paths [12]. DRMs must locate the adjacent DRM along the path for end-to-end signaling messages. Additionally, a DRM may have to configure routers by using a management interface, for example, through installation of traffic profiles for differentiated services by using Simple Network Management Protocol (SNMP), Common Open Policy Service (COPS), or command line interfaces.

The architecture decouples resource management signaling from mobility management signaling. For instance, if an MN requests resources along the new path before it finally registers with the mobility management at the new AR, data packets traversing the new path will immediately receive the corresponding QoS after handover.

QoS Signaling Interfaces and Mobility Management

Within the mobility-aware QoS signaling architecture several logical interfaces can be identified (Fig. 2). Basically, it can be distinguished between signaling for resource management, for mobility management, and at the application level. Direct signaling between the applications may be required to let applications explicitly adapt the content of their data flows to the current resource availability. The latter may change due to handover, especially if a change of wireless access technology is involved (a so-called *vertical handover*). Thus, applications should be notified via an internal interface of QoS changes and should signal the sender at the application level, which can then adapt its sending rate.

In our architecture, two types of signaling interfaces can be distinguished:

- A interfaces: QoS signaling within a domain
- B interfaces: B_1 and B_2 between domains

Mobile nodes have to signal their individual resource requirements to the DRM via interface A. In order to request and reserve resources along the path of autonomous systems from the correspondent node (CN) to the mobile node, signaling messages must be exchanged between adjacent DRMs over interface B_1. Handover preparation messages can be signaled over interface B_2. In contrast to B_1, one of the domains (autonomous system 2 in Fig. 2) for interface B_2 is not located on the current data path. When signaling an anticipated handover via interface B_2, resources are requested in advance for the new path that is associated with the next point of attachment in the new domain. An example of an anticipated handover between domains is presented later.

In addition to explicit signaling for resource reservation, location management or other approaches to seamless mobility can be integrated into the architecture as well. For instance, movement prediction can be used by a DRM to reserve resources in advance without the need to let the MN request resources explicitly via interface A.

We only make minimal assumptions about mobility registration in order to achieve solutions for different mobility management mechanisms. Resources may be reserved for the new path before mobility management switches the data flow to it or after the MN registered at the new AR, as detailed in the next section. For some mobility solutions, additional information may be needed to determine the actual data flow. For instance, with mobile IPv6, we assume route optimization and do not consider traffic sent over a home agent. Similarly, for some micromobility solutions the DRM must know the topology and mobility mechanisms used to determine the data flow. A classification of the interaction between resource and micromobility management is given in [11] for several existing approaches.

QoS Signaling for Handovers

In the following, we discuss handover signaling and some related problems such as asymmetric paths for end-to-end signaling. A flexible QoS signaling protocol has to deal with different handover types (e.g., hard, soft, anticipated handover, and variations of these). This section focuses on QoS signaling for different handovers for the previously presented architecture. The particular goal is to analyze different handover types and find a signaling solution that covers all potential cases. The result is represented by an integrated handover state model (presented later) that is the basis for the specification of QoS signaling protocols. Particularly, this integrated state model allows one to describe transitions between different handover types. In other words, if a step of one handover type fails, the handover can still be finished by using another handover type. QoS support is improved if an already initiated handover can be continued without having to start a completely new signaling sequence.

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Handover Distinctions and Scenarios

Several types of handovers may be considered for IP-based mobile networks. Our goal is to design signaling protocols that support multiple handover types. Not every network or MN will support all handover variants (e.g., soft handovers). Some nodes have to drop their current connection before selecting a new AR. Other nodes are able to scan for new access points while still connected to the current AR. Different handover cases can be distinguished that have impacts on mobility management and resource reservations. At first, an MN may perform an *intradomain handover* (current AR and new AR in the same domain) or an *interdomain handover* (new AR located in a different domain). Several optimizations for intradomain handovers are available that result in faster signaling procedures because the signaling messages may stay local within the domain, and there is no need to perform full re-authentication.

A further case is vertical handover between different radio access technologies. It is possible that the currently allocated resources must be adapted if a vertical handover is to be performed, because different link layer technologies offer very different capabilities. Consequently, this adaptation may require signaling at the application level as well as signaling for resource adaptation along the complete path between CN and MN, even for intradomain handovers.

When considering QoS, the actual handover decision depends on two main criteria:

- Signal availability: This comprises radio parameters like signal-to-noise ratio. The IP layer must be informed by lower layers about conditions and availability of radio connections.
- Resource availability: When carrying out a handover to a new AR, it must be ensured that the available resources *on and to* that AR are sufficient to satisfy the QoS requirements of the MN.

Therefore, handover strategies for IP-based mobile networks should be based on both criteria. However, for some cases of anticipated or vertical handover, no signal measurements may be available.

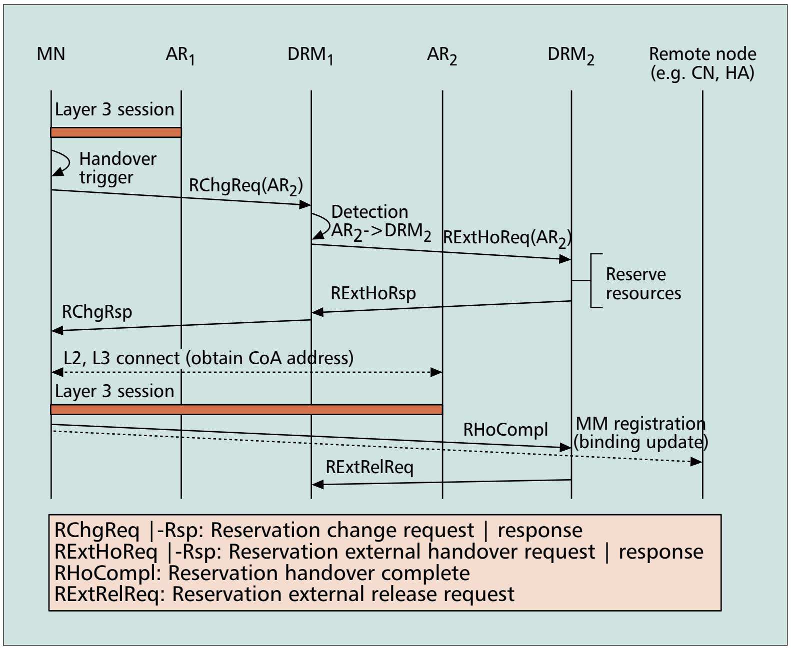

Figure 3. *A sequence diagram for interdomain anticipated handover.*

An Example of Anticipated Handover

In this section we show an example of the operation of the protocol to emphasize the requirements and assumptions used in our approach. The example in Fig. 3 shows a message sequence diagram for anticipated handover in an interdomain case. The advantage of an anticipated handover is that resource management signaling is performed before attaching to a new access point. The following example presents the interaction between DRMs of *different domains*.

First, the MN detects new access points and selects its target AR. Subsequently, a request for changing the MN's point of attachment from AR_1 to AR_2 is issued to the current DRM_1 (RChgReq). This DRM must detect that AR_2 is located in a different domain and has to determine the responsible DRM (a special DNS entry may be used for this purpose).

A handover request (RExtHoReq) is subsequently sent from DRM_1 to DRM_2 in order to request resources from the new domain. Depending on resource availability, DRM_2 sends a corresponding response message (RExtHoRsp) back to DRM_1, which in turn informs the MN about the result (RChgRsp). If resource allocation has succeeded at DRM_2 it waits for a handover confirmation message from the MN (RHoCompl). If this message is not received within a certain time, the pre-reserved resources are automatically released. Thus, the MN will connect to the new AR and is then able to confirm the completion of the anticipated handover procedure. DRM_2 informs DRM_1 that the reserved resources in the old domain are no longer being used (RExtRelReq). DRM_1 can then explicitly release unused resources. Otherwise, the reservation will time out if no refresh messages are received from the MN within a certain time period.

Receiver-Initiated Reservations

Another issue regarding local handover optimization are receiver-initiated reservations. In IP networks, the two paths between two nodes may not be the same (asymmetric paths). Furthermore, the receiver cannot determine the path taken by a packet from the sender. Consider now a receiving MN that changes its point of attachment to a new network domain. In order to reduce the handover delay, the handover should be handled as locally as possible. However, the receiver does not know the new data path from the sender. The problem is that there is no easy way to find out the forwarding path of packets from the reverse direction. This is caused by the unidirectional nature of routing; that is, only the path and next hop towards the destination of a packet is known, but not the previous router that forwarded it.

Figure 4 shows that the data forwarding path may be different than the signaling path in the reverse (with respect to the data path) direction.

This shows that we have to use end-to-end signaling if the route changes completely after a handover. There are cases where optimizations can be applied if the point where the old and new reservations cross (crossover point) can be detected. This can be supported by appropriate session identifiers and is discussed below. Other optimizations can be applied if the mobility management or resource managers can identify the crossover point.

RSVP's solution to this fundamental problem is to install state while a PATH control message is forwarded, and use this state for finding and traversing the path from the reverse direction. However, this requires that the sender sends a PATH control message first and the reverse forwarding path state is updated frequently to detect route changes.

The Session Identifier and Ownership

A *session* associates some state information (e.g., the amount of reserved resources) with a related data flow. The association between session and data flow may change over time, especially in MNs. Thus, the data flow may change its source or destination addresses while some part of the reservation state remains unchanged. During an anticipated handover, a second flow may be temporarily added to the session. An MN must be able to address a reservation it has established (i.e., a session) in order to change (especially in case of a handover) or release the reservation.

There are several options for identifying a reservation. A *globally unique identifier* is advantageous in a handover because it is easier to identify a crossover domain where the old and new paths meet. A domain can easily identify whether it had this reservation installed already. This helps avoid double reservations along an existing and static reservation subpath. A problem, though, is guaranteeing the global uniqueness of the identifier even if collisions for randomly generated large numbers (e.g., 128 bit) are relatively unlikely.

Another option is to use a locally unique identifier, where locally means within a DRM. This identifier may be shorter than the globally

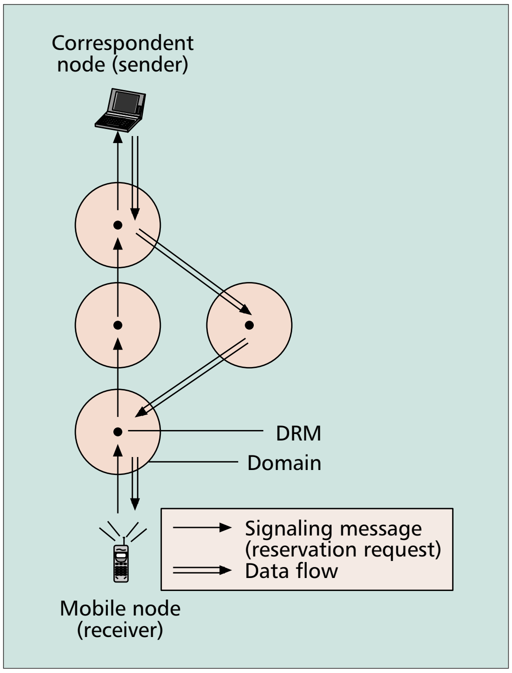

Figure 4. *Signaling receiver-initiated reservations.*

unique identifier, but it is not possible with the local identifier to identify already existing reservations at other entities. We call this locally unique identifier a *session handle*. This session handle is thus only valid for addressing between two peers. Initially, when the reservation is established, the session handles are exchanged. Subsequently, a peer uses the handle of the remote peer to address the reservation. This will be slightly more efficient when searching for the reservation context, because the locally generated handle can be used directly as an index for access. However, only peers that previously knew the reservation can address and identify them correctly. Therefore, it is not possible to identify crossover domains with the session handle alone.

We combine both approaches and use a session handle between two peers. A globally unique *session identifier* is formed by the 128-bit IPv6 address of the DRM and its locally generated session handle that is 32 bit long. The session handle is used whenever possible, because it is more efficient. This is especially true for the communication between an MN and the DRM. However, if an already existing reservation has to be found (i.e., for a handover), the globally unique identifier is used. Therefore, the session identifier has to be propagated along the complete end-to-end path. By using the IPv6 address of the DRM as part of the session identifier, it is possible for other DRMs to identify and contact the DRM that issued the session handle. This is especially useful for re-authentication and verifying authorization in case an MN wants to resume a session from the previously visited domain during a hard handover.

A related important issue in this context is the *ownership* of the reservation and authorization of session control. The identifier of the reservation has to be bound to credentials and authentication information that authorizes and legitimates the user, although as a first viable approach it may be suggested to bind session control to the underlying signaling transport connection. While this would result in only modest security, it is inadequate in a mobile environment because signaling transport connections may change more often. Furthermore, a session should be bound to its users rather than to end systems or applications. For secure and accountable service provisioning it is therefore necessary to create security associations between the mobile user and a DRM for a session first. Using anticipated handovers is advantageous in this case, too, because security associations can be prepared and established before the actual handover takes place.

Integrated Handover State Model

A handover can be described with the integrated state model presented in Fig. 5. It forms the basis for the further design of MARSP on the interface to the MN. The state model is drawn by using a grid with connection states on the horizontal axis and reservation states on the vertical axis (see below). By using this grid, any possible handover type can be described with a path from the top left (state S) to the bottom right (state F). The intermediate handover states are denoted H_1–H_{11}. The depicted transitions in the state model do not cover reject or failure transitions in order to simplify the model. In the following a description of the horizontal and vertical axes of the diagram is given.

The integrated state model describes the connection states of handover sequences on the horizontal axis. The states comprise connection with the old AR at layer three ($L3_O$), connection with the new AR at layer 3 ($L3_N$), and a connection with both ARs simultaneously ($L3_O$, $L3_N$). Moreover, a separate state where mobility management registration was performed (i.e., sending of binding updates) is introduced ($L3_N$, MMreg) in order to describe the trigger for the handover of data packets between the old and new data paths. In a similar manner the significant states of resource reservation are described on the vertical axis.

The main benefit of this integrated state model is that for any change it can be switched appropriately between handover types while preserving reservations. When the operation of one handover type fails to complete, the handover can still be finished by using another handover type (e.g., with a hard handover instead of an anticipated handover).

In the following we describe the transitions for the anticipated handover type in the state model, which is the preferable method for efficient and fast handovers. By using the anticipated handover type the resources are already reserved when the actual handover is performed. Another advantage of anticipated handover is that the MN has several target ARs to choose from as long as the signaling is still carried out over the old AR. Therefore, it is possible to include the whole set of potential ARs in the resource request. This gives the network the pos-

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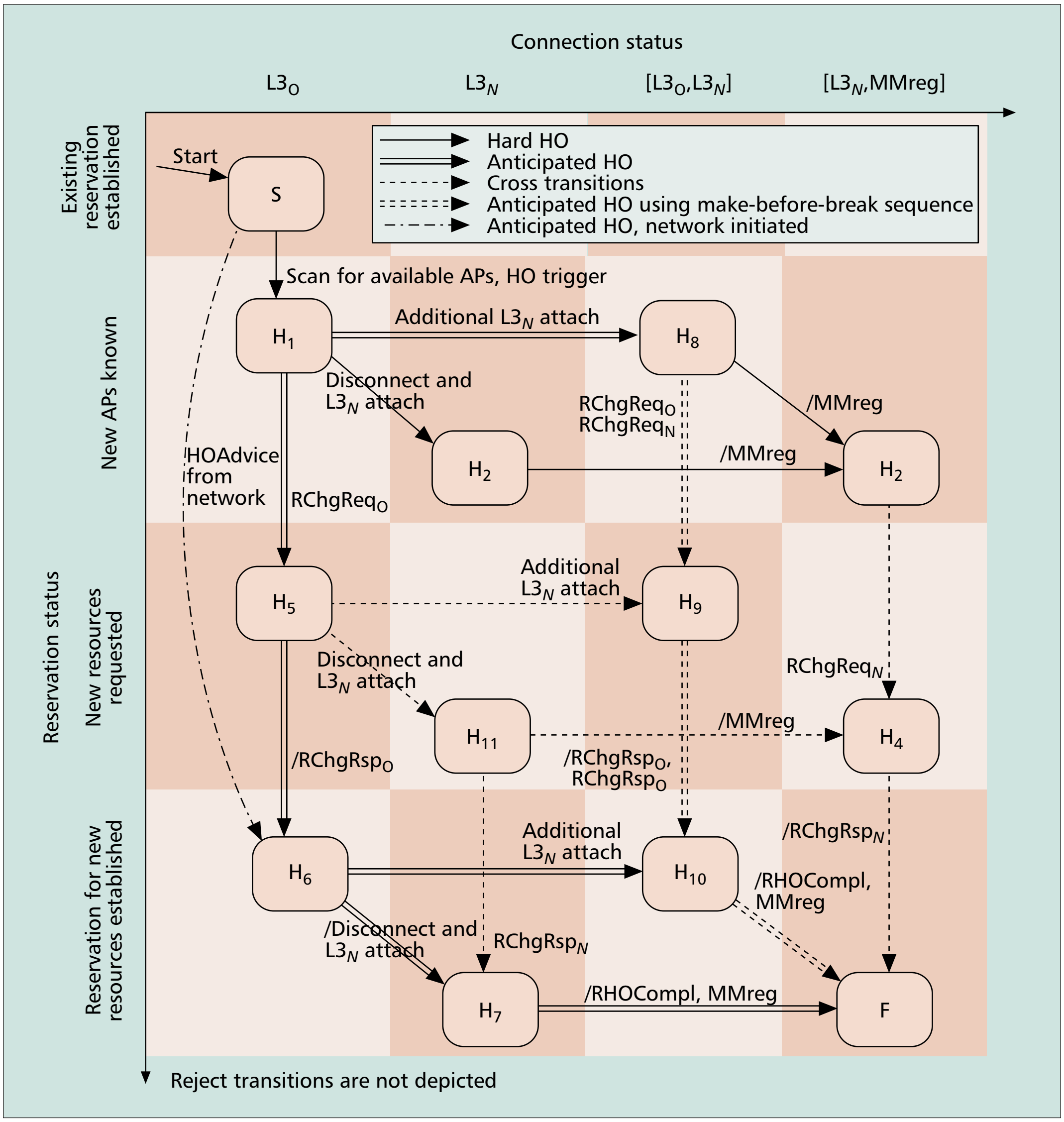

Figure 5. *The integrated handover model.*

sibility to prefer a specific AR for the handover. The trace for anticipated handover consists of the following transitions:

- S–H_1: The MN scans for available APs or makes use of potential handover triggers.
- H_1–H_5: In state H_1, the MN may be aware of several alternative ARs for the handovers and send a resource request (RChgReq).
- H_5–H_6: Depending on the available resources, the DRM answers with a reply containing the identification of the best AR fulfilling the requirements. This reply already denotes successful resource reservation for the new path.
- H_6–H_7: Now the MN disconnects from the old AR, connects to the new AR on layers 2 and 3 (in case the MN supports simultaneous layer three connections: H_6–H_{10}).
- H_7–F: The MN sends a message about completion of handover to the network (*RHoCompl*). This message is needed in anticipated handover to show that the MN really connects to the AR where it has previously reserved resources. Furthermore, the *RHoCompl* message may trigger the release of unused resources in the network after handover. In addition to resource management, the MN triggers a mobility management registration (*MMReg*) in this step.

An advantage of the integrated handover model is that it also shows combinations of the previously mentioned handover types. For example, when connectivity is unexpectedly lost to the old AR during an anticipated handover (state H5), it is still possible to finish the handover as a hard handover without need for retransmission of the resource request.

CONCLUSIONS

We have discussed several approaches and design issues for QoS in mobile IP-based networks. Based on a comparison of centralized vs. decentralized approaches, we have developed our DRM-based QoS architecture with a focus on anticipated handover. To support different handover cases, a novel integrated model was developed to describe the different cases in a unified model. This permits switching between these handover cases dynamically during handover. The designed QoS signaling protocol supports all these handover cases, including anticipated handover as well as transitions between different handover types. We have addressed intrinsic problems of reservations in IP-based networks such as receiver-initiated reservations and session ownership. Currently, a prototype implementation of the proposed QoS signaling protocol is under evaluation in our testbed. More details of our approach can be found in [13, 14].

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BIOGRAPHIES

JOACHIM HILLEBRAND (hillebrand@docomolab-euro.com) is a researcher in the Active IP Networking group at DoCoMo Communications Laboratories Europe (DoCoMo Euro-Labs), Munich, Germany. His current research areas are QoS for IP-based mobile networks and signaling protocols. He studied electrical and communications engineering at the Technical University of Graz, Austria, where he received his Dipl.-Ing. (Master's) degree in 2000. In 2001 he was a system engineer for Siemens AG, Munich, Germany, in the area of 3G radio access networks.

CHRISTIAN PREHOFER (prehofer@docomolab-euro.com) is manager of the Active IP Networking group at DoCoMo Euro-Labs, Munich. His current research areas are QoS for IP-based mobile networks, and self-organized and context-aware networking. He studied computer science at the Technical University in Munich and also received a Master's degree in 1992 from the University of Illinois at Urbana-Champaign. He obtained his Ph.D. and habilitation in computer science from the Technical University of Munich in 1995 and 2000, respectively.

ROLAND BLESS [M] (bless@tm.uka.de) is a research assistant at the University of Karlsruhe, Institute of Telematics. He studied informatics at the University of Karlsruhe and got his Ph.D. degree (Dr.-Ing.) in February 2002. His research interests are QoS, QoS management, DiffServ, multicast, mobility, and QoS signaling. He is actively participating in IETF Working Groups and brought parts of his work into the IETF standardization process. Dr. Bless is a member of the German GI.

MARTINA ZITTERBART [M] (zit@tm.uka.de) is a full professor of computer science at the University of Karlsruhe, Germany. She received her doctoral degree from the University of Karlsruhe in 1990. She was a visiting scientist at the IBM T.J. Watson Research Center, 1991–1992. She was a full professor at the Technical University of Braunschweig from 1995 to 2001. Her primary research interests are in the areas of high-performance networking, mobile communications, next-generation networking, ambient technologies, and e-learning. She is a member of ACM and the German GI.

We have addressed intrinsic problems of reservations in IP-based networks such as receiver-initiated reservations and session ownership. Currently, a prototype implementation of the proposed QoS signaling protocol is under evaluation in our testbed.