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Interworking of WLAN-UMTS Networks: An IMS-Based Platform for Session Mobility

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ABSTRACT

In this article a framework for interworking between a WLAN and the UMTS is presented. The uniqueness of this architecture is that the IP multimedia subsystem proposed by the 3GPP has been used as an arbitrator for network coupling and real-time session management. Apart from the advantage of a cellular network user being able to enjoy higher levels of bandwidth over a WLAN, IMS also provides a common platform for unified session control, as well as higher levels of terminal and service mobility over a heterogeneous networking environment. The article concludes by presenting the potential of this model for service continuity during and after vertical handoff with simulation results for validation.

INTRODUCTION

Ubiquitous data services and very high data rates across heterogeneous networks can be achieved by using a wireless local area network (WLAN) as a complementary technology for cellular data networks [1]. Thus, there has been a strong demand for efficient internetworking mechanisms between WLANs and third-generation (3G) cellular data networks. With the aim of addressing this requirement, a variety of internetworking architectures have been proposed in recent work. By and large, these internetworking architectures may be categorized as tight coupling, loose coupling, and peer-to-peer networking (also referred as no-coupling) [2]. Despite the fact that there are various internetworking architectures proposed, many unresolved issues exist.

This article presents an internetworking model capable of providing a mobile host (MH) with the highest possible level of continuation of service while moving between a WLAN and a Universal Mobile Telecommunications System (UMTS) network. The significance of this architecture is that the Third Generation Partnership Project (3GPP) IP multimedia subsystem (IMS) has been used for supporting real-time session negotiation and management. The motivation for using 3GPP IMS as a mediator for coupling can be summarized as follows. First, IMS is capable of facilitating (application-layer-based) media session establishment and control for all-IP-based networks. Second, IMS can negotiate end-to-end quality of service (QoS) levels during session setup, which also is in line with the preconditions call flow model (RFC 3312). Third, because IMS-based signaling flows through the home subscriber server (HSS) of the home network, policy-based service control becomes feasible. Last, Session Initiation Protocol (SIP)-based session and terminal mobility mechanisms may be directly applicable (although the IMS specification in UMTS Release 5 does not address these issues) for enabling service continuation during vertical handoffs. Furthermore, it also can be conveniently exploited as a mediator for signaling in a heterogeneous networking environment with additional controls as inspired by [3, 4]. By default, the SIP has been selected by the 3GPP as the signaling protocol for the IMS [5]. The capability of SIP to support terminal mobility, session mobility, and service mobility has made it an attractive candidate as a mobility management protocol [6].

Within the context of the proposed framework, this article also presents how a successful IMS-SIP-controlled session handoff takes place between a WLAN and a UMTS network. A make-before-break type handoff is used between the two networks, such that the service continuity is maintained during the session handoff procedure. In the event a previously handed off session is required to be retrieved, a similar mechanism is applied. Furthermore, the ability of a proposed interworking framework for providing terminal and session mobility is verified using an OPNET-based simulation platform. The remainder of this article is structured as follows. The next section investigates the recent advancements in WLAN-UMTS internetworking. This is followed by a section on the presented architecture, which describes how the IMS has been used as a mediator for session handoff. Next the OPNET-based simulations are presented. Prior to the final conclusions, we present a comprehensive discussion on how the model performs against the current standards.

This work is supported by an ARC Linkage Project in collaboration with SingTel Optus.

RECENT ADVANCEMENTS

As mentioned previously, internetworking architectures presented in the current literature can be primarily categorized as tightly coupled, loosely coupled, and peer-to-peer networked. This section briefly introduces these three coupling architectures and discusses the current issues.

TIGHT COUPLING

In tight coupling, as illustrated by flow 1 in Fig. 1, the WLAN is directly connected to the UMTS core network. Thus the WLAN data traffic passes through the UMTS core network before reaching the external packet data networks (PDNs). The key functional element in the system is the GPRS interworking function (GIF), which emulates an IEEE 802.11 extended service set (ESS) to a serving GPRS support node (SGSN) via the standard Iu-ps interface [1]. The GIF makes the SGSN consider the WLAN as a typical radio network controller (RNC) within a UMTS terrestrial radio access network (UTRAN), composed of only one cell. Therefore, the handover between a WLAN and a UMTS network can be considered as a handover between two individual cells. A clear advantage of this approach is that the UMTS mobility management techniques can be directly applied. However, the biggest disadvantage is that a bottleneck situation may arise at the SGSN as a result of the increased data traffic flowing through the WLAN.

LOOSE COUPLING

Alternatively, a loosely-coupled architecture transports signaling over an IEEE 802.11 WLAN to the UMTS core network (CN), and data flows directly through the IP-based network. Flow 2 in Fig. 1 illustrates an overview of the loose-coupling architecture. In this scenario, signaling provides authentication, authorization, and accounting (AAA) between the two interworking networks. Nonetheless, there are other variants to this internetworking architecture, which may require the user data traffic to be routed to the UMTS CN [7, 8]. A clear advantage of this method is that because the data traffic is routed directly via an IP network (or the Internet), a potential traffic bottleneck can easily be avoided. However, in regard to a loose-coupling architecture, handoffs are less efficient and mobility can only be considered when the user is not in an active session [2].

PEER-TO-PEER NETWORKING

In the previously presented coupling methods, the UMTS CN acts as the "master" network, and the IEEE 802.11 WLAN behaves as the "slave" network. The peer-to-peer coupling mechanism, as illustrated by flow 3 in Fig. 1, can be seen as an extension to the loose-coupling architecture; it treats the two networks as peers [9]. Mobile IP (MIP) and AAA servers are used to provide a framework for mobility [10]. MIP is used to restructure connections when an MH roams from one peer network to another, and AAA servers provide AAA functionality. However, due to known deficiencies of the MIP protocol itself, this may not be the best solution for frequently roaming users.

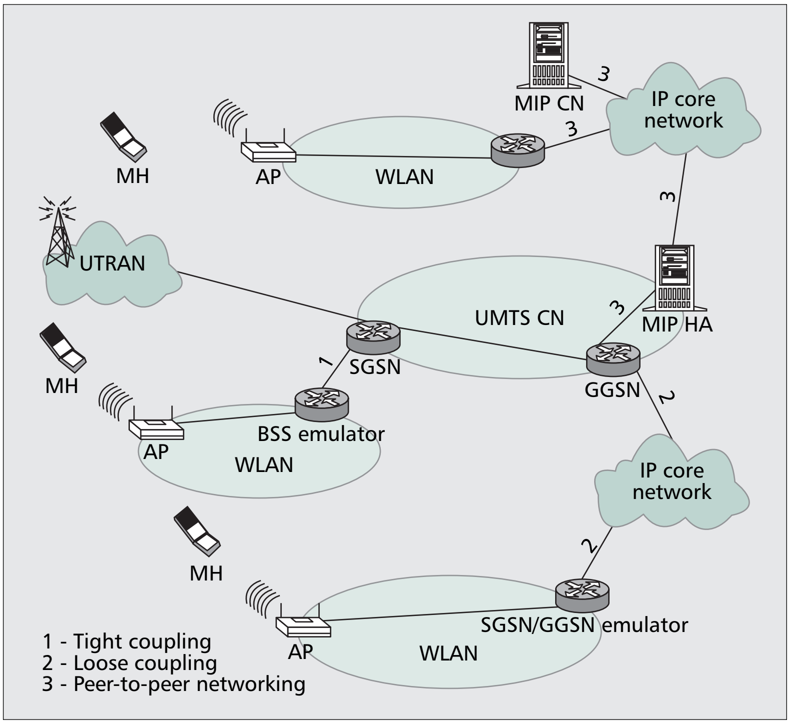


Figure 1. *Current internetworking architectures.*

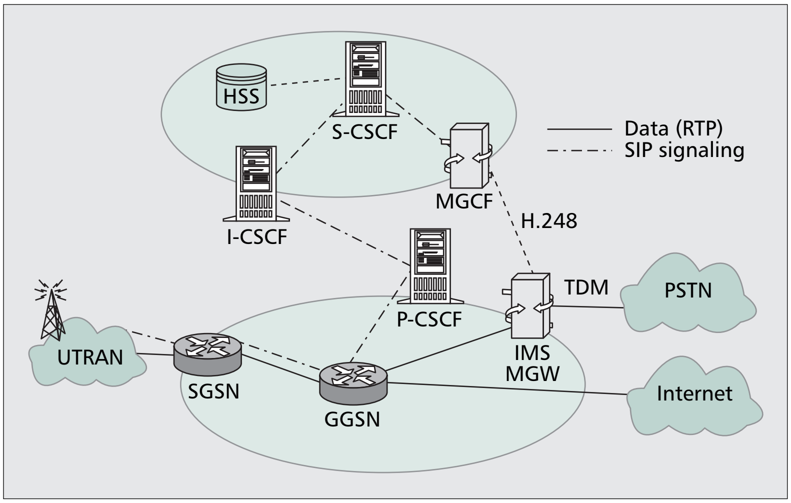
WLAN-3G CELLULAR INTERWORKING ARCHITECTURE

The internetworking model presented in this article provides an MH with the highest possible level of internetworking where fully seamless continuity of service across WLAN-UMTS networks is considered to be the ultimate accomplishment. As an arbitrator for internetworking between the WLAN and the UMTS network, IMS has been used in this approach. A clear advantage of using IMS is its capability for real-time session negotiation and management. Therefore, prior to presenting the details of this novel architecture, we present a brief overview of the IMS.

IMS: AN OVERVIEW

IMS was introduced by UMTS Release 5 and Release 6 within its core network [11]. It comprises the required characteristics for control of multimedia sessions and plays an essential role in the provision of IP multimedia services in a UMTS network. It also provides for an entry point for third-party multimedia applications and services in a controlled and secure manner.

Figure 2 provides a general overview of the IMS architecture and outlines the essential network elements used for providing real-time IP multimedia services [11]. The call state control functions (CSCFs) and the HSS are the key elements of this framework. They are essentially involved in processing signaling messages for controlling multimedia/call sessions. Apart from this, the CSCFs are also involved in the address



■ **Figure 2.** *An overview of the IMS architecture.*

translation, perform service switching and negotiation, and handle the subscriber profile.

Depending on various configurations and scenarios, the roles for the CSCFs are categorized as follows. The proxy-CSCF (P-CSCF) is the first contact point of the IMS, which is located in the same network as the GGSN. This could either be in the home network or the visiting network. The P-CSCF forwards the Session Initiation Protocol (SIP) registration messages and session establishment messages to the MH home network. The interrogating-CSCF (I-CSCF) is the main entrance of the home network from a visited network. With the assistance of the HSS, the I-CSCF selects the appropriate serving-CSCF (S-CSCF). The S-CSCF is the node that eventually performs the actual user registration and session control for the IMS network. The home location register (HLR) has evolved into the HSS. Interfacing with the I-CSCF and the S-CSCF, the HSS can be regarded as a master database that acts as a repository for subscription and location information. The media gateway control function (MGCF) interconnects with circuit switched networks via the corresponding IMS media gateway (IMS-MGW). Also, the media resource function controller (MRFC) performs processing of media streams through the corresponding media resource function processor (MRFP).

The protocols that have been defined within the IMS architecture can be classified under three broad categories. The first category comprises the protocols used in the signaling and session control plane. The SIP is the core protocol chosen by 3GPP for signaling and session management within IMS [5]. Further, the extensible nature of SIP has been utilized by 3GPP for incorporating additional features to suit IMS [3]. The second and third categories consist of protocols used in the media plane and protocols used for authentication and authorization.

Interworking Model

Our proposed internetworking architecture, with signaling and data routes, is illustrated in Fig. 3. The flow of data originates from the MH, through the SGSN and the GGSN (of the visitor network, in this case), and reaches the destination network. Because 3GPP allows both home-GGSN and visitor-GGSN approaches for roaming, either approach can be used for user data routing. In either approach, the data flow bypasses the IMS network altogether. Thus, IMS is said to follow the philosophy of using different paths for user data and signaling through the network.

The establishment of a SIP session within the 3GPP-IMS framework involves several functions. The key steps required for obtaining access to SIP services can be summarized as follows. The first step involves the MH powering on and locking to the UMTS network. After the appropriate cell is selected, the MH can be considered ready for the establishment of a data session. This article assumes that this function was already performed by the MH and is not discussed in detail.

After the previously mentioned system acquisition is completed, the next step is to establish a data connection or set up a data pipeline for the SIP and other services. To perform the SIP registration, initially the MH is unaware of the IP address of the P-CSCF. Thus, the data connection must be completed in two steps by using the Attach and Packet Data Protocol (PDP) context activation message sequences. The activation of a PDP context assigns an IP address for the MH. The context activation creates an association for this IP address between the SGSN and the GGSN that can be used for establishing the path required to carry SIP-related signaling messages to the P-CSCF through the GGSN. With the activation of the PDP context, the MH can identify the P-CSCF for the registration with the UMTS SIP network.

Prior to establishing a SIP session, the MH must perform a service registration function to advise the IMS of its location. The MH acts as a SIP client and sends a SIP registration message to its home system through the P-CSCF. The basic steps for a SIP service registration can be summarized as follows. First, the HSS for the MH is notified of its current location so that the HSS can update the subscriber profile accordingly. Next the HSS checks if the MH is allowed registering in the network. Based on the subscriber profile and operator limitations, the authorization is granted. Once authorized, a suitable S-CSCF for the MH is assigned, and its subscriber profile is sent to the designated S-CSCF.

After the activation of the PDP context and the service registration, the MH is ready to establish a media/data/call session. As illustrated in Fig. 4, the data flows in the SIP-session origination procedure can be described as follows. The mobile origination procedure is initiated by a SIP INVITE message sent from the UMTS interface of the source MH. This initial message is forwarded from the P-CSCF to the S-CSCF of the originating network, via the CSCFs of the terminating network, and finally to the destination. This SIP INVITE request carries a Session Description Protocol (SDP) body indicating the IP address and port numbers where the source wants to receive the media streams. Furthermore, the INVITE also contains a request to follow the *precondition call flow model*. This is important because some clients require certain preconditions (i.e., QoS levels) to be met before establishing a session. The requirement for using the preconditions call flow model in the IMS is mainly because in cellular networks, radio resources for the media plane are not always available. If the preconditions extension is not used, when the called party accepts the call, the source and destination may not be ready and consequently, the first few packets may be lost.

Next, this model requires that the destination responds with a 183 Session Progress containing a SDP answer. The SDP answer contains the media streams and codecs that the destination can accept for this session. The acknowledgment for the reception of this provisional response by a PRovisional ACKnowledgement (PRACK) request follows afterwards. If the destination does not receive a PRACK response within a determined time, it transmits the provisional response. When the PRACK request successfully reaches the destination, a 200 OK response is generated by the destination with an SDP answer. Next, an UPDATE request is sent by the source containing another SDP offer, in which the source indicates that the resources are reserved at its local segment. After the destination receives the UPDATE request, it generates a 200 OK response. After this is done, the MH can start the media/data flow, and the session will be in progress (via the UMTS interface).

Session Handoff

As the WLAN interface becomes active, the ongoing media sessions can be handed over to the newly activated WLAN interface. This is where the requirement for a mechanism for a pure SIP (or application layer)-based session handoff arises. This is because IMS performs pure SIP-based signaling at the application layer, and IPv4 or IPv6 mobility cannot directly support such session mobility. Current work indicates at least three such mechanisms for achieving this [12]. These are the re-INVITE method with new location information [5], the third-party call control (3pcc) mechanism [13], and the SIP REFER method [14]. The simple re-INVITE method lacks the capability for obtaining previous session information, and the second mechanism has the disadvantage of requiring the original session participant to always be contacted for any session modifications. However, the SIP REFER method explicitly transfers the session to the new destination and hence becomes the obvious choice.

Under realistic conditions, a vertical handoff decision ideally must be triggered by a network selection mechanism. Because network selection criteria are beyond the scope of this article, a manual triggering for handoff is considered. It is worth noting that all activated interfaces (e.g., WLAN) must perform a SIP registration function with the S-CSCF of the originating home network.

The basic steps for an IMS-SIP-based session handoff is illustrated in Fig. 4 and can be

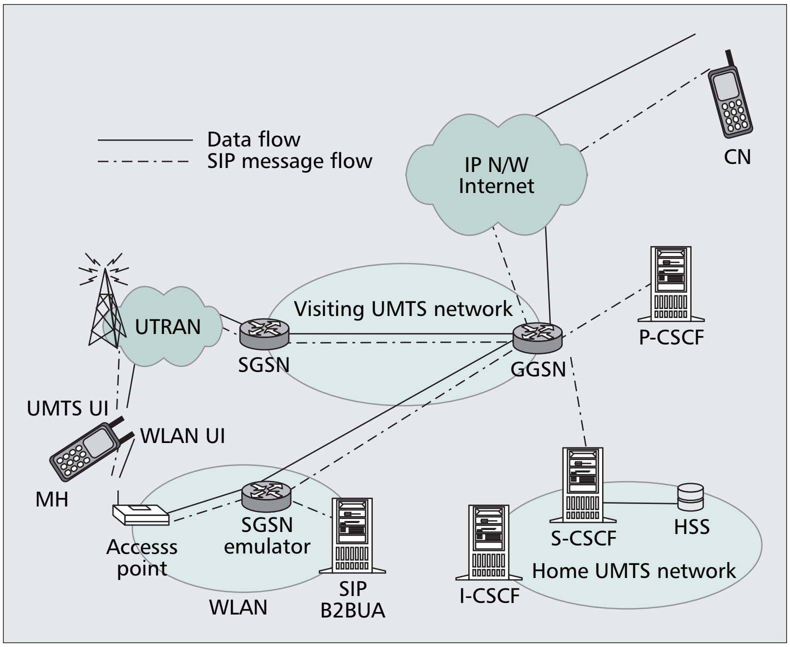


Figure 3. *WLAN-UMTS internetworking architecture.*

described as follows. The UMTS interface notifies the WLAN interface with a SIP REFER request (step 8). The REFER request contains a "Refer-To" header line containing the destination SIP URI and a "Replaces" header line identifying the existing session to be replaced by the new session. Next, the WLAN interface sends the CN an INVITE message with the "Replaces" header received from the previously received REFER request (step 10). Also, the new IP address and port numbers are also included in the SDP body of this INVITE message. The receipt of the "Replaces" header is what indicates that the initial session is to be replaced by the incoming INVITE request and hence be terminated. Now the WLAN interface has successfully established a direct signaling relationship with the CN. After the WLAN interface has successfully established a session with the CN, it sends a NOTIFY request to the UMTS interface updating the final status of the REFER transaction (step 12). This NOTIFY message contains the session information of the newly established session enabling the UMTS interface to subsequently retrieve the session (if so desired). After the data flow is established between the WLAN and the CN, the UMTS interface tears down its session with the CN (steps 15–16).

Also, note that in the event that the provided information in the replaced header does not match any existing session, the triggered INVITE message sequence does not replace the initial session and will be processed normally. Thus, any failed session handoff attempt can not destroy the initial session.

Session Retrieval

In the event that the UMTS interface wishes to retrieve a session that previously was handed-off to a WLAN interface, the message flow illustrated in Fig. 5 takes place.

A fully functional IMS signaling model was constructed and integrated to the existing UMTS special model of the OPNET. Because the existing components of the SIP model provided in the standard model library do not address the specifications of the 3GPP IMS, substantial modifications were required.

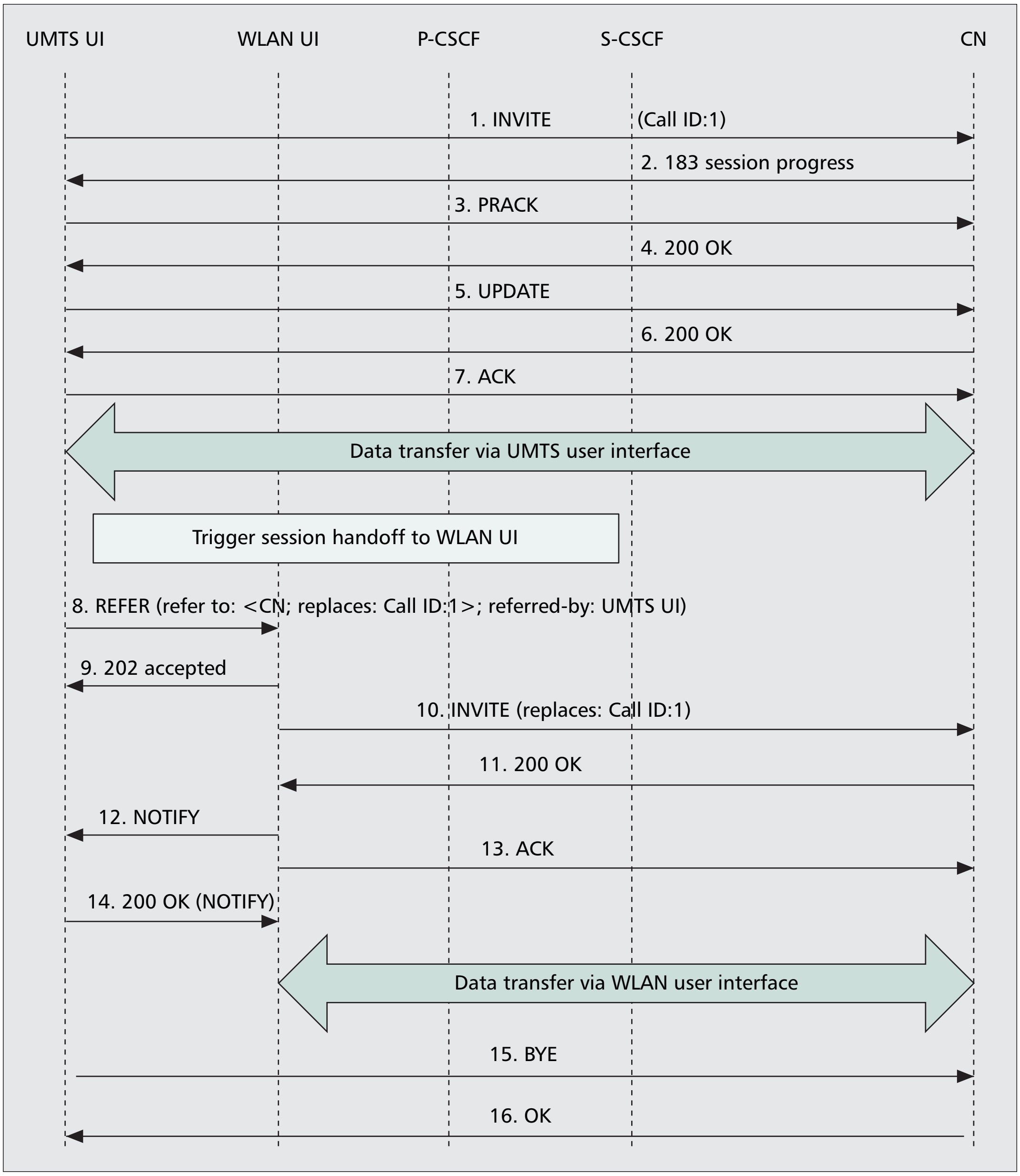


Figure 4. *IMS-SIP-based session handoff.*

As previously discussed, the UMTS interface must receive a REFER request from the WLAN interface with its URI included in the "Referred-By" header (step 19). However, to prompt a REFER request from the WLAN interface the UMTS interface must send a "nested REFER," which is a REFER request for another REFER according to RFC 3892 (step 17). The "Refer-To" header of a nested REFER request specifies the UMTS interface as the refer target and specifies that the referral is in the form of a REFER request. Next, the UMTS interface is ready for initiating a session with the CN by sending a SIP INVITE with "Replaces" and "Referred-By" headers that will replace the existing session with the CN (steps 20–22). When the CN accepts the INVITE request from the UMTS interface and after the session is established, the session with the WLAN interface could be terminated (Steps 23–24).

Network Modeling, Simulation, and Results

To investigate the ability for interworking of the previously described architecture, where the IMS is used as an arbitrator for session control, a network simulation scenario is modeled. A fully functional IMS signaling model was constructed and integrated to the existing UMTS special model of the OPNET. Because the existing components of the SIP model provided in the standard model library do not address the specifications of the 3GPP IMS, substantial modifications were required. These included modifications in SIP proxy servers (user agent servers [UASs]) to function as different CSCFs, user agent client (UAC) processes to communicate with modified UASs, IMS-SIP based messaging and flow between the CSCFs, a roaming facility between multiple domains, and a facility

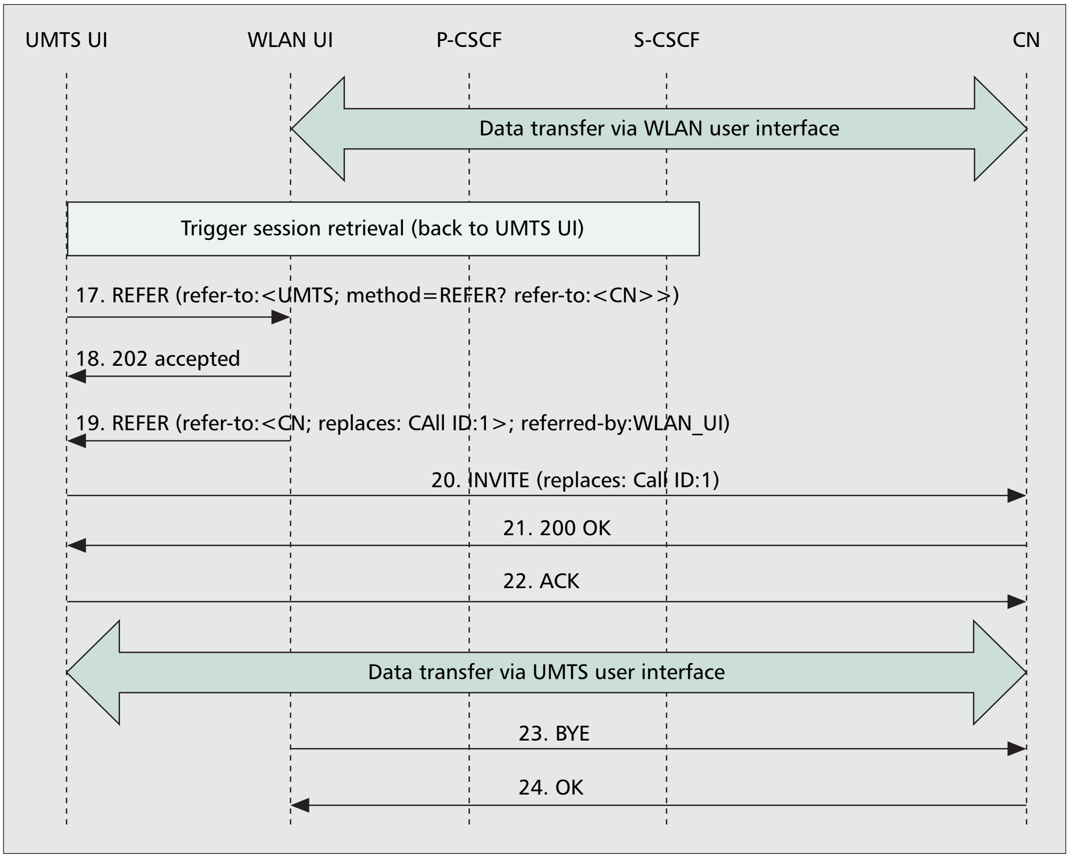


Figure 5. *IMS-SIP-based session retrieval.*

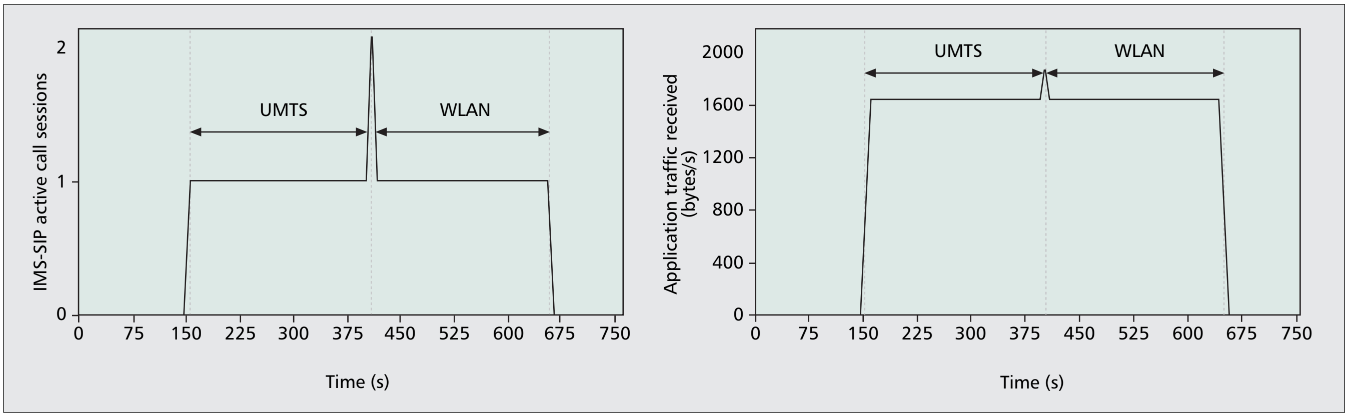
The preliminary simulation results of the proposed architecture clearly indicated the feasibility and potentials of this approach. The proposed model will be improved for automatically negotiating IMS-based preconditions during/after a session handoff for ensuring QoS and seamless service continuity.

for introducing process delay controls (i.e., for messages sent between CSCFs and the HSS queries). Thus a UMTS network that is fully capable of using IMS-based SIP signaling is modeled.

An infrastructure basic service set (IBSS) WLAN is connected via an SGSN emulator to the GGSN of the visiting UMTS network. For simulation purposes the two networks have two separate IP address pools. The P-CSCF (WLAN) can be seen as a SIP back-to-back user agent (B2BUA) that is capable of interworking with the IMS-SIP and capable of forwarding SIP requests. S-CSCF is the only IMS node implemented in the home UMTS network. This is because the I-CSCF mainly is used for the SIP registration process, and it is assumed that both the UMTS and the WLAN interfaces of the user equipment (UE) already have been registered. The corresponding node (CN), which is an IMS-SIP UAC, is connected to a destination IP network via the public IP network/Internet (IP cloud). The IMS-SIP flows of messages essentially follow the sequences described in Fig. 4 and Fig. 5. As specified in the previous sections, the mobile host is expected to have multiple interfaces (UMTS and WLAN). Both interfaces are active throughout the simulation. Manual triggering of vertical handoff is done for initiating session handoff and retrieval.

For the purpose of evaluating the model, the details of the actual data flow briefly can be described as follows. A VoIP data session, as predefined in the OPNET application definitions and profile definitions, is used for generating a constant data flow between the UE and CN. Although different traffic types may be permitted under the umbrella of VoIP technology, the underlying information transmission technology remains the same. The traffic type could be data, voice, video, voice and video, and so on. Therefore, depending on the available bandwidth, different codecs can be used. The GSM codec was used for the following simulation. However, because the objective of these simulations is to study the capability of the model for successfully performing an IMS-SIP-based session handoff at the application layer in a heterogeneous networking environment, the type of data flow used has a minimal impact on the final outcome. Thus, from the point of view of the simulation, details of its characteristics may be overlooked as long as the same flow is used throughout the simulation.

First, a SIP session is established between the UMTS interface and the destination CN, and next the data flow takes place. The average IMS-SIP session establishment time over an UMTS network (for the given setup) is 480 ms. When session handoff is triggered, the already activated WLAN interface proceeds with steps 8 to 14. This takes approximately 150 ms. As the two graphs in Fig. 6 indicate, there exists a time when both interfaces become simultaneously active and data flow takes place via both interfaces. This relates to the sudden jump in IMS-SIP sessions from one to two and an increase in the data flow, due to data duplication, in the graphs of Fig. 6. This is because a new session is established before breaking down the existing



■ **Figure 6.** *Numbers of active IMS-SIP sessions and corresponding application traffic flow during a UMTS to WLAN session handoff.*

session, thus complying with the type of make-before-break type handoff. Also, Fig. 6 indicates how session continuation can be achieved during and after handoff (despite the data duplication).

Discussion

The obtained simulation results indicate the capability of the proposed interworking model to successfully perform a session handoff from a UMTS interface to a WLAN interface. Also, the retrieval of this session from a WLAN to a UMTS interface can be similarly simulated. The session also can be initiated at the WLAN interface and consequently be handed off to a UMTS interface and if desired, retrieved.

The described IMS-SIP-based session handoff and retrieval mechanisms can be classified as make-before-break type handoff methods. As the name suggests, the existing session is not terminated until the new session is successfully established, which helps achieve service continuation during session handoff. As stated in the simulations section, service continuation is achieved over separate IP domains. Unlike in the case of a peer-to-peer coupling mechanism, this approach does not require a mechanism such as MIP for IP address mapping. It also is not as complex as handling session handoff in a loosely coupled interworking architecture where session management is not centrally controlled. However, it is naturally more complex than a tightly-coupled interworking mechanism, where the GPRS core network treats the WLAN as another RNC. Therefore, the described vertical handoff mechanism seems to be capable of addressing the session mobility issue for independently operating, heterogeneous networks.

This makes our framework compatible with scenario four (i.e., capable of maintaining service continuity during a vertical handoff) in the recommendations stated for interworking given by 3GPP TR 22.934 [15]. As a consequence, there may exist a time when both sessions are active, and data flow via both interfaces is taking place. However, because the two networks have different traffic conditions, the QoS of the data flow may vary. Therefore, an appropriate filtering mechanism for eliminating duplicate packets must be implemented at a lower layer. Because this article primarily concentrates on IMS-SIP-based session handoff, a solution for overcoming packet filtering is not included.

It is important to note that, unlike the case of a tightly-coupled approach, the WLAN does not behave as another BSS. It essentially emulates the WLAN as another SGSN belonging to the same UMTS network. The data originating from the WLAN can be routed via the SGSN emulator directly to the GGSN. Therefore, high volumes of WLAN data traffic would not create a bottleneck situation at the UTRAN or the SGSN, which was one of the disadvantages of the tightly-coupled approach. Although the data flow is not tightly coupled in this approach, the IMS-SIP-based signaling is closely coupled. Thus the IMS of the UMTS network can centrally manage any sessions being handed off between the WLAN and UMTS networks.

Conclusions

This article presented an internetworking model for WLAN and UMTS networks with the IMS framework of the 3GPP acting as a unified session controller. It addressed many deficiencies of the existing internetworking architectures. The most significant benefit was its capability for negotiating and managing real-time sessions with the use of the IMS as a centralized mediator for coupling. The preliminary simulation results of the proposed architecture clearly indicated the feasibility and potentials of this approach. Although transient packet loss during a session handoff has been avoided by the handoff mechanism, measures for avoiding data duplication have been recommended. Furthermore, the proposed model will be improved for automatically negotiating IMS-based preconditions during/after a session handoff for ensuring QoS and seamless service continuity.

Acknowledgments

The authors would like to acknowledge the use of OPNET Modeler for the simulation of this work, which was supported under the OPNET University Program.

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BIOGRAPHIES

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