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A 3GPP-IMS based Approach for Converging Next Generation Mobile Data Networks

Kumudu S. Munasinghe and Abbas Jamalipour
School of Electrical and Information Engineering
University of Sydney
NSW 2006, Australia
kumudu@ee.usyd.edu.au and a.jamalipour@ieee.org

***Abstract*— This paper presents a promising architecture for converging third-generation (3G) cellular data networks and Wireless Local Area Networks (WLANs) by using the IP Multimedia Subsystem (IMS), proposed by the 3G Partnership Project (3GPP), as an arbitrator. The IMS provides real-time session management, and unified session control. Within the scope of the presented framework, terminal and session handoffs are investigated for two different roaming scenarios. The first scenario investigates handoff from UMTS to WLAN and the second scenario investigates handoff from WLAN to UMTS. The paper concludes by presenting some simulation results obtained for these handoff scenarios using an OPNET based simulation model.**

Keywords-3GPP; IMS; UMTS; WLAN; SIP; interworking;

I. INTRODUCTION

As the modern high-speed data applications tend to impose a challenge on the bandwidth limitations of existing 3G cellular networks, a strong need for efficient mechanisms for interworking these with WLAN technologies arise. As a result, mobile users will be able to experience ubiquitous data services and very high data rates across heterogeneous networks by using WLANs as a complementary technology for next generation cellular data networks, while providing the end user with a seamless experience [1]. This will enable a user to access 3G cellular services via a WLAN, while roaming within the range of a hotspot.

With the aim for addressing this need, a variety of internetworking architectures for 3G Cellular and WLANs have been proposed. 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], [3]. However, these approaches seem to provide limited internetworking capability as neither of these designs has successfully addressed the issue of seamless continuation of services.

Having identified the importance of such an interworking mechanism, our work is motivated towards developing a solution that is capable of achieving the highest possible level of service continuation during a vertical handoff. Therefore, this paper presents an internetworking model capable of meeting these challenges. Nevertheless, the significance of this architecture is that it has used a novel approach, that is, the use of the 3GPP's IMS for supporting real-time session negotiation and management with additional controls as inspired by [4], [5].

The next section investigates the recent advancements in WLAN-UMTS internetworking. Followed by this comes the section on the presented architecture, which describes how the IMS has been used as a mediator for internetworking. Next section is on an OPNET based simulation with results for session handoff. Prior to the final conclusions is a brief discussion on our future works.

II. OVERVIEW OF WLAN-UMTS INTERWORKING

As previously stated and illustrated by Fig. 1, the main architectures for internetworking WLANs and UMTS networks may be primarily categorized as tightly coupled, loosely coupled, and peer-to-peer networked.

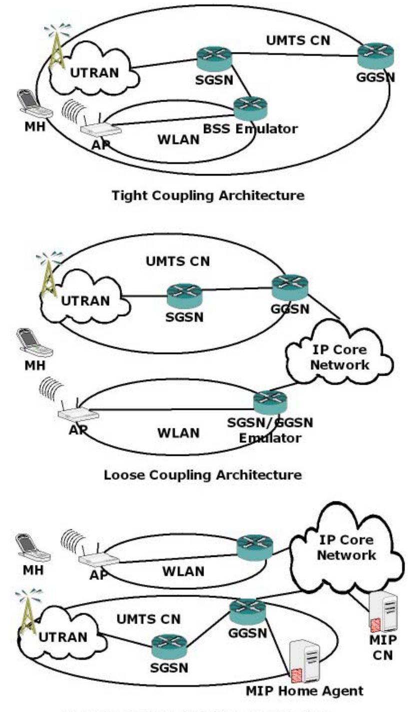

Figure 1. Current Internetworking Architectures.

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Tight coupling connects the WLAN directly to the UMTS core network. The key functional element in this 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 $I_{u\text{-}ps}$ interface [1]. The GIF emulates the WLAN as a typical Radio Network Controller (RNC) within a UMTS Terrestrial Radio Access Network (UTRAN), composed of only one cell. 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.

The loosely coupled architecture exchanges signaling between the WLAN and the UMTS CN, the data flows directly via an IP based network. There are also other variants to this internetworking architecture, which require the user data traffic to be routed via the UMTS CN [6], [7]. Since the data traffic is routed directly via an IP network, this method helps to avoid a potential traffic bottleneck. However, in this case, handoffs are less efficient and mobility may not be guaranteed for a user engaged in an active session [3].

The peer-to-peer coupling mechanism can be seen as a further extension of the loose coupling architecture, where the two networks are treated as peers [2]. However, Mobile IP (MIP) and AAA servers are used for providing a framework for mobility [8]. However, due to known deficiencies of the MIP protocol itself, this may not be the best solution for frequently roaming users.

Despite the fact that there are various internetworking architectures proposed in current works, many open issues still exist. The first of which is the issue of session mobility across WLAN and UMTS networks. Efficient ways to provide/enable seamless continuity of service across WLAN and 3G cellular networks can be ranked as a top issue. Another important issue is to define a mechanism for data routing in heterogeneous networks. Furthermore, matching the QoS requirements and service provisioning such environments is also another related issue.

III. IMS BASED INTERWRKING

This section aims at introducing our proposed interworking model, which is aimed towards addressing some of the previously mentioned inadequacies. This framework provides a mobile host the highest possible level of internetworking, where fully seamless continuity of service across WLAN-3G cellular networks can be seen as its ultimate accomplishment. As an arbitrator for internetworking between the WLAN and the UMTS network, the IMS is deployed. A clear advantage of using the IMS is its ability for real-time session negotiation and management using the Session Initiation Protocol (SIP). Therefore, prior to introducing this novel architecture, a brief overview of the IMS and SIP is presented.

A. Introduction to the IP Multimedia Subsystem

The UMTS Release 5 within its core network, introduced the IP Multimedia Subsystem [9]. It consists of the essential requirements for controlling of multimedia sessions and

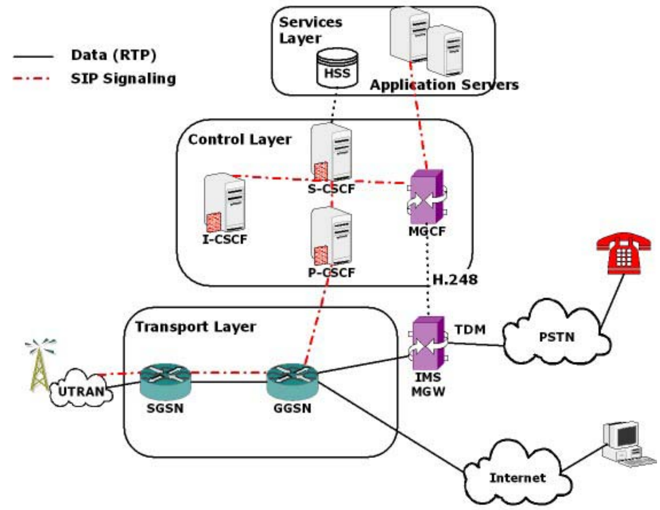

Figure 2. An Overview of the IMS Architecture.

provisioning of IP multimedia services for a UMTS network. A general overview of the IMS architecture is provided in Fig. 2. This section provides an outline of the main networking fundamentals of the IMS used for providing real-time IP multimedia session management [9].

The key elements of the IMS framework are the Call State Control Functions (CSCFs) and the Home Subscriber Server (HSS). A CSCF can be loosely defined as a SIP proxy server and the HSS as a master database for user profiles. The CSCFs can be identified as follows; Proxy-CSCF, Interrogating-CSCF, and Serving-CSCF. The P-CSCF is the first SIP proxy receiving a SIP request, which also acts as a SIP Back-to-Back User agent (B2BUA). The P-CSCF forwards session requests to the S-CSCF via the I-CSCF. The task of the I-CSCF is to select the appropriate S-CSCF by checking with the HSS. If the relevant S-CSCF is known, the I-CSCF may be bypassed.

The S-CSCF is the actual SIP server that eventually performs the user registration and handles session control for the IMS network. The Media Gateway Control Function (MGCF) interconnects with circuit switched networks via the corresponding IMS Media Gateway (IMS-MGW).

B. SIP Overview

SIP is the core protocol chosen by the 3GPP for signaling and session management within the IMS [10]. By and large, SIP can be defined as an application layer based flexible framework used for establishing, maintaining, and tearing down multimedia sessions. SIP is capable of supporting multiple IP media streams and other TCP or UDP based streaming applications.

Nevertheless, SIP is not just a single standalone protocol, which is fully capable of call control. It rather behaves as a suite of protocols when it comes to providing a complete solution. For example, a standard VoIP application embeds the Session Description Protocol (SDP) within the SIP messages for negotiating bearer path attributes. Once the parameters of the session are agreed upon, a media session can now be established. The media flow typically uses the Real-Time

Protocol (RTP) if it is VoIP traffic. Even though SIP does not play a role in the media session, it is used for terminating or changing the parameters of the session.

SIP is based on a request/response model where the SIP User Agent Client (UAC) invokes the requests the SIP User Agent Server (UAS) responds. Each request by the SIP-UAC invokes a method in the SIP-UAS. The basic SIP methods can be identified as REGISTER, INVITE, ACK, BYE, CANCEL, OPTIONS. Additional extensions to these basic methods are also available. More extensive information on these methods is available from [10]. Furthermore, the extensible nature of SIP has also been utilized by the 3GPP for incorporating additional features to suit the IMS [4].

C. SIP based Mobility Support

SIP can be used to implement all four mobility aspects defined by IMT-2000; namely, personal, terminal, session, and service mobility [11]. Personal mobility is allowing a single user to access via different terminals and to be addressed at each location by a unique personal identity. Terminal mobility refers to the users' ability to roam between disparate networks (or IP subnets), while maintaining access to the same set of subscribed services. Session mobility refers the users' ability to maintain an active session while switching between terminals. SIP can successfully implement session mobility (or mid-call mobility) by sending an INVITE method while the multimedia session is still in progress. This is better known as a re-INVITE method. This enables the addition and removal of terminals while maintaining the existing session alive. Further, changes could be added to the session to match the capability of the added terminals. Lastly, the Service mobility can be defined as the ability of the network to consistently provide personalized services to the user while changing devices regardless of the location. It is worth noting that within the scope of this paper, in regards to a dual interface terminal roaming between a UMTS network and a WLAN, only SIP based terminal and session mobility is addressed. The design also ensures that the roaming interface maintains a unique IP address throughout the session in order to avoid complexities of mid-call mobility.

D. The Proposed Framework

Our recommended framework for internetworking is illustrated in Fig. 3. The flow of data originates from the source MH, through the SGSN and the GGSN, and reaches the destination network. This model uses the Visitor-GGSN approach to avoid the inter-PLMN (Public Land Mobile Network) backbone and to make data routing simpler for the network operator [12]. In whichever approach, the data flow bypasses the IMS network. Thus the IMS is said to follow the philosophy of using different paths for user data and signaling through the network. The SIP signaling messages originate from the MH via the UTRAN, through the SGSN and GGSN, out to the CSCFs and finally to the destination network. It is important to note that when the MH requires establishing a session, this request is always sent to the (Home) S-CSCF via the (Visiting) P-CSCF. During the exchange of SIP signaling, both the SGSN and GGSN act as routers by merely forwarding SIP messages.

The data originating from the WLAN is routed via a SGSN emulator to the UMTS GGSN. It essentially emulates the WLAN as another SGSN belonging to the same UMTS network. Thus mobility can be managed by the UMTS network. Some of the functionalities of the BSS are bypassed in this approach and the load on the UMTS network, created by the high volumes of WLAN data traffic, may also be sufficiently reduced. Furthermore, a MH does not require any change of IP addressing between the WLAN and UMTS network as long as the two networks are connected to the same GGSN.

The establishment of a SIP session within an UMTS IMS environment is involved with several functions. The key steps required for obtaining access to SIP services can be summarized as follows. The first step involves with the MH powering on and locking to the UMTS network. This paper assumes that this function is already performed by the MH, and will not be discussed in detail. Once the above mentioned system acquisition is done, the next step is to establish a data connection, or set up a data pipeline, for the SIP and other services. In order to perform the SIP session establishment the MH is initially 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. With the activation of the PDP context the MH is able to identify the P-CSCF for the registration with the UMTS SIP network.

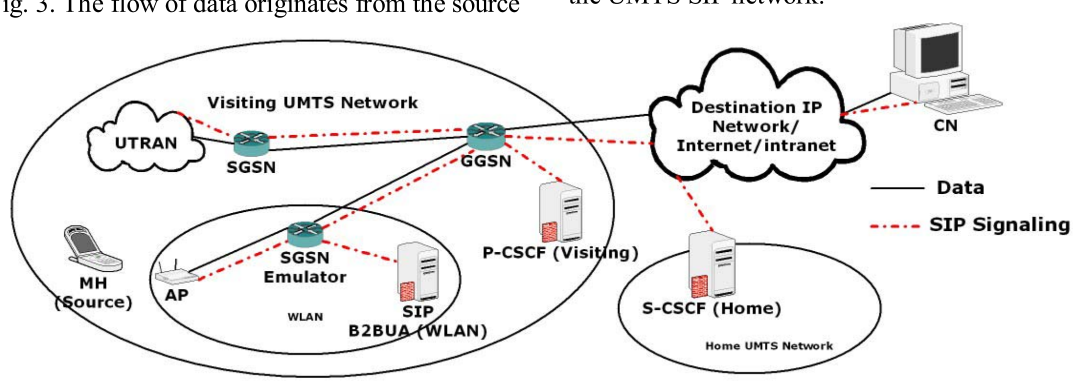

Figure 3. Architecture for WLAN-3G Cellular Internetworking.

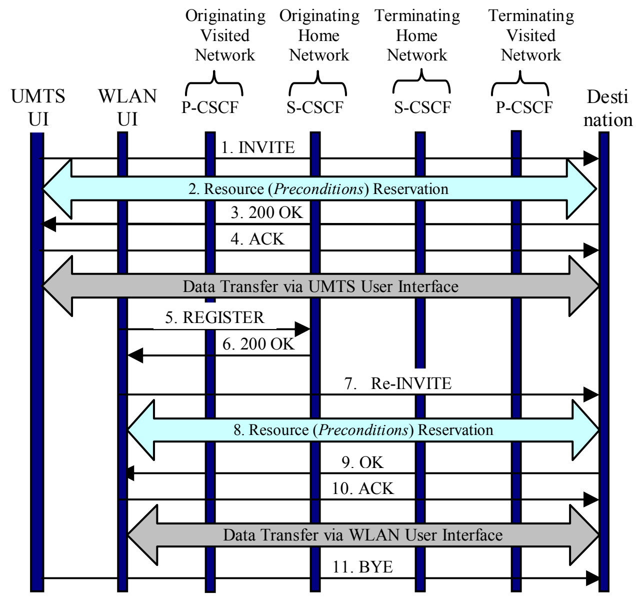

Figure 4. SIP Based Session within IMS.

Prior to establishing a SIP session, the MH requires performing a service registration function to let the IMS know its location. The MH acts as a SIP client and sends a SIP registration message to its home system through the P-CSCF. Once authorized, a suitable S-CSCF for the MH is assigned and its subscriber profile is sent to the designated S-CSCF. Now the MH is ready to establish a (multimedia/voice call) session. As illustrated by steps 1-4 in Fig. 4, the sequence of the SIP session setup procedure can be described as follows.

The mobile origination procedure is initiated by a SIP INVITE message sent form the source MH. Next the two end-points go through the Session Description Protocol (SDP) negotiation stage. Then it comes to the resource reservation stage. The network determines and reserves the necessary resources for supporting this session. Once the resources are reserved a confirmation of session setup (i.e., a SIP OK) and an acknowledgement (i.e., a SIP ACK) is exchanged between the session terminating and initiating points. Once this is done, the source MH can start the media/data flow and the session will be in progress.

E. Session Handoff

When the MH, which is currently connected to the UMTS network, detects the presence of a WLAN around its vicinity, vertical handoff procedures may be initiated. This can specifically be seen as a make-before-break instance of vertical handoff where there exists overlapping coverage. As per the illustration in of the overlapping coverage scenario in Fig. 5, the WLAN signal strength is first observed over time t_0 to t_1 (say). As the intensity of the WLAN signal starts increasing from L (say) and reaches a certain threshold level H (say), the network selection algorithm will start making a decision for handoff. Apart from the WLAN signal strength, the network selection procedure will also be considering other conditions such as available/required bandwidth, delay, and user preferences. Since network selection criteria are beyond the scope of our current research, a detailed discussion will not be included.

However, once such a decision is made, the next step is to activate the existing WLAN interface and initiate the IMS-SIP based handoff mechanism. This plays a vital role in achieving SIP based terminal and session mobility during and after vertical handoff. As illustrated by steps 5-11 in Fig. 4, the basic steps for IMS-SIP based "make-before-break" session handoff can be best described as follows. Firstly the newly activated WLAN interface gains access to the IP network. Next, it performs a SIP registration function with the S-CSCF of the originating home network. However, if this interface has previously been registered this step may be skipped. The next step is to send a SIP Re-INVITE (with same Call-ID and other identifiers corresponding to the ongoing session) to the destination SIP UAC (steps 7-10). Once the WLAN interface successfully initiates a data session flow the UMTS interface terminates its ongoing SIP session (step 11).

Alternatively, when the mobile node roams out of the WLAN, as illustrated in Fig. 5, the situation relates to a non-overlapped coverage. That is, in the event of a fast roaming user, the WLAN link may be lost before mobile node reverts back to the UMTS interface. Thus there is a higher likelihood that a break-before-make instance of vertical handoff may take place. (It is also worth noting that as a result of a sudden drop in signal strength, a break-before-make handoff may result in situations where coverage is overlapping). In the non-overlapped coverage scenario depicted in Fig. 5, the WLAN is the preferred interface. As the signal strength of WLAN starts dropping rapidly the network selection algorithm will be triggered at time t_3 (say). Next, at time t_4 UMTS interface activation and IMS-SIP based session handoff mechanism will take into effect. During this time frame the WLAN signal strength will further deteriorate and consequently a coverage disruption may result between t_4 and t_5. The typically long

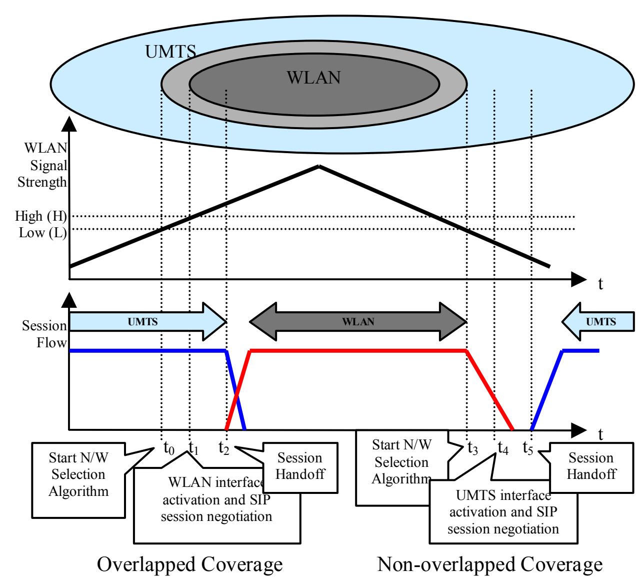

Figure 5. Vertical Handoff Scenarios for Overlapped and Non-Overlapped Coverage.

UMTS call setup delay could further worsen the handoff delay for such a non overlapped break-before-make scenario. Nevertheless, due to various network conditions there may be other delays in the order of SIP requests reaching the destination.

IV. Network Modelling and Results

For validating the potential for interworking of the presented architecture, a network model is constructed for simulation using OPNET Modeler 11.5. Since OPNET's standard SIP components do not address the specifications of the 3GPP's IMS, substantial modifications are required. Thus a fully functional SIP-IMS model for OPNET is constructed and integrated to OPNET's existing UMTS Special Module. The newly developed SIP-IMS model is an enhanced version of the basic IMS-SIP signaling model, which is currently available under the contributed models library of the OPNET University Program [13]. Fig. 6 illustrates the constructed simulation scenario.

Modifications are made for SIP Proxy Servers (UASs) to function as different CSCFs, UAC processes to communicate with modified UASs, IMS-SIP based messaging and flow between the CSCFs, roaming facility between multiple domains, and facility for introducing process delay controls (i.e. for messages sent between CSCFs and the HSS queries). As a result, a UMTS network that is fully capable of using IMS based SIP signaling for session management is developed. Next a simple WLAN is connected via an SGSN emulator to the GGSN of the Visiting UMTS Network. The P-CSCF (WLAN) can be seen as a SIP B2BUA, which is capable of interworking with the IMS-SIP and capable of forwarding SIP requests. The S-CSCF is the only IMS node implemented in the Home UMTS Network. This is since the I-CSCF is mainly used for SIP Registration process and it is assumed that both UMTS and WLAN interfaces of the MH have already been registered. Corresponding Node (CN), which is an IMS-SIP UAC, is connected to a destination IP network via a public IP network (IP Cloud). The IMS-SIP message flows basically follow the sequence described in Fig. 4.

Using the newly developed IMS-SIP based platform a series of simulations are performed for evaluating vertical handoff for the previously described scenarios. That is, firstly a make-before-make handoff (from UMTS to WLAN) and secondly a break-before-make handoff (WLAN to UMTS) is simulated.

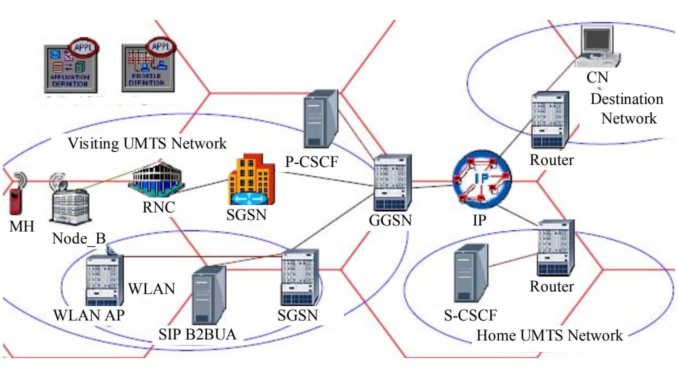

Figure 6. The OPNET Simulation Model.

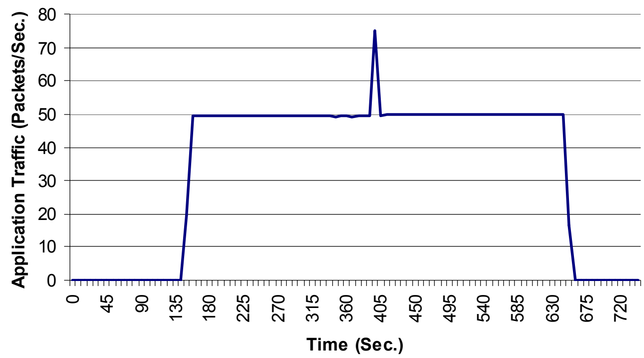

Figure 7. A Make-before-break type Handoff from UMTS to WLAN during Overlapped Coverage.

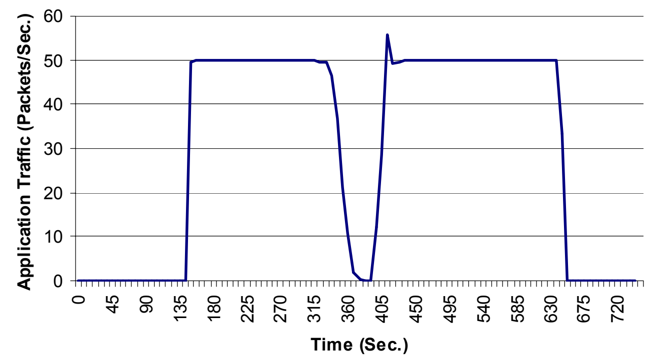

Figure 8. A Break-before-make type Handoff from WLAN to UMTS during Non-Overlapped Coverage.

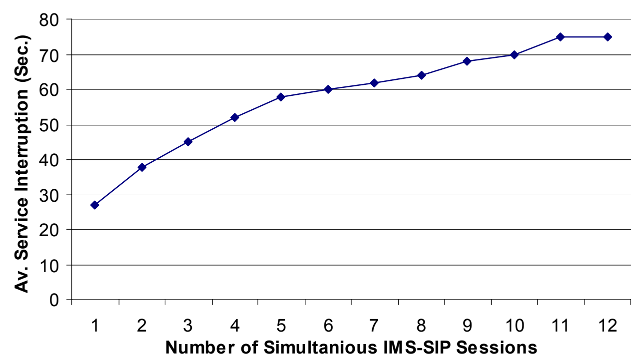

Figure 9. Av. Service Interruption Delay for a Break-before-make Handoff.

However, it is worth noting the assumptions made when obtaining these results. Both the UMTS network and WLAN belong to a single IP subnet and IP addressing and routing is statically assigned. Since there are no multiple networks available (except for one UMTS and one WLAN), the need for a network selection algorithm is eliminated. Handoff decisions are individually based on the signal strength of the WLAN, to which the MH either roams into or roams out of.

As the results in Fig. 7 indicate, this architecture is capable of providing acceptable levels of seamless continuity of services during a make-before-break type handoff where overlapped coverage is present. Since there exists a time when both interfaces become simultaneously active with two IMS-SIP sessions in place, data flow takes place via both interfaces resulting data duplication. This is because a new session is established before breaking down the existing session, thus complying with the type of make-before-break type handoff. It is also worth noting that the handoff is not entirely smooth and there must be appropriate mechanisms at lower layer for overcoming this issue of data duplication.

Fig. 8 shows that there is a brief service disruption delay when handoff takes place for a non-overlapped coverage environment. Due to the resultant transient packet loss and delay, continuity of service cannot be guarantied, which means that some applications may require re-establishing of sessions. Graph in Fig. 9 indicates how the average service interruption delay for a break-before-make handoff behaves against simultaneously increasing IMS-SIP sessions. According to these results the average service interruption delay for a similar handoff is 27 seconds. For a handoff taking place with non-overlapped coverage, the interruption of service delay may be further worsen by the typically long UMTS call setup times. As per the graph, the service interruption delay shows a linear increase with increasing IMS-SIP handoffs.

V. FUTURE WORKS

The main motivation for our future works is towards standardizing a handoff mechanism for IMS based vertical handoff scenarios with minimal transient packet loss and delay. Results indicate that transient packet loss and delay varies depending on each scenario. Results also indicate that the make-before-break handoff scenario is an ideal base for our future work. However, if a situation of break-before-make type handoff arises, a substantial level of packet loss and delay will be encountered. A promising new method to further improve the break-before-make handoff scenario is to introduce a network layer based soft-handoff scheme to assist SIP's inefficiencies [14]. Work is currently underway on how this soft-handoff scheme may be introduced to the IMS.

On the other hand, if the UMTS interface is continuously kept active (while being connected to the WLAN), the handoff time form WLAN to UMTS can be improved. Since the typically long UMTS network setup delays may be avoided, the efficiency of break-before-make handoff can be considerably improved. Nevertheless, maintaining dual connections simultaneously may have practical concerns from a user cost (battery life) or network utilization point of view. Another important issue worth noting is that the current architecture is designed in such a way that both the UMTS network and WLAN belongs to the same IP subnet. However, if the two networks are to be placed in different IP subnets a mechanism such as MIP will be required for maintaining the same IP address while roaming. However, since the IMS works on SIP, a pure SIP based approach is currently being designed.

VI. CONCLUSIONS

An internetworking model for WLAN and 3G cellular networks with the 3GPP's IMS framework acting as an arbitrator was presented in this paper. It addressed many deficiencies of the existing internetworking architectures. The most significant benefit is its capability for negotiating and managing real-time sessions with the use of the IMS as a unified session controller. IMS-SIP based terminal and session mobility was examined within the scope of the proposed framework for two scenarios; that is, when roaming from UMTS to WLAN and from WLAN to UMTS. Results obtained from the OPNET based simulation platform indicated the behavior of handoff for these scenarios. Simulation results indicated that a make-before-break type handoff from UMTS to WLAN is capable of providing acceptable levels of seamless continuity of services. Results also indicated a situation with data duplication, which had to be addressed at a lower layer. However, the break-before-make type handoff scenario from WLAN to UMTS showed a brief interval of service interruption due to its non-overlapped nature of coverage.

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