

**KING FAHD UNIVERSITY OF PETROLEUM &  
MINERALS**

**COMPUTER ENGINEERING DEPARTMENT**

**A Final Project Report**

**"Wireless Local Area Networks Integration for  
Mobile Network Operators"**

**by Dr. Ashraf S. Hasan Mahmoud (Principal Investigator)**

**Dr. Marwan Abu Amara (Co-Investigator)**

**Dr. Tarek R. Sheltami (Co-Investigator)**

Dhahran 31261, Saudi Arabia

Email:{ashraf, marwan, tarek}hg@kfupm.edu.sa

March 2012

# جامعة الملك فهد للبترول والمعادن قسم هندسة الحاسب الآلي

التقرير النهائي للبحث

## "دمج و ربط الشبكات المحلية اللاسلكية لمشغلي شبكات الجوال المعلوماتية"

إعداد:

- د. أشرف محمود (باحث رئيسي)
- د. مروان أبو عمارة (باحث مشارك)
- د. طارق الشلطي (باحث مشارك)

الظهران، 31261، المملكة العربية السعودية

{ashraf, marwan, tarek}@kfupm.edu.sa

2012 March

## **Abstract**

This final project report summarizes the findings and outcomes of the project FT/2005-12 conducted for the time period from September 2005 to March 2007.

Users' demand for broadband multimedia services increases rapidly and mobile operators attempt to satisfy this demand by introducing new technologies to their networks such as the 3G Universal Mobile Telecommunication System (UMTS). In order to provide acceptable prices and higher data rates to the users, new access technologies should be integrated with conventional 3<sup>rd</sup> generation (3G) technologies. Wireless Local Area Networks (WLANs) radio access technology is one suitable access technology that can complement 3G networks. It is being widely deployed in condensed areas such as airports, train stations, and hotels in what are referred to as hotspots.

This report firstly numerates possible network architectures that may be deployed to enable integration between 3G networks and WLANs to provide services for hotspots locations. Then the report also identifies a UMTS-based integration solution that may be deployed by the local telecommunications operator. Thirdly, we summarize the features and capabilities of a deployment and capacity assessment excel-based calculator that is developed as part of this project. The calculator may be used for deploying the proposed integrated network in typical hotspot locations such as airports and otherwise.

In addition to the original project goals listed above, the project has have accomplished the following items. The project has produced an elaborate OPNET-based simulation tool that may be used to analyze and study vertical handoffs for 3G/WLAN integrated networks. The simulation tool is also augmented with details of respective protocol stacks of various network entities involved and detailed message-exchange steps as specified in the corresponding standard documents and RFCs. Thirdly, the investigators have utilized the tool to produce studies that compare various mobility solutions and their derivatives for different Internet protocol versions. The studies were able to assess for the first time in the literature the various delay components for the vertical handoff event and give insight into potential and critical enhancements for the integrated network.

Finally, the outcomes of this project are as summarized in section 6 of this final report document.

## الخلاصة:

هذا التقرير النهائي يلخص المستجدات و النتائج للمشروع FT/2005-12 الذي تم تنفيذه في الفترة من شهر سبتمبر 2005 إلى شهر مارس 2007.

إن طلب المستخدمين لخدمات الوسائط المتعددة ذات النطاقات العريضة في تزايد مضطرد و مشغلي خدمات الجوال يحاولون أن يواجهوا هذا الطلب بإضافة تقنيات جديدة لشبكاتهم مثل خدمات الجيل الثالث و مشتقاتها. و لكي يتمكن المشغلون من توفير خدماتهم بأسعار مناسبة و معايير عالية فإنه ينبغي إدماج تقنيات وصول جديدة مع ال تقنيات التقليدية للجيل الثالث. الشبكات المحلية اللاسلكية هي واحدة من هذه التقنيات التي يمكن استغلالها والتي يمكن أن تكمل شبكات الجيل الثالث. ويجري نشرها حاليا على نطاق واسع في المناطق ذات الاستخدام الكثيف مثل المطارات ومحطات القطارات، والفنادق في ما يشار إليه بالنقاط الساخنة.

هذا التقرير يعدد أولا البنى المختلفة المحتملة للشبكة التي قد يتم نشرها لتمكين التكامل بين شبكات الجيل الثالث 3G والشبكات المحلية اللاسلكية لتقديم خدمات لمواقع النقاط الساخنة. ثم يحدد التقرير أيضا إلى حل التكامل المستند لتقنية ال UMTS التي قد يتم نشرها من قبل شركة الاتصالات المحلية. وثالثا نلخص ميزات وقدرات الآلة الحاسبة التي تم تطويرها كجزء من هذا المشروع والتي ويمكن استخدامها لتقييم نشر الشبكة المقترحة متكاملة في المواقع الساخنة مثل المطارات وغير ذلك.

إضافة إلى أهداف المشروع الأصلية المذكورة أعلاه، فإن المشروع قد حقق إنجازات نلخصها في البنود التالية. أنتج المشروع أداة محاكاة مبنية على برمجيات ال OPNET التي يمكن استخدامها لتحليل ودراسة handoffs العمودية للشبكة المتكاملة 3G/WLAN. ثم تم تزويد أداة المحاكاة بكل تفاصيل أعمدة البروتوكول لكل من الأجهزة المعنية في الشبكة وكذلك تفصيلات الخطوات اللازمة على النحو المحدد في وثائق الأنظمة والمراجع ذات الشأن. ثالثا، استخدم المحققين هذه أداة لإنتاج دراسات تقارن بين مختلف الحلول المستخدمة في معالجة تنقل المستخدم ومشتقاتها وفق إصدارات مختلفة لبروتوكول الإنترنت. وكانت هذه الدراسات قادرة على تقييم و للمرة الأولى في هذا المجال المكونات الزمنية لعملية ال handoff العمودية وتعطي نظرة ثاقبة لفرص مهمة وحاسمة في تحسين الأداء بالنسبة للشبكة المتكاملة.

وأخيرا، يتم تلخيص نتائج هذا المشروع في القسم 6 من وثيقة التقرير النهائي هذه.

## Table of Contents

Abstract.....	1
الخلاصة:.....	2
Table of Contents.....	3
1 Introduction .....	5
2 Background.....	5
2.1 Wireless LANs (WLANs).....	5
2.2 The Universal Mobile Telecommunication System (UMTS).....	6
2.2.1 3GPP Role in UMTS.....	6
2.2.2 Global System for Mobile Communication (GSM).....	6
2.2.3 Basic UMTS Architecture .....	7
2.3 UMTS/WLAN Interworking.....	9
2.3.1 Classification of WLAN/UMTS Interworking Architectures .....	9
3 Project Objectives.....	10
4 Results and Findings.....	11
4.1 Architectures for WLAN Integration.....	11
4.1.1 Vendor based solutions.....	11
4.1.2 Other Proposed Interworking Architectures.....	14
4.2 Target Architecture For 3G/WLAN Integration.....	16
4.3 Deployment and Capacity Calculator .....	18
4.3.1 KFIA WLAN- Cellular Interworking Framework (KWIF).....	19
4.3.2 PWLAN Deployment and Capacity Estimation .....	21
5 Additional Achievements .....	23
5.1 Developed Simulation Tools.....	23
5.2 Modeling and Analysis of Signaling Overhead.....	26

5.3	Sample Results and Evaluation .....	28
6	Summary of Accomplished Work .....	30
	References: .....	33
	List of Acronyms: .....	36
	Appendix A: .....	39
	Appendix B: .....	40

# 1 Introduction

The third generation (3G) wireless data networks are designed to offer both traditional voice communications and packet data services for multimedia applications with better performance and greater cost effectiveness. With the rapid deployments of the Universal Mobile Telecommunications Systems (UMTS), one of the standardized systems for 3G wireless data networks, operators are on the look for maximizing utilization of such networks and providing a wide variety of new data services. It should be noted that in a typical 3G wireless data network, there will remain some geographical areas within the cell coverage where mobile stations require more usage of high-speed data services. Such geographical areas are referred to as hotspots. Temporary or permanent hotspot areas are created in heavily populated places such as airports, coffee shops, hotels, exhibitions, and convention centers. Microcell, picocells, and repeater solutions have been proposed, and the performance of such solutions has been evaluated [1-3]. However, such solutions are expensive, from cost perspective and/or installations perspective. With the availability of WLANs, service providers of 3G wireless data networks can properly address the traffic requirements in hotspot locations with a less costly solution.

An important aspect to consider when using WLANs to address traffic requirements in hotspot locations is the issue of integrating WLANs with 3G wireless data networks leading to hybrid mobile data networks allowing subscribers to experience seamless and ubiquitous data services and very high data rates. The integration aspect of WLANs with 3G wireless data networks results in many technical challenges, including seamless vertical handoffs across WLAN and 3G radio technologies, security, common authentication, unified accounting and billing, WLAN sharing among several 3G wireless data networks, and consistent Quality of Service (QoS) and service provisioning [4].

From a business point of view a 3G operator must ask the following question: Is WLAN a competing technology to 3G technology or a complementing technology? The study in [5] showed that WLANs are economically profitability as a complementary, rather than a competing solution for 3G wireless data network operators.

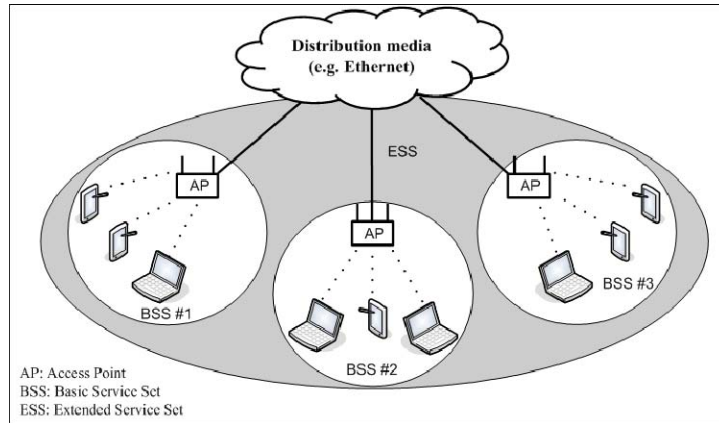
## 2 Background

In this section a brief overview of WLANs and UMTS technologies and the main components of each network will be presented. We also present the broad integration schemes identified in the field.

### 2.1 *Wireless LANs (WLANs)*

A WLAN is a Wireless Local Area Network. The technologies for WLANs are specified by the IEEE 802.11 [6, 7]. WLANs operate in the unlicensed bands with speeds ranging from 1Mbps to 54Mbps. There are two main operation modes in WLANs: the infrastructure mode, and the ad hoc mode.

In the infrastructure mode, the wireless devices communicate to a wired LAN and each other, via an Access Point (AP) as shown in Fig. 1. Therefore, the AP is the central point where all communication traffic should pass through. An AP and the wireless devices connected to it are known as a Basic Service Set (BSS). Two or more BSSs in the same subnet form an Extended Service Set (ESS) [8].



**Figure 1: WLAN in an infrastructure mode.**

In the ad hoc mode, also known as peer-to-peer mode the wireless devices communicate with each other directly. A group of two or more devices communicating in this mode are called an Independent Basic Service Set (IBSS).

Typically, WLANs in infrastructure mode are used for integration with UMTS. WLAN lacks capabilities such as authentication, subscription and roaming services which are provided by the UMTS network.

## **2.2 The Universal Mobile Telecommunication System (UMTS)**

The UMTS utilizes the well established GSM infrastructure by adding minor modifications. Hence, understanding the GSM network architecture helps in comprehending the evolving process of the UMTS network and its releases. The role of 3GPP in organizing and maintaining the UMTS specifications is first highlighted. Then, the GSM architecture as well as the UMTS domain architecture and its major interfaces are briefly described.

### **2.2.1 3GPP Role in UMTS**

The UMTS specifications are maintained and defined by the 3<sup>rd</sup> Generation Partnership Project (3GPP) [9]. It aims to make a compromised standard that account for political, commercial, and industrial pressures. While the 3GPP is responsible for rolling out 3G mobile networks based on the 2G GSM mobile network, the 3GPP number 2 (3GPP2) was created to update the IS-95 (a 2G system) radio technology implemented in the US. When 3GPP cannot handle some issues related to local requirements they are left to the Operator Harmonization Group (OHG). The OHG finds a compromised solution. The 3GPP, 3GPP2, and OHG cooperate to create a true global mobile cellular system utilizing the WCDMA technology [10].

### **2.2.2 Global System for Mobile Communication (GSM)**

The Global System for Mobile Communication (GSM) network consists of two domains: The Network Switching Subsystem (NSS) and the Base Station Subsystem (BSS). Fig. 2 depicts a simplified GSM networks architecture [11]. The NSS consists of:

1. The Mobile Switching Center (MSC).
2. The Gateway Mobile Switching Center (GMSC).
3. The Visitor Location Register (VLR).

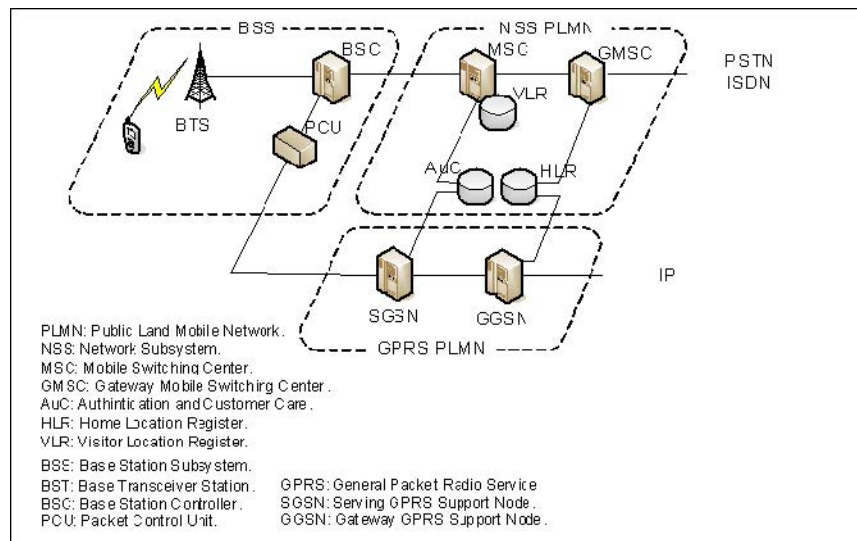


4. Home Location Register (HLR).
5. Authentication and Care Center (AuC).

The MSC is responsible for interfacing the Base Station Subsystem (BSS) to the NSS, whereas the Gateway GMSC interfaces the NSS to external networks such as Public Switched Telephone Networks (PSTN) and Integrated Service Digital Networks (ISDN). The VLR is integrated with MSC to store subscribers' information roaming in its area. The HLR is responsible for storing subscribers' profiles and information. The AuC maintains billing and charging information.

The BSS is composed of the Base Station Transceiver (BTS) and the Base Station Controller (BSC). The BTSs are responsible for radio communications with the mobile terminal. Multiple BTSs are connected to a BSC which controls them. The BSC further manages the mobiles served by the corresponding BTSs and also interfaces to the NSS.

Upgrading the 2G GSM network to 2.5G requires introducing the Global Packet Radio System (GPRS) Public Land Mobile Network (PLMN). The GPRS PLMN provides data services such as internet access to the GSM subscribers by allowing them to connect to IP networks as shown in Fig.2. In addition, this upgrade requires the addition of Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN) in the network subsystem side. Also, the Packet Control Unit (PCU) has to be added to the BSS to make it capable of sending and receiving data packets. Therefore, the PCU interfaces the BSS to the SGSN to provide the required functions for authentication, authorization, and accounting. In turn, the GGSN provides the access to external IP networks.



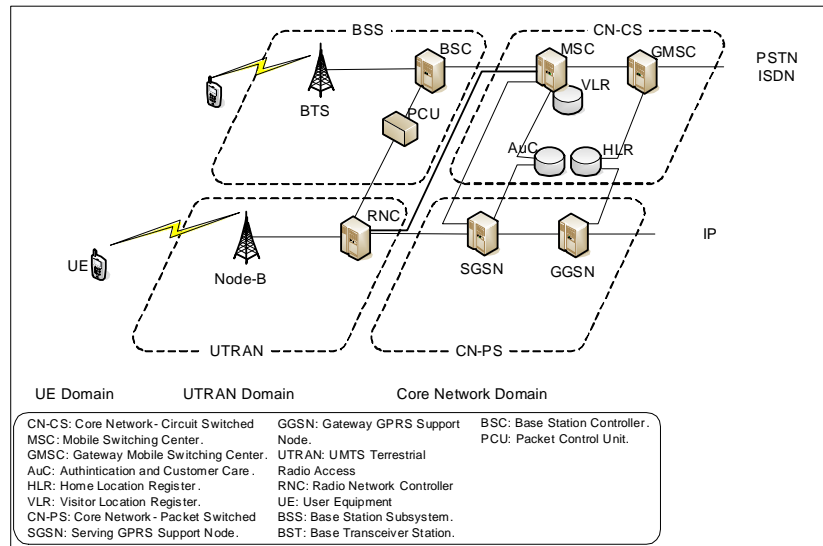
**Figure 2: GSM network architecture.**

### 2.2.3 Basic UMTS Architecture

The UMTS network uses the Wide Code Division Multiple Access (WCDMA) technology to provide wireless access. It provides a large coverage with high mobility support and high data rates up to 384 kbps. Three domains are defined in the UMTS network as follows [10]:

- The User Equipment (UE) domain,
- The UMTS Terrestrial Radio Access Network (UTRAN) domain
- The Core Network (CN) domain.

Each domain is briefly described in the following material. Fig. 3 illustrates the basic UMTS architecture.



**Figure 3: Basic UMTS network architecture.**

The UE domain includes the equipment used for enabling the user to access the UMTS network. It consists of the Mobile Equipment (ME) and the UMTS Subscriber Identity Module (USIM). The ME is a device that provides the radio communication with the base station. The USIM is a smart card that contains authentication algorithms and keys necessary for subscribers' authentication and billing.

The UTRAN domain interfaces the UE domain to the CN domain. The Node-B and Radio Network Controller (RNC) are the basic blocks of the UTRAN. The Node-B conveys data between the UE domain and the RNC by converting radio signals to data stream and vice versa. The RNC manages the radio resources in the UTRAN by controlling Node-Bs. In addition, it interfaces the UTRAN domain to other domains such as the CN domain.

The CN domain links the UTRAN domain to external circuit switched and packet switched networks. It consists of the Packet Switched (PS) network, the Circuit Switched (CS) network and the Registers. The PS network contains a Serving GPRS Support Node (SGSN) and a Gateway GPRS Support Node (GGSN). The SGSN connects the UTRAN domain to the PS domain and routes packets inside the PS. The GGSN interfaces the PS to external packet switched networks such as Asynchronous Transfer Mode (ATM) networks, Frame Relay networks, and X.25 networks. The SGSN and GGSN are interconnected to provide routing functions.

The CS network contains a Mobile Services Switching Centre (MSC) and a Gateway MSC (GMSC). The MSC provides all the switching functions such as managing connections, call rerouting, including allocation/de-allocation of radio channels. The GMSC interfaces the CN to external circuit switched networks such as Public Switched Telephone Networks (PSTNs), Public Land Mobile Networks (PLMNs), and Integrated Service Digital Networks (ISDNs).

The Registers are databases such as the Visitor Location Register (VLR), Home Location Register (HLR), and the Account and Customer Register. They are located in the user's home network. They store information related to subscribers such as subscribers' profiles and UE current location.

## 2.3 UMTS/WLAN Interworking

Focusing on the integration issue, the UMTS and WLANs can interconnect in several ways that affect the services offered and the complexity of the system. In this subsection, we specify the broad classes of UMTS/WLAN interworking architectures. We also present the 3GPP recommended interworking scenarios.

### 2.3.1 Classification of WLAN/UMTS Interworking Architectures

The interworking architectures between UMTS and WLAN may be classified depending on the attachment point between the WLAN and UMTS network. Therefore, there are four possible architectures as shown in Fig. 4. These are the open, loose, tight, and integration coupling [12].

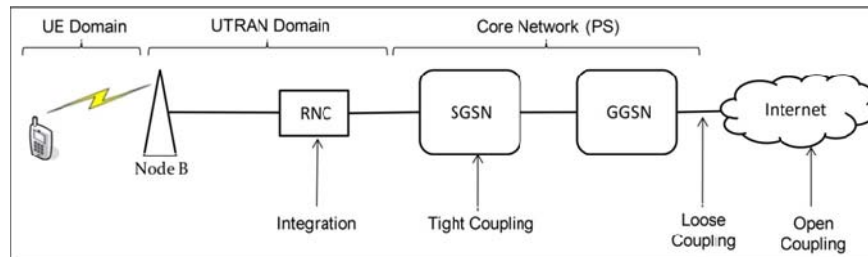


Figure 4: Coupling scenarios between WLAN and 3G network.

In the open coupling, the UMTS and WLAN networks are considered as two independent networks that share a common billing and customer care to subscribers. As a result, separate authentication procedures are used in each network. Moreover, any ongoing session in use will always be terminated, as the user equipment switches between the two networks.

For the loose coupling, authentication, authorization, and billing must be accomplished by the UMTS network. It requires authentication, authorization and accounting for 3G subscribers in a WLAN to be done by the UMTS network using the user's USIM. This is accomplished by adding new components to the two networks. Also, access to the UMTS PS based services may be extended to subscribers in a WLAN environment like MMS, IP multimedia, location based services and Wireless Application Protocol (WAP). Moreover, seamless service continuity may be provided to maintain service continuity across the UMTS and WLAN radio access technologies. For example, a user starting a WAP session from the 3G radio access technology should be able to continue this session after moving to a WLAN and vice versa.

For the tight coupling, the WLAN network is connected to the core network and specifically to the SGSN in the same manner as the RNC. This requires the definition of a new interface between WLAN and the SGSN so that the WLAN is viewed as an additional RNC. This configuration forces the WLAN's traffic to pass through the UMTS network which may congest the Core Network backbone. However, in this scheme the user will be able to continue his session seamlessly when handing off from one network to the other.

Finally, integration coupling is similar to the tight coupling method in terms of potentially providing seamless handoff. However, in this case a WLAN can be viewed as a cell managed at the RNC level. In this scheme the WLAN is considered as an additional radio access technology that is attached to the UMTS network. This allows the access to 3G Circuit Switched-based services with seamless mobility from the WLAN network. For example, a user can conduct normal voice calls utilizing the WLAN air interface.

From a service integration perspective, the integration of WLANs and 3G wireless data networks leads to six possible service integration scenarios ranging from the simplest form of integration, *Common Billing and Customer Care*, that provides only a common bill and customer care to the subscriber but otherwise features no real interworking between the WLAN and the 3G wireless data network, to the most complex form of integration, *Access to 3G Circuit-Switched-Based Services with Seamless Mobility*, that allows access to 3G circuit-switched services from the WLAN system and seamless mobility to such services [4, 13]. The list of all six possible service integration scenarios is shown in Table 1.

**Table 1: Interworking scenarios and their features.**

Scenario	Features
1	Common billing and customer care
2	Scenario 1 + 3G-based access control and charging
3	Scenario 2 + access to 3G packet-switched based services
4	Scenario 3 + service continuity
5	Scenario 4 + seamless service continuity
6	Scenario 5 + access to 3G circuit-switched based services with seamless mobility

### 3 Project Objectives

The objectives stated in the original proposal are as follows.

1. Numerate architectures/solutions relevant to existing or future Saudi Telecom Company (STC) mobile network infrastructure.
2. Propose UMTS compliant network infrastructure that is both backward compatible with existing infrastructure and incorporates WLANs data services.
3. Provide a typical deployment scenario in support of required functionality by specifying required network elements and possibly the corresponding commercial available product.

In the original project proposal, King Faisal International Airport (KFIA) was used as an example of the target deployment site. In addition the Saudi Telecom Company (STC) was cited as the mobile operator that would deploy the described architectures and services specified in this report. However, the findings of this study apply to general hotspot locations and can be implemented by any mobile telecom operator.

In addition to the above objectives, the following items have been also pursued and/or accomplished:

4. Build a detailed and uniform simulation tool to study and analyze the signaling procedure pertaining to handoff events for the UMTS/WLAN integrated network.
5. Augment the simulation tool with parameters, procedures and entity characteristics specific to the 3GPP standard infrastructure. In addition, add in the security and authentication procedures needed to realistically estimate the overall overhead.
6. Analyze different candidate protocols for managing the mobility issue in an UMTS/WLAN integrated network and identify different overhead components and also the effect of various other network inputs such as load, WLAN speeds, and background traffic.

It must be mentioned that this final report describing the outcomes of the project of concern is specific to the project period: September 2005 to March 2007. It only outlines and elaborates on the work done in the project's original period. Therefore this report does not extend the original work to new technologies especially in the area of broadband wireless networks such as new releases of the 3GPP network specifications and Long Term Evolution (LTE) or even the new wireless local area network standards such as IEEE802.11n. This final report is required for administrative purposes. The outcomes of the original project in terms of developed tools and publications are already published and dispensed.

## **4 Results and Findings**

The following three subsections correspond to the original three objectives of the project. The first subsection elaborates on the numerous integration architectures identified in the literature, while the second section zooms on the architecture identified for realistic deployment and expansion scenarios for mobile operators. The third subsection presents an excel-based calculator developed to assist in the deployment and capacity engineering for an integrated 3G/WLAN in a hotspot location.

### **4.1 Architectures for WLAN Integration**

In this subsection we present a survey of architectures that are proposed for interworking 3G with WLAN. We group the presented architectures into two groups: vendor proposed solutions and those proposed by researchers in the field. The material below focuses on the main features of each of the proposed solutions. More technical details are found in [14].

#### **4.1.1 Vendor based solutions**

##### **Cisco PWLAN solution**

The proprietary solution provided by Cisco is depicted in Fig. 5. The literature provided by Cisco documents refer to the integrated network as a public WLAN or PWLAN. This solution can be most closely classified as a scenario 4 solution (reference to Table 1 scenarios) as service connectivity is provided over various networks where it adopts the loose coupling approach. The cellular access gateway provides WLAN users with subscriber identity module (SIM) based authentication for which the RADIUS authentication protocol is used. In addition, as shown in figure, Mobile IP handoffs occur between GGSN and the Access Zone router (AZR), the designated gateway for the WLAN [15]. The key network entity in this architecture is the PWLAN mobile exchange which is comprised of the following components: (1) Access points, (2) Access Zone Routers (AZR), (3) Service Selective Gateway technology, (4) CNS Subscriber Edge and Services Manager (SESM), (5) CNS Access Registrar, and (6) IP Transfer Point-Mobile Application Part (ITP-MAP) gateway.

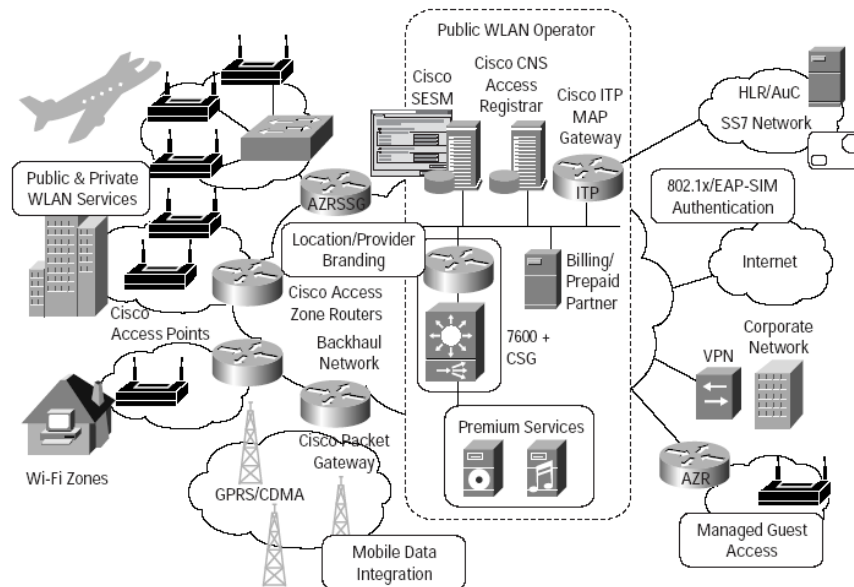
The Cisco Mobile Exchange framework in conjunction with the Cisco Mobile wireless home agent, an entity based on the Internet Engineering Task Force (IETF) Mobile IP (MIP) RFC 3344, identify a host device by a single IP address even if the device moves its physical point of attachment from one network to another. Therefore, subscribers with mobile devices can roam to another network without restarting applications or terminating and reestablishing a connection. This allows seamless roaming over different access technologies and provider networks, including mobile data networks based on 3G.

Some of the most important services and features cited include:

1. Services enablement—The Cisco PWLAN solution allows operators to enable the introduction of value-added services with incremental revenue streams. Examples

of such services include applications ranging from music, movies, sports, gaming, or ring tones for the consumer, to business-class, WLAN-optimized services for voice over IP (VoIP) for the enterprise or hosted virtual private network (VPN) services that offer security for all users.

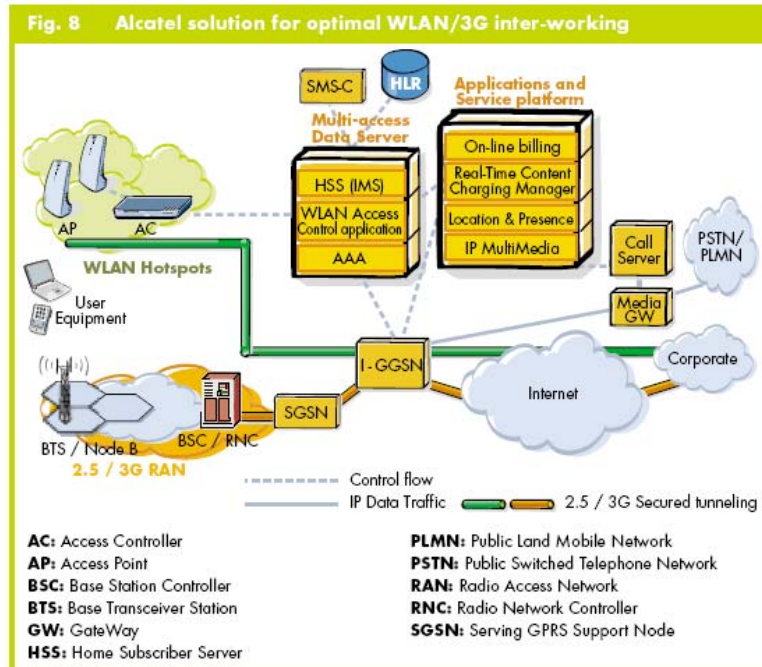
2. Flexible service billing options—The Cisco PWLAN solution supports flexible billing models, including postpaid, prepaid (time or volume), tariff, and billing based on subscription content. Additional features enable the network to quickly detect when a user has left the service area without logging out and automatically close their session. In doing so, billing accuracy is preserved and network resources are freed.
3. Authentication transparency—The Cisco SSG access control platform can proxy Extensible Authentication Protocol (EAP) authentication messages from hotspot access points and automatically create user sessions upon successful EAP authentication, thereby eliminating the need for “double authentication,” first at Layer 2 with 802.1x/EAP and then at Layer 3 through the Web portal. This feature allows an operator to take advantage of the Cisco SSG for centralized accounting record generation for both 802.1x/EAP and Web-authenticated users.



**Figure 5: Cisco PWLAN solution architecture.**

### **Alcatel PWLAN solution**

Similar to the solution provided by Cisco, Alcatel’s PWLAN proprietary solution attempts also to provide session connectivity with respect to services (i.e. scenario 4) using the loose coupling method. Again, this solution is based on Mobile IP. However, the proposed architecture provides provisions to allow for different service scenario, probably lower, levels based on customer preference [16]. The provided solution is depicted in Fig. 6.



**Figure 6: Alcatel 3G/WLAN interworking architecture.**

The Alcatel PWLAN solution provides extensive support for integration of GSM/UMTS and WLAN. To allow the operator to make optimal use of this integration technology, adequate interworking mechanisms have been provided between GPRS/UMTS and WLAN networks. Three levels of interworking targeted by Alcatel are enumerated below [17]:

- Common access control, through the use of (U) SIM based authentication: Users can take out a single subscription and receive a single bill. The preferred solution is Internet Protocol (IP) roaming, which means that Authentication, Authorization and Accounting (AAA) mechanisms are used between the WLAN and the home PLMN; within the home PLMN, the AAA server (Multi-access Data Server) communicates with the Home Location Register (HLR) for (U)SIM based authentication
- Access to all 3GPP PS services from both 2G/3G and WLAN: All flows are routed through the home PLMN by using tunneling mechanisms. This interworking scenario gives the home operator full control of the service offering (including billing, policy control), and provides the user with the same set of services that he or she is used to in the mobile network, but with higher throughput.
- Service continuity across different access technologies (2G/3G, WLAN) through support for mobile IP: Although initially users will simply want to access their services, they will rapidly also demand service continuity, despite the implications for throughput and quality.

Again, main services and features cited by the vendor include: enhanced real-time charging, optimal and innovative support for Multimedia Message Service (MMS) over WLAN, and full connectivity capability. This is in addition to supporting macro-mobility to maintain an established application session while switching between access networks and open software to simplify the integration of services and application clients such as MMS services on top of the IP Multimedia Subsystem (IMS).

## Juniper Networks PWLAN solution

The previous two PWLAN approaches require gateways at every hotspot to perform the subscriber management and service functions that control users' access to the Internet. These gateways increase the overall cost of each hotspot. The solution offered by Juniper Networks is based on removing these services and functions from the hotspot and grouping them together in the service operator's backbone network. Therefore the overall hotspot cost decreases as gateways are no longer required, at the expense of more obtrusive entities and modification for the operator's network [18]. The proposed solution by Juniper Networks is shown in Fig. 7 where again the solution attempts to provide scenario 4 in terms of service connectivity with support for roaming utilizing loose coupling. With this solution, the needed AAA server readily integrates into the existing infrastructure, enabling providers to retain existing mobile GPRS/3G or DSL back-office systems.

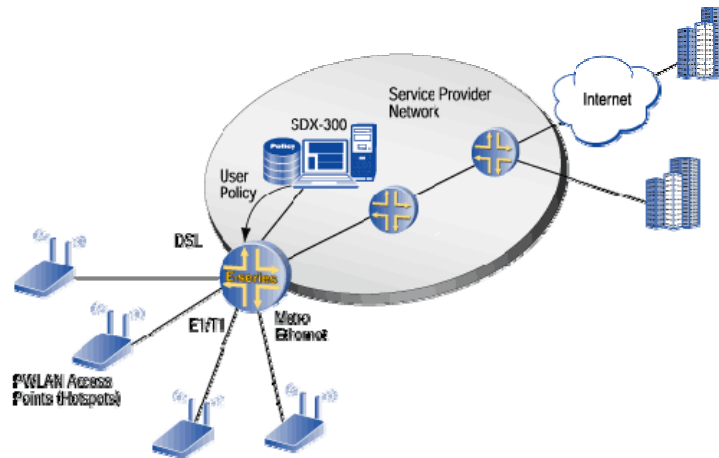


Figure 7: Juniper Networks PWLAN solution architecture.

At the core of the solution provided by Juniper Networks are the critical E-series broadband service routing platform and the service deployment system (SDX) entities. The former is responsible for collecting output from AP's, providing proper session termination, enforcing QoS policies and routing traffic into the IP backbone. It also performs multiservice routing where it can interface to a variety of wide and local area network technologies. The SDX allows service providers to create and deploy new IP services to subscribers. These IP services include video on demand (VOD), IP television, and integrated voice and data. Services are offered over a variety of broadband access technologies: Wi-Fi 802.11 wireless hotspots, DSL, cable, Ethernet, ATM, Frame Relay, SONET, and fixed wireless. Some of the prime features cited by Juniper Networks include: ease of service activation aided by the customized edge routers, multiple authentication options, and allowing service providers to customize different bills for PWLAN subscribers.

### 4.1.2 Other Proposed Interworking Architectures

In the research literature there are numerous proposals for 3G/WLAN interworking architectures. Example studies may be found in [4], [19], [20], [21], [22], [23], [24], [25], [26], and [27]. In this subsection, we survey the most distinguished ones focusing on the coupling strategy and the main services provided.

The study in [4] proposes two interworking architectures that are based on loose coupling. However, the two architectures differ in the services they provide. The first architecture satisfies scenario 2 requirements, while the second architecture fulfills scenario 3



requirements [28]. Scenario 2 requires that the 3G users' access to the WLAN be controlled by the 3G authentication and authorization schemes through the 3G network. In addition to this requirement, the 2<sup>nd</sup> architecture provides an access to the 3G based services (such as MMS and video streaming) to the 3G users via the WLAN radio access network. The major drawback for both architectures is that they do not support vertical handoff between WLAN and UMTS. This means a user must disconnect from one network and reconnect to the other when handing off which results in session restart.

In contrast to the previous architectures, the authors in [19] propose an interworking architecture between GPRS and WLAN. GPRS is a 2G radio access technology that is widely deployed and accepted as an access technology to UMTS. In this study, two architectures, one based on tight coupling while the other is based on loose coupling, are introduced. For the tight coupling architecture, a GPRS Interworking Function (GIF) component must be added to the WLAN network to interface the GPRS mobility management protocols with the SGSN. In addition, the Wireless Adaption Function (WAF) must be incorporated in the dual interface user equipment. Both of the GIF and the WAF work interactively to implement the GPRS mobility management protocols over the WLAN network transparently to the user and the WLAN. The Internet Engineering Task Force (IETF) protocols are used in the second proposed loose coupling architecture. This requires the addition of new equipment by the cellular operator to the WLAN. This equipment is responsible for authentication, authorization, accounting, and mobility support.

Quality of Service (QoS) is a major concern when discussing WLAN/UMTS interworking because WLANs by nature do not support QoS. In [20], a QoS management architecture is presented. The architecture supports several QoS negotiation arrangements. These arrangements vary from pure hierarchical, to peering and mixed hierarchical/peering architectures. The session setup delay and policy exchange load is minimized when the proposed architectures are implemented.

In [21] and [22] a novel wireless link between the UMTS and WLAN is proposed to enhance the performance of the interworking architecture. In [21] a loose coupling architecture that uses this link is introduced. This architecture is called Hyper Coupling with Radio Access System (HCRAS). On the other hand, a tight coupling architecture named Tight Coupling with Wireless Access (TCWA) is proposed in [22]. HCRAS [22] uses mobile IP and fast handoff techniques to handle mobility. The novelty of this architecture stems from the introduction of a new wireless communication link between the base station in UMTS and the WLAN. This radio link utilizes the 802.16 WiMAX technology and attempts to reduce the handoff delay through efficient routing of signaling and data traffic between the networks. As a result, this link partially relieves the UMTS core network from signaling congestion which results in a better overall performance. TCWA [23] utilizes the 802.16 WiMAX radio access to create a direct wireless link between the UMTS's base station and the WLAN. To provide a high level of security all the signaling traffic is routed through the WiMAX link to UMTS core network instead of going through the internet. TCWA reduces the handoff latency by dynamically distributing the data traffic between UMTS core network and the additional WiMAX link. The architectures for both HCRAS and TCWA are shown in Fig. 8 and Fig. 9, respectively.

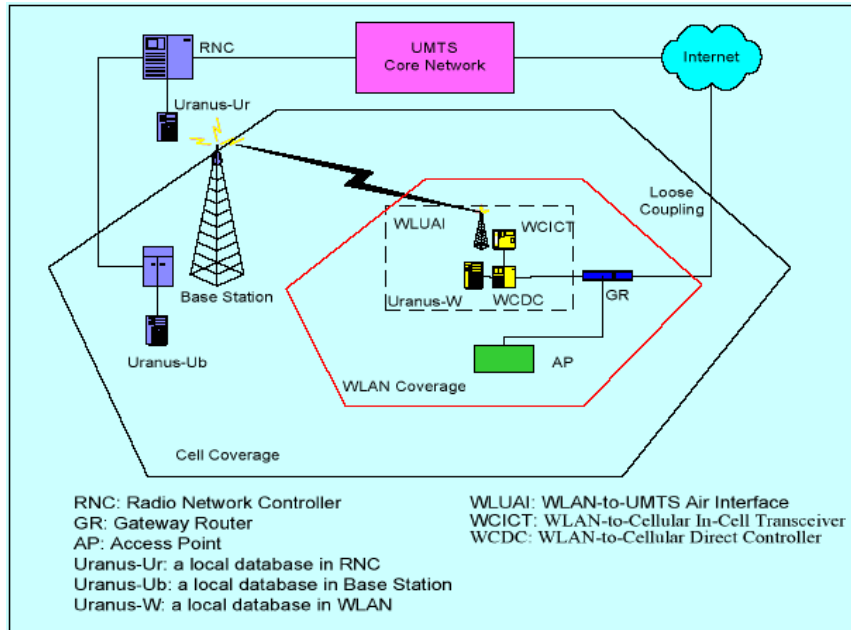


Figure 8: HCRAS architecture [21].

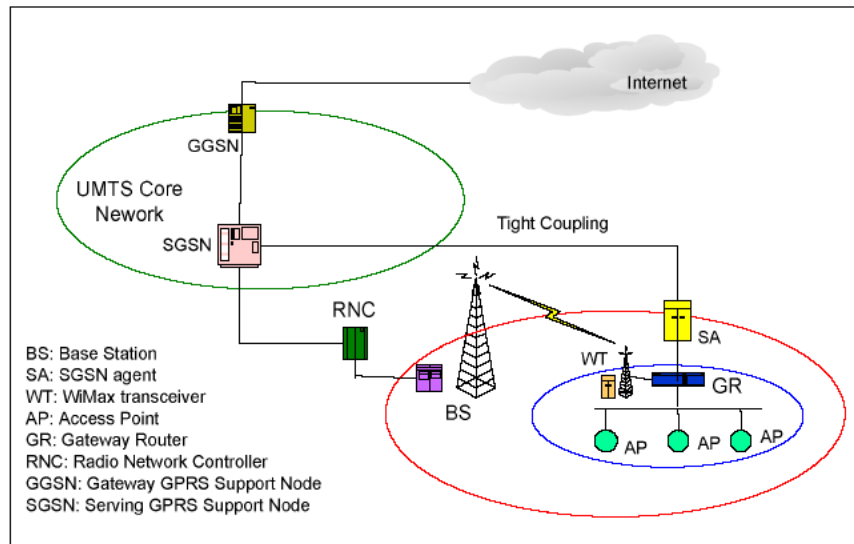


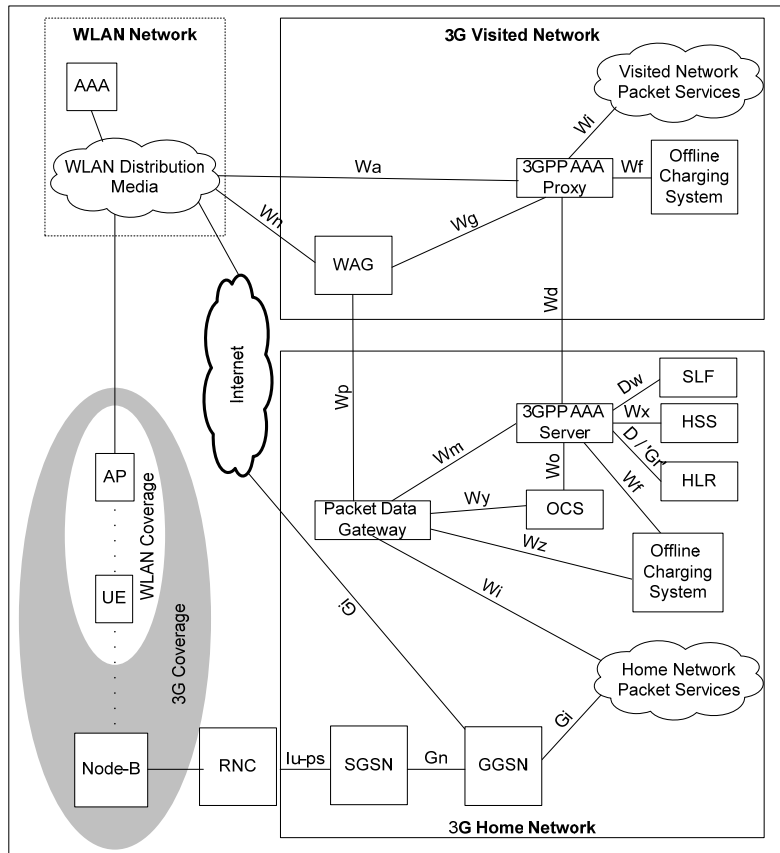
Figure 9: TCWA architecture [22].

## 4.2 Target Architecture For 3G/WLAN Integration

The studies cited above indicated that the most flexible solution is the one based on loose coupling, at least from the perspective of the mobile operators. It also provides a reasonable degree of seamless connectivity in terms of roaming services and access to IP multimedia services. Therefore, this project identifies the loose coupling architecture as the target architecture for adoption and analysis. In fact the loose coupling method is also adopted by 3GPP as the prime method for integrating WLAN with 3G networks [29]. Figure 10 shows

the generic loose coupling architecture that is approved by 3GPP. This interworking architecture requires new network entities to be added to the WLAN and the 3G network (UMTS) in order to satisfy the integration requirements. The required interworking components to join the WLAN and UMTS networks are:

- The Authentication, Authorization and Accounting (AAA) Server.
- Wireless Access Gateway (WAG).
- 3GPP AAA Proxy.
- 3GPP AAA Server
- Packet Data Gateway (PDG).



**Figure 10: The 3GPP loose interworking architecture for WLAN/3G integration.**

The AAA server must be added to the WLAN network as it is responsible for applying authentication procedures for the WLAN users and forwarding the authentication information to the 3G network. The subscribers get access to packet switched services via the Wireless Access Gateway (WAG), a gateway for routing data to and from the WLAN and 3G networks. The WAG forces the packets to be routed through the PDG and it performs some filtering functions and collection of accounting purposes. The AAA information is relayed between the WLAN network and the 3GPP AAA server by the 3GPP AAA Proxy. It is located in the UMTS network. It can be integrated with 3GPP AAA server in one physical entity. Also, it reports the charging and accounting information to the offline charging system in the visiting network.

WLAN 3G users are authenticated by the 3GPP AAA Server based on the authentication information forwarded from the WLAN AAA Server. Moreover, it generates charging and

accounting information to the offline charging system. In addition, it provides the 3GPP AAA Proxy with suitable policy enforcement information.

It should be noted that the proposed architecture above is very generic and does not specify the mobility solution utilized to manage the vertical handoff events between the two integrated networks. This very critical issue is left for vendors and solution providers to decide on. In fact, these design issues are typically not specified by the standards bodies to allow for differentiation amongst vendors and service providers. The vendor solutions cited in the previous subsection adopt mostly, if not all, the Mobile IP (MIP) protocol for management of mobility for subscribers. However, there exist two other main solutions that are also possible candidates for handling mobility. These are Session Initiation Protocol (SIP) and Mobile Stream Control Transmission Protocol (m-SCTP). For most of the evaluations and tools developed under this project, the investigators always developed three parallel scenarios and outputs to correspond to each one of the potential mobility solutions. While this approach almost tripled the size of the work, but it was needed to evaluate and compare amongst the different needed technologies.

The proposed integrated network is evaluated in [30] for a different mix of traffic sessions, namely FTP, HTTP, and MMS for both Mobile IP and m-SCTP underlying mobility solutions. While the focus of the paper is the recommended loose coupling method, it also evaluates the performance in terms handoff delays for an open coupling based architecture. Under the assumption stated in the paper, it is argued that Mobile IP is preferred over the m-SCTP and that loose coupling produces generally lower handoff delays relative to open coupling. Another comparative study is also conducted in [31] where the focus is on comparing the SIP solution to the m-SCTP. The later study concludes that performance for SIP and m-SCTP are very close except in scenarios where the handoff event is for user switching from the WLAN to the 3G system where the SIP based solution produces excessive delays. This is justified by the additional SIP signaling required at various levels like SIP proxy server, registration server and intermediate proxy servers.

The simulation models developed and the obtained results in [30] and [31] seemed to generate a huge interest from researchers across the globe concerned with integration studies. The investigators have/had received an enormous amount of emails and inquiries requesting that we share specifically the simulation code in addition to more results. A sample of these inquires is shown in Appendix A.

### ***4.3 Deployment and Capacity Calculator***

The principle objective of this subsection is to develop guidelines or a framework for an integration architecture and interworking strategy for local mobile operators. Local operators can then develop and enhance their infrastructure based on this framework, so as to tap into an important market which will continually grow into the future. KFIA has been selected as an example to setup this technology and the interworking framework proposed. However, the architecture and interworking framework proposed are not restricted to KFIA or airports only but can be incorporated in other types of hotspot regions such as restaurants, hotels convention centers and so on.

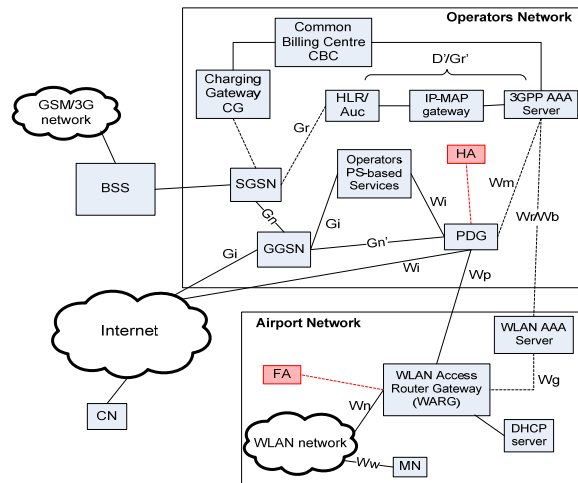
The previous subsection identified the target architecture for use in 3G and WLAN interworking scenarios where acceptable service continuity is provided. In this subsection we customize the solution for deployment in a typical hotspot location such as an international airport with focus on the needed network entities to carry out the required functionalities. We then introduce a deployment and capacity calculator that may be used by engineers to estimate the required capacity and needed infrastructure.

For the sake of brevity, the presented material below shown only one customization based on the Mobile IP protocol, the most popular mobility solution. The original work found in [14] and [32] contain other variations in the design assuming SIP and m-STCP, as potential alternatives for Mobile IP, and show further details.

### 4.3.1 KFIA WLAN- Cellular Interworking Framework (KWIF)

The customized solution based on the architecture shown in Fig. 10 is discussed in this subsection. When the Mobile IP protocol is used to manage mobility for subscribers, then the resulting network required for integrating WLAN and 3G services may look like the network shown in Fig. 11. The figure presents an interworking architecture supporting scenario 4 that is based on Mobile IP. Scenario 3, i.e. access to 3G PS- based services, is supported by routing the user data to the 3G operator’s network which is also the user’s home network in this scenario. To provide Scenario 4, i.e. access to 3G PS- based services with service continuity, support is required by introducing the new Home Agent (HA) and Foreign Agent (FA) entities shown in dark (or red) color. This allows the same IP session to be maintained which consequently results in service continuity.

The Mobile IP HA’s prime responsibility is to allow mobility management and therefore is located in the operator’s network and is connected to the PDG. It performs mobility management functions for the mobile node when it is in its home network, i.e. the operator’s network in this case. The other new component; the Mobile IP FA, is located in the KFIA network and is connected to the WARG. It performs mobility management functions for the mobile node when it is in the foreign network, i.e. the airport network in this case.

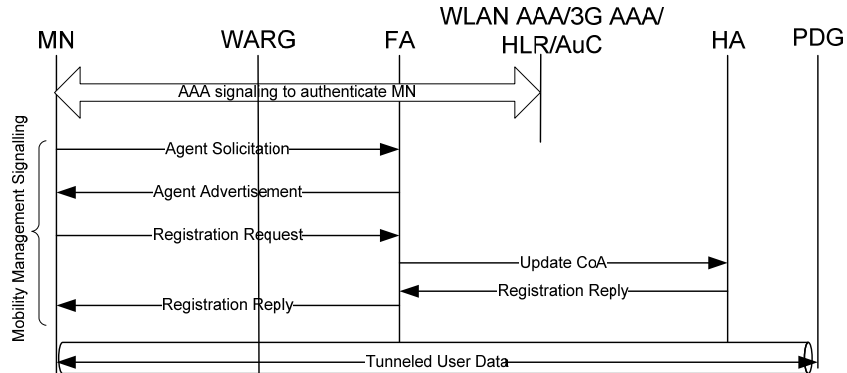


**Figure 11: Proposed Mobile IP based interworking architecture for KFIA.**

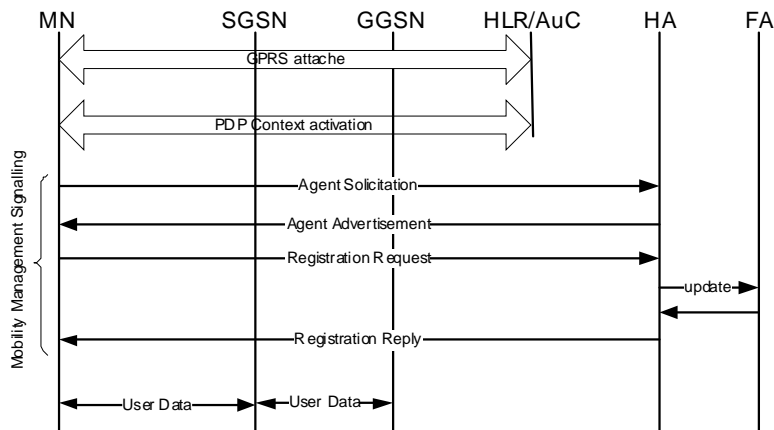
The handoff of a MN from the 3G network to the WLAN network or vice versa is the core function performed by the MIP protocol. The sequence of messages and events that are required to achieve this functionality for our specific network architecture are shown in Fig. 12 and Fig. 13 for the cases of 3G to WLAN and WLAN to 3G handoff events, respectively.

The studies in [23], [33], and [34] describe the Mobile IP protocol and its operation for mobile networks. The signaling diagrams shown in Fig. 12 and Fig. 13 are derived from these studies. Diagrams specify that a tunnel is created between the PDG and the UE to transport user data over the network to the internet or vice versa. The HA and FA help in establishing this tunnel and in routing the respective traffic. The shown diagrams consolidate the signaling

required for authentication in one step. The detailed sub-signals are elaborated in section 5.2 of [14] and also in section 4.5 of [32].



**Figure 12: 3G to WLAN handoff procedure using Mobile IP.**



**Figure 13: WLAN to 3G handoff procedure using Mobile IP.**

Focusing on the 3G to WLAN handoff case shown in Fig. 12, where it is assumed the operator's network is the MN's home network, the MN sends or receives data packets from the 3G network using GPRS for example. When the MN decides or the network decides to handoff to the WLAN based on the signal strength or some other algorithm, it starts with the set of handoff steps which involve only the physical and link layer at this stage. It will also be authenticated and authorized by the operator's network at this stage too. This will include communication with AAA servers as well as operator's HLR and AuC if necessary. After authentication, the MN may be assigned an IP from the foreign network using DHCP server for example. Also the MN will be detached from the operator's home network. However, this can be avoided by sending PDP connect standby message to its SGSN. This will help to reduce the re-attach effort on the MNs' part.

For the WLAN to 3G handoff case shown in Fig. 13, the procedure is quite similar to that of Fig. 12. The only difference is that if the MN did not attach to the network or activate the PDP session before, it should attach to the network and activate a session before getting access to the 3G network. As mentioned earlier, if the MN has already had a session which has not timed out or it was sending PDP/MM context standby messages to the 3G network,

the original PDP session may be already active at the instant of the handoff. Another point to note is that the HA will send an update message to the FA to delete the entry that included the MN's MIP association.

Customized network architecture diagrams employing SIP and m-SCTP and the corresponding signaling diagrams similar to those in Fig. 12 and Fig. 13 can be found in [14] and [32].

### 4.3.2 PWLAN Deployment and Capacity Estimation

The material in this subsection attempts to build rules to estimate the number of users that the WLAN can serve and also an estimate of the number of access points required to provide coverage. The variables defined in Table 2 are used for the calculations.

**Table 2: Variables used for dimensioning of PWLAN deployment.**

NAME	DEFINITION
$U_{PEAK}$	The number of passengers on a peak day
$P_R$	Penetration ratio
$U_{WiFi}$	The number of users that require WiFi capability
$D_{USER}$	Average data rate assigned to each WiFi user
$U_F$	The number of users per floor of the airport
$D_{AP}$	The data rate provided by the WiFi access point (AP)
$N_{AP}$	The number of access points
$A_F$	The area of a floor
$A_{AP}$	The coverage area of an AP
$n$	The number of users served by a single AP
$\alpha$	Efficiency factor

#### Example Calculations Using KFIA data:

Assume it is required to provide WLAN services for the three floors: Mezzanine, Departures and Arrivals of the KFIA. Using the information at [35], the peak number of passengers going through the airport,  $U_{PEAK}$ , may be estimated to be 38,000 passenger at any point in time. If the penetration rate is set at 20%, then the number of users requiring WiFi connectivity can be estimated to be  $U_{WiFi} = P_R \times U_{PEAK}$  or 7,000 users. Let the average WiFi user capacity required  $D_{USER}$  be 512 kbps.

To estimate the number of access points required we first distribute the WiFi data users over the three floors of the building as follows. Let 20% of the user be located in the Mezzanine floor while 40% are located in each of the Departures and Arrivals floors of the building. If the average WiFi data capacity per user is 512 kbps, then the required capacity for the Mezzanine floor is estimated at 700 Mbps, while that required for each of the Departures and the Arrivals floors equal to 1400 Mbps. At this stage it is required to estimate the number of required access points to supply the computed raw capacity. One approach that may be used is to utilize the results found in [36] wherein Bianchi produces curves that relates the number of WiFi stations attached to the access point versus the efficiency of the distributed control function (DCF) for various parameters of the network. This may be utilized as follows.

If we assume that all access points are configured at their maximum speed of 54 Mbps (i.e.  $D_{AP}$  is equal to 54 Mbps) and that all access points are equally loaded, then one can estimate the number of access points needed in a particular floor using:

$$N_{AP} = \max \left( \left\lceil \frac{U_F \times D_{USER}}{\alpha \times D_{AP}} \right\rceil, \left\lceil \frac{A_F}{A_{AP}} \right\rceil \right)$$

where the efficiency of the access point,  $\alpha$ , is to be computed using results from [36]. To produce a parametric relation between the access point efficiency and the number of terminals that may be served by a single access point, we curve-fit the efficiency curves produced by Bianchi (referring to Fig. 6 of [36]). For example, for the default WiFi network parameters, the parameter  $\alpha$  is related to  $n$  using

$$\alpha = 0.9853 - 0.1047 \log(n)$$

In addition, the number of users,  $n$ , is also equal to  $U_F / N_{AP}$ . Therefore we get  $U_F / N_{AP} = \alpha D_{AP} / D_{USER}$ . Substituting back in the previous model for the efficiency, we get

$$\alpha = 0.9853 - 0.1047 \log \left( \frac{\alpha D_{AP}}{D_{USER}} \right)$$

The previous relation may be solved iteratively for the parameter  $\alpha$  for the given assumptions on the maximum access point throughput  $D_{AP}$  and average user connection rate  $D_{USER}$ . Finally, the target number of access points per floor is given by  $U_F / n$ .

### Capacity and Access Point Number Calculator:

The previous calculation are built into a code that is associated with a Microsoft excel sheet to produce results in terms of charts and tables for wide range of input parameters. In addition to computing the number of access points per floor, the developed tool utilizes this calculation to also estimate the signaling overhead between the WLAN AAA entity and the 3G AAA based on the analysis for the message exchange diagrams and the corresponding protocol stacks. Snap shots of the interface and sample results are shown in Fig. 14 and Fig. 15.

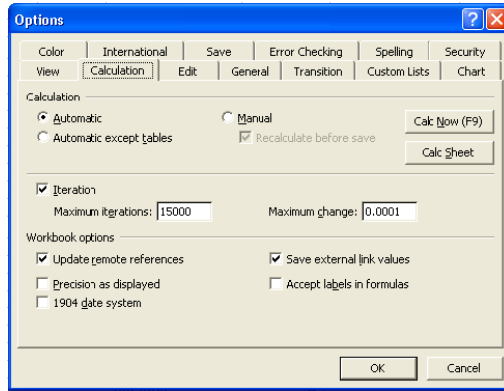


Figure 14: Developed calculator options pane.



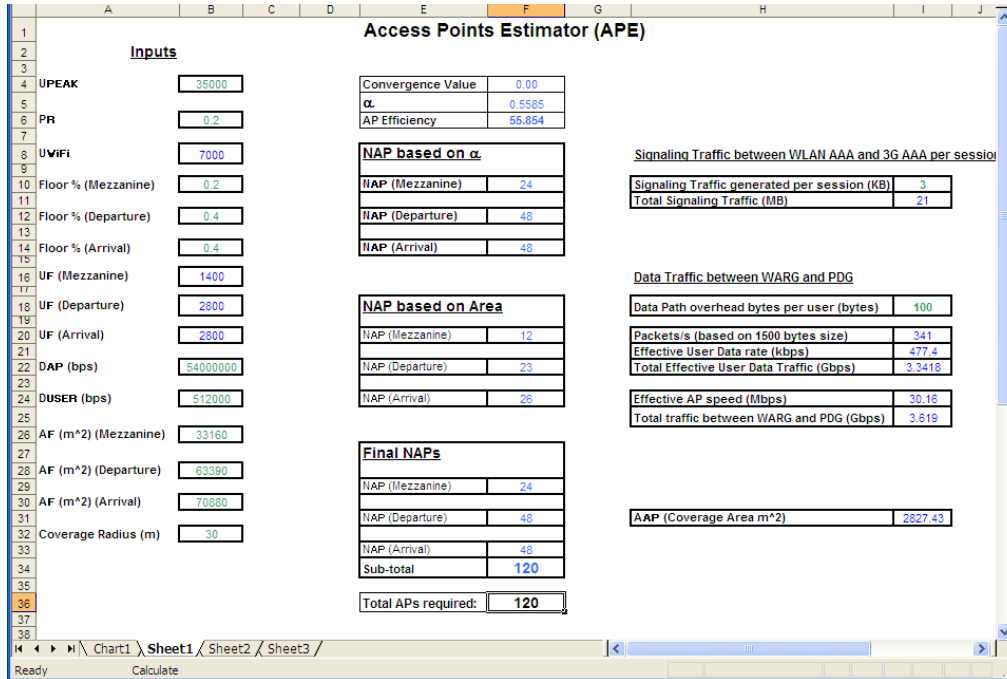


Figure 15: Example execution for the developed calculator.

## 5 Additional Achievements

Based on the huge interest received by the preliminary studies in [30] and [31], the investigators decided to extend the project and develop a more detailed and uniform analysis of the proposed architecture. The received interest cited in Appendix A revealed the lack of a specialized tool or even a customized tool in the field that may be used for analyzing integration solutions. The new extension is aimed to fill in the gap found in the literature and simulation tools and it attempts to construct a single tool that evaluates the three mobility solutions: Mobile IP, SIP, and m-SCTP and their derivatives under uniform conditions with more realistic assumptions.

The work resulting from this extension is documented in a Master thesis by Al-Helali [37] supervised by the principal investigator and the co-investigators, and also by the publications in [38], [39], [40], [41], and [42]. The project has shared some of the developed models with the OPNET community by depositing these models in the contributed models section of OPNET. The project has also shared the code and the results with the rest of the research community by providing links to the simulation packages developed under project.

The first subsection below specifies the main features of the resulting simulation tool. The modeling of signaling and overhead is detailed in the second subsection, while samples of the obtained results are shown in the third subsection. For more details the interested reader is referred to the corresponding thesis and publications.

### 5.1 Developed Simulation Tools

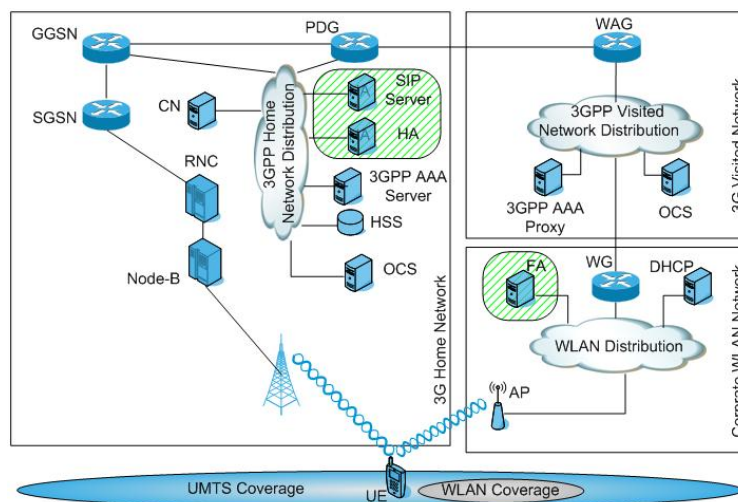
The investigators have set the following guidelines for the tool to be developed:

1. The tool must utilize a well known and proven network simulation platform with focus on ease of development and flexibility provided to the designers.

2. The aim is to characterize the vertical handoff delay for integrated 3G/WLAN network with as realistic assumptions as possible and capability to provide various configurations and settings to allow for the at most flexibility. Noting that prior studies in the field tend to report a lumped figure for the handoff delay, the intention here is to be able to report various component of the handoff delay and study the effect of the individual handoff steps on the overall handoff delay figure.
3. The tool needs to account for the detailed message exchange steps using the message sizes and headers specified by the corresponding standards documents. In addition, the designers must analyze the protocol stacks at the involved network entities to incorporate the actual overhead incurred in the involved handoff steps.
4. The tool should be able to evaluate the handoff delays and its components for the three potential mobility solutions Mobile IP (MIP), SIP, and m-SCTP with their derivatives over both IPv4 and IPv6 Internet protocols.

The UMTS/WLAN interworking architecture specified in subsections 4.2 and 4.3 is used as the basis for the simulation model. The specified architecture with support for roaming scenario is shown in Fig. 16. In this architecture, subscribers can access Packet Switched services provided by their operator's network from the WLAN through another operator's network. The network consists of three sub networks: the 3G home, the 3G visited, and the WLAN. The Wireless Gateway (WG), the Wireless Access Gateway (WAG), and the Packet Data Gateway (PDG) interface the three sub networks as shown in Fig. 16 using a WAN connection such as a 1.54Mbps T1 link. A DHCP server is attached to this network for IP management in the WLAN network.

The shaded entities in Fig. 16 highlight the components that are specific to a mobility solution. For example, to support mobility using MIP, the WLAN is considered as the foreign network and installs a FA server while the home 3G network is assumed to be the home network and provides MIP home services 3G via an HA server. In the case of SIP evaluation, the SIP server is attached to the home 3G network.

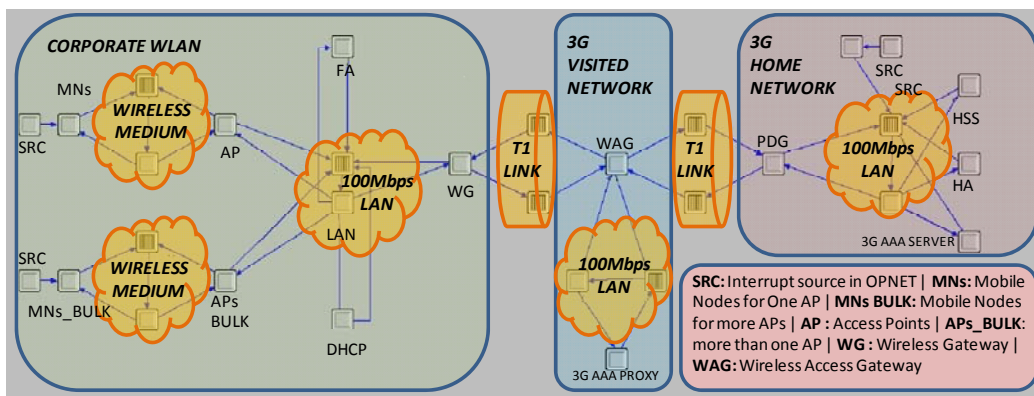


**Figure 16: Simulated UMTS/WLAN interworking architecture.**

OPNET Modeler 11.5 platform [43] is employed to develop a simulation model that matches the major core network components and the links connecting them. The network depicted in Fig. 16 is modeled using OPNET queues and processes as shown Fig. 17.

The nodes, modeled as OPNET processes, are the active components in the network. They represent the communicating ends, routers, servers, and APs. Each process consists of two states: the waiting state and the active state. The arrival of packet to the process initiates an interrupt that forces the process to leave the waiting state and move to the active state. The active state defines and controls the behavior of a node. The procedure derived from the corresponding to standards documents is coded into the active state. For example, the active state in a simple node such as the WG defines how the node will extract the Data Link (DL) header of the arrived packet. It then augments the DL header based on the link type, before forwarding it to the proper port. On the other hand, the active state may define complicated tasks in a more complex node such as the 3G AAA server which may be required to lookup the proper response and generate the corresponding reply.

The links are modeled using FIFO M/M/1 queues with a fixed service rate and infinite capacity. The service rate is set as a function of the link's transmission speed and type. For instance, a 1.54Mbps T1 link is represented by queue with service rate 1.54Mbps while a LAN is represented by a shared queue with a 100Mbps service rate. These service rates are set by the provided user interface.



**Figure 17: The OPNET model implementation using network of queues for 3G/WLAN integrated network.**

The OPNET model in Fig. 17 assumes that subscribers join the WLAN at some specified rate according to a Poisson Process. The roaming subscribers are distributed evenly between APs in the WLAN. Rather than simulating individual APs and the corresponding processing at each basic service set area, we divide the handoff traffic into two district groups. The first group is the traffic of interest referred to by MNs and AP in the upper left corner of the corporate WLAN shown in Fig. 17, while the second group is the handoff background traffic referred to by the MNs\_BULK and APs\_BULK in the lower left corner of the corporate WLAN shown in same figure. It should be noted that MNs generate the same traffic and go through the same handoff steps whether they are part of the first or the second group. In addition, the developed model allow the simulation of variable loading on the network links to account for traffic on the LAN and WAN connections that is not related to the handoff requests being generated. Default network loading values are set at: 20, 50, or 80 percent of the raw link capacity.

The arrival of a MN to the WLAN triggers the handoff session. The MN starts executing the AAA procedure, DHCP procedure, and the mobility procedure in sequence as will be illustrated in the next section. The MN creates a packet of the size specified in the related RFCs and standards documents. The packet size is the sum of message payload, control data, and the protocol headers from the DL and above. Next, the packet is dispatched to the network where its size will reflect the actual capacity it will consume from network resources

and its transmission speed through various links. The packets are generated and routed based on the signaling procedures as prescribed by the corresponding RFC or standard document.

## 5.2 Modeling and Analysis of Signaling Overhead

To arrive at a more realistic modeling of the integrated network, the protocol stack for each of the network entities shown in Fig. 16 is analyzed and the messages exchanged at every layer of the protocol stack are identified and cataloged.

To account for the elaborate signaling occurring for authentication, authorization, and accounting purposes, that is typically missing from most of the related literature, the developed tool models the exact steps taking into consideration the respective message sizes and formats. A typical signaling diagram that is implemented in the code is shown in Fig. 18. This signaling diagram corresponds to the UMTS to WLAN handoff events. The shown message exchange diagram depicts the four different components of the overall handoff delay namely the AAA delay, the DHCP delay, the mobility delay, and the one-way delay. The AAA delay involves all the signaling required for authentication, authorization, and accounting. The DHCP delay measures the time required for the MN to complete the DHCP procedure, while the mobility delay is the time needed to execute the signaling pertaining to the mobility solution adopted for the simulation scenario. This delay component and the corresponding configurations are further detailed in the material below. The last component, the one-way delay is the time needed for the first packet sent from the other end to arrive to the MN through the newly enabled interface after the completion of the handoff procedure.

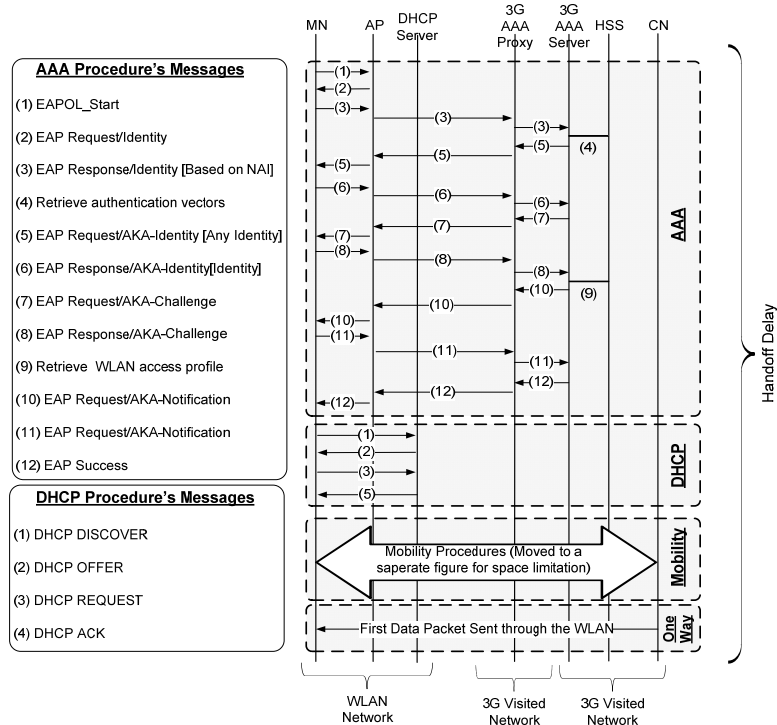
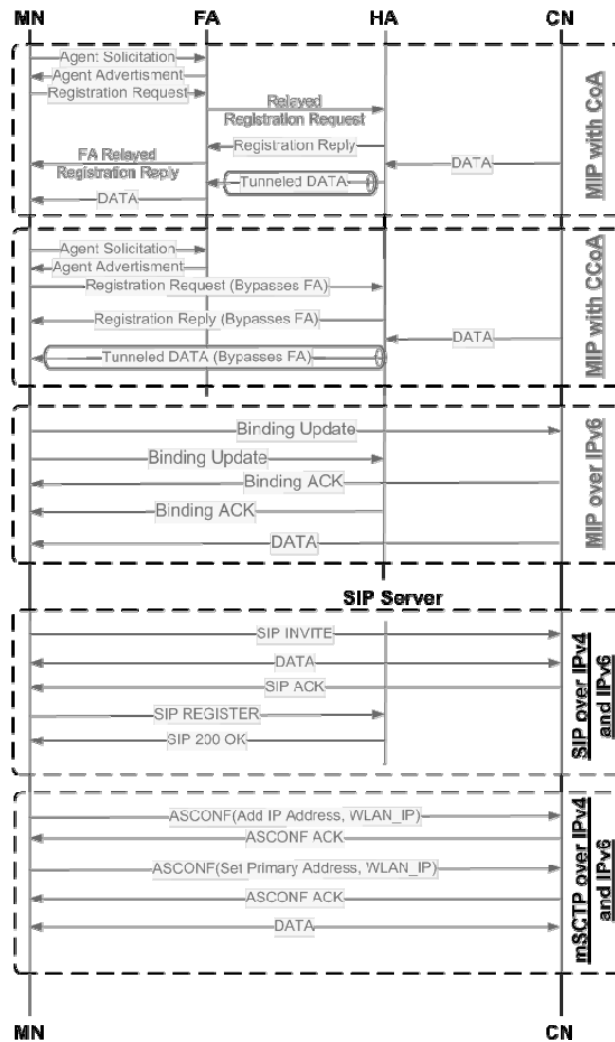


Figure 18: UMTS to WLAN Handoff Procedures.

The mobility delay component, depicted in Fig. 18 as one double headed giant arrow, depends on the particular mobility solution enabled in the simulation model. The developed tool allows for the evaluation of the following mobility solutions:

1. Mobile IP with care-of-address (MIP-CoA),
2. Mobile IP with collocated care-of-address (MIP-CCoA),
3. Mobile IP over IPv6,
4. SIP procedure for IPv4 and IPv6,
5. m-SCTP procedure for IPv4 and IPv6.

Again, the exact signaling for each of the above procedures is extracted from the corresponding RFCs and the message formats and sizes are identified and then coded into the tool. The signaling for the above procedures is summarized in Fig. 19.



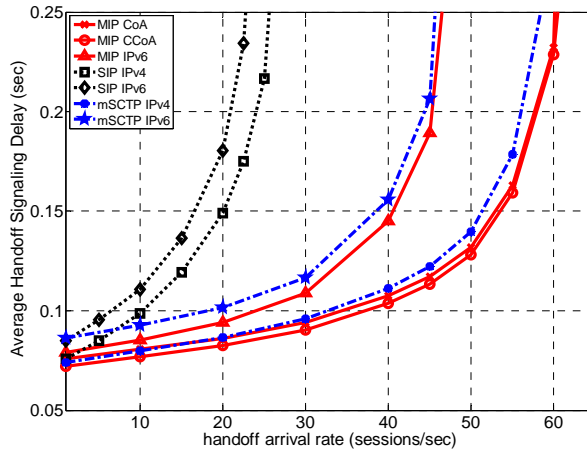
**Figure 19: Mobility Procedures (MIP with CoA, MIP with CCoA, MIP over IPv6, SIP over IPv4, SIP over IPv6, mSCTP over IPv4, and mSCTP over IPv6).**

Further details of the AAA signaling and the various configurations of mobility solutions are documented in [37] and the corresponding publications [38], [39], [40], [41], and [42].

### 5.3 Sample Results and Evaluation

A wide array of performance related results are generated from the developed tool. These results are fully documented in [37] and dispensed in the corresponding publications [38], [39], [40], [41], and [42]. In this subsection we present a sample of these results.

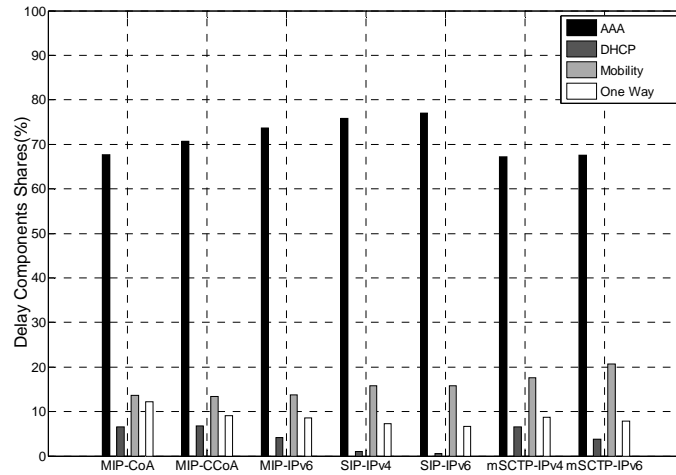
The handoff delay for the different configurations listed in the previous subsection is shown in Fig. 20, assuming 54 Mbps WLANs with 80 percent network loading. As expected, we notice that all traffic run over IPv4 generates less handoff delay relative to the configuration using IPv6. Particularly, the delay for MIP over IPv6 is 15 percent higher than the delay of MIP with CCoA over IPv4. This is a result of using IPv6 in the IP layer which forces all the other procedures necessary for completing the handoff process, such as the AAA procedure, to run on top of IPv6 also. While the AAA procedure satisfies the security requirements imposed by 3GPP, it involves a very large number of messages, contributing the largest portion of the delay as will be shown below. Likewise, we can observe that mSCTP over IPv4 and SIP over IPv4 have consistently better performance than mSCTP over IPv6 and SIP over IPv6. SIP over IPv4 is an application layer mobility solution, which uses text encoded messages. This makes it very sensitive to network loads and greatly increases the queuing delay due to the fact that some of its messages are in the order of 2-3Kbits. Generally, if we exclude SIP over IPv4, we can see that no scheme using IPv6 surpasses the corresponding IPv4 version.



**Figure 20: Handoff signaling delay for Mobile IP, SIP, mSCTP configurations with 54 Mbps WLAN access.**

As discussed in the previous sections, the total handoff delay is composed of four components: the AAA delay, the DHCP delay, the mobility delay, and one-way delay component. Fig. 21 depicts an example of total handoff delay break down for the 54Mbps WLAN scenario with handoff arrival rate equal to 20 requests per second. It is clear that the AAA procedure constitutes the major portion of the total delay, contributing to more than 65 percent in all the schemes and peaking at more than 70 percent in the case of MIP over IPv6, SIP over IPv4, and SIP over IPv6. The AAA generates the highest portion of delay because it involves more than 26 messages. In addition, many of these messages are exchanged between more than two entities connected by WAN links. The second greatest contributor in all the schemes is mobility procedures taking from 13 percent to 20 percent of the total delay. Since DHCP is limited to the local WLAN and the delays in the AP and LAN, it contributes only 4 to 7 percent.

Based on these findings the investigators believe that more research is required to improve the AAA procedures, as the resultant reduction would have a huge impact on performance.



**Figure 21: Relative weight of delay components contributing to the overall handoff signaling delay for all the configurations with 54 Mbps WLAN access.**

Finally, Fig. 22 depicts a comparison for the total handoff delay for the various mobility solutions and configurations for two distinct traffic loadings of the network: 20% and 80%. The traffic loading correspond to load presented to the network but not related to the handoff request traffic. As expected, greater traffic loads lead to higher overall delays due to larger delays at the wired network when data is being forwarded to the MN. Characterization for other traffic loads and using other speeds of the WLANs are also available and document in the references cited above.

The 3GPP recommends that handoff delays be within 100 to 200 msec [44]. Consequently, analyses conducted reveal that low WLAN rates such as 2 Mbps cannot fulfill this requirement even for minimum handoff arrival rates. On the other hand, a 54Mbps WLAN provides the optimal handoff delay for all the configurations except SIP, which loses its stability as the number of arrival increases. This supports the premise that interworked WLANs should be designed with rates above 2 Mbps, especially at the WLAN borders where one expects roamers will make handoffs more frequently.

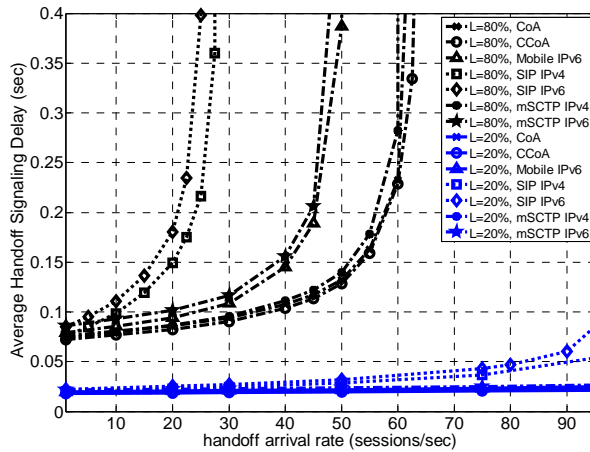


Figure 22: Handoff signaling delay for all the configurations and under network loads of 80% and 20%.

## 6 Summary of Accomplished Work

The following table summarizes the accomplished work items and the corresponding project objective. It also depicts the related publications.

Table 3: Summary of accomplished work.

Item no.	Achieved work	Project objective	Publications/Report
1	Numeration of integration solutions provided by vendors and those found in related literature – Section 4.1 of this report.	(1)	[14] and [32].
2	Identification of target network architecture for deployment – Section 4.2 of this report.	(2)	[14], [32], and [37].
3	Deployment scenario and capacity calculator – Section 4.3 of this report.	(3)	[14] and [32].
4	Preliminary assessment of mobility solutions with different configurations and various Internet traffic mixes – Section of 4.2 of this report.	(2) and (3)	[30] and [31].
4	Development of OPNET-based simulation tool for characterization of mobility solutions – Section 5.1 of this report.	(4) – of extended objectives	[37], [38], [39], and [40].
5	Detailed modeling of protocol stacks and signaling – Section 5.2 of this report.	(5) – of extended objectives	



6	Comparative analysis of mobility solutions taking into account constituent delay components – Section 5.3 of this report.	(6) – of extended objectives	[37], [41], and [42].
---	---	------------------------------	-----------------------

The full details of the studies supported by the project are shown in Table 4 below.

**Table 4: List of publications and report supported by the project.**

Item no.	Publication / Document	No. of citations*	Remark
1	Ejaz Rahman, Junaid Jaffar, Ashraf Mahmoud, "Investigation of WLAN-Cellular Integration Architecture for Cellular Operators and Deployment Issues at King Fahd International Airport," Senior Design Project Report, Computer Engineering Department, King Fahd University of Petroleum and Minerals, January, 2006.		
2	A. Mahmoud, T. Sheltami, M. Abu Amara, E. Rahman, J. Jaffar, "WLAN Integration For Future Generation Mobile Network Operators – A Case Study," Proceedings of 18th National Computer Conference (NCC 18), March 26-29, Riyadh - Saudi Arabia, pp. 47-54, 2006.		
3	Marwan Abu-Amara, Ashraf Mahmoud, Tarek Sheltami, Adel Al-Shahrani, Khalid Al-Otaibi, S. M. Rehman, and Taha Anwar, "Performance of UMTS/WLAN Integration at Hot-Spot Locations Using OPNET", 4th IEEE GCC, 11-14 November, Bahrain, 2007.	3	
4	Syed Asadullah, Ashraf S. Mahmoud, Marwan Abu-Amara, "Vertical handoff characterization for SIP and mSCTP based UMTS-WLAN integration solutions," 4th IEEE GCC, 11-14 November, Bahrain, 2007.	5	Paper attached to this report.
5	Abdul Aziz Al-Helali, Ashraf Mahmoud, Talal Kharoubi, Tarek Sheltami, "UMTS-WLAN Integration Characterization for Hotspot Locations," Master Thesis Proposal submitted to Deanship of Graduate Studies, King Fahd University of Petroleum and Minerals, September 2007.		
6	Abdul-Aziz Al-Helali, Ashraf Mahmoud, Talal Al-Kharobi, Tarek Sheltami, "A Novel Dual-Mode User Equipment Design And Enhanced Gateway Selection Algorithm For B3G Networks," 37th International Conference on Parallel Processing (ICPP-08), Portland, Oregon, USA, September 8-12, 2008, pp. 162-166, 2008.	3	Paper attached to this report.
7	Abdul-Aziz Al-Helali, Ashraf Mahmoud, Talal Al-Kharobi, Tarek Sheltami, "Permanence Evaluation and Analysis of Enhanced Gateway Selection Algorithm For B3G Networks," The 3rd International Conference on Modeling, Simulation, and Applied Optimization (ICMSAO'09), January 20-22 2009, Sharjah, United Arab Emirates.		
8	Abdul-Aziz Al-Helali, Ashraf Mahmoud, Talal Al-Kharobi, Tarek Sheltami, "Characterization of Vertical Handoff Delay for Mobile IP Based 3G/WLAN Integrated Networks," IEEE 69th Vehicular Technology Conference (VTC2009-Spring), 26-29 April 2009, Barcelona, Spain.	4	Paper attached to this report.
9	Abdul-Aziz Al-Helali, Ashraf Mahmoud, Talal Al-Kharobi, Tarek Sheltami, "Analysis of Handoff Delay Components for Mobile IP-Based 3GPP UMTS/WLAN Interworking Architecture," IEEE 23rd International Conference on Advanced Information Networking and Applications (AINA-09), Bradford, UK, May 26-29, 2009.	3	Paper attached to this report.

10	Abdul Aziz Al-Helali, "Performance Evaluation of Mobility Solutions for Integrated WLAN/3G Networks", Master Thesis submitted to Deanship of Graduate Studies, King Fahd University of Petroleum and Minerals, Feb 2010.		
11	Ashraf Mahmoud, Abdul-Aziz Al-Helali, Marwan Abu-Amara, Talal Al-Kharobi, Tarek Sheltami, "Comparative Performance Study for Integrated 3G/WLAN Networks Using Mobile IP, SIP, and m-SCTP Protocols," 2010 IEEE 71st Vehicular Technology Conference: VTC2010-Spring, 16–19 May 2010, Taipei, Taiwan.		Paper attached to this report.

\* Google scholar citations

The attached papers are found in Appendix B.

## References:

- [1] H. Andersson, *et al.*, "Improving system performance in a WCDMA FDD network using indoor pico base stations," 2002, pp. 467-471 vol. 1.
- [2] S. Ghorashi, *et al.*, "Non-real time packet transmission for a microcell (hotspot) embedded in CDMA macrocell systems," in *IEEE International Conference on Communications, 2003 (ICC '03)*, 2003, pp. 997-1001 vol. 2.
- [3] M. Rahman and P. Ernström, "Repeaters for hotspot capacity in DS-CDMA networks," *Vehicular Technology, IEEE Transactions on*, vol. 53, pp. 626-633, 2004.
- [4] A. K. Salkintzis, "Interworking techniques and architectures for WLAN/3G integration toward 4G mobile data networks," *Wireless Communications, IEEE*, vol. 11, pp. 50-61, 2004.
- [5] I. Welling, *et al.*, "Techno-economic evaluation of 3G & WLAN business case feasibility under varying conditions," 2003, pp. 33-38 vol. 1.
- [6] *IEEE 802.11 working group* Available: <http://www.ieee802.org/11/>
- [7] *IEEE Standards Association.* Available: <http://standards.ieee.org/getieee802/802.11.html>
- [8] B. Bing, *Wireless Local Area Networks the New Wireless Revolution*: Wiley, 2002.
- [9] (2007). *The 3rd Generation Partnership Project (3GPP)*. Available: <http://www.3gpp.org>
- [10] H. Kaaranen, *et al.*, *UMTS Networks: Architecture, Mobility and Services* Wiley, 2005.
- [11] R. Kreher and T. Rüdibusch, *UMTS Signaling : UMTS Interfaces, Protocols, Message Flows and Procedures Analyzed and Explained*: Wiley, 2005.
- [12] R. Samarasinghe, *et al.*, "Analysis of intersystem handover: Umts fdd & wlan," *Centre for Telecommunications Research*, 2003.
- [13] A. K. Salkintzis, "WLAN/3G interworking architectures for next generation hybrid data networks," 2004, pp. 3984-3988 Vol. 7.
- [14] R. Ejaz, *et al.*, "Investigation of WLAN-Cellular Integration Architecture for Cellular Operators and Deployment Issues at King Fahd International Airport," Senior Design Project Report, 2006.
- [15] C. S. Inc., "PWLAN for Service Providers solution overview," 2004.
- [16] S. Olivier and P. Poiraud, "Public WLAN for Mobile Operators," *Alcatel Communications Review*, vol. 1st quarter, 2004.
- [17] N. Drevon, *et al.*, "Interworking strategy and service continuity between GSM-UMTS-WLAN Radio Technologies," *Alcatel Communications Review*, vol. 4th quarter, 2004.
- [18] J. Networks. *Public Wireless LANs.* Available: <http://www.juniper.net/solutions/literature/solutionbriefs/351024.pdf>
- [19] A. Salkintzis, *et al.*, "WLAN-GPRS integration for next-generation mobile data networks," *IEEE Wireless Communications*, vol. 9, pp. 112-124, Oct. 2002.
- [20] W. Zhuang, *et al.*, "Policy-Based QoS-Management Architecture in an Integrated UMTS and WLAN Environment," *IEEE Communications Magazine*, vol. 41, pp. 118-125, Nov. 2003.
- [21] L. Liu and C. Zhou, "HCRAS: A Novel Hybrid Interworking Architecture between WLAN and UMTS Cellular Networks," in *Second IEEE Consumer Communications and Networking Conference*, Jan. 2005, pp. 374-379.

- [22] L. Liu and C. Zhou, "An Improved Interworking Architecture for UMTS-WLAN Tight Coupling," *IEEE Wireless Communication and Networking Conference*, vol. 3, pp. 1690-1695, Mar. 2005.
- [23] S. Tsao and C. Lin, "Design and Evaluation of UMTS-WLAN Internetworking Strategies," in *Proceedings of IEEE Vehicular Technology Conference*, 2002, pp. 777-781.
- [24] M. M. Buddhikot, *et al.*, "Design and implementation of a WLAN/CDMA2000 interworking architecture," *IEEE Communications Magazine*, vol. 41, pp. 90-100, 2003.
- [25] S. Tsao and C. Lin, "VSGN: A Gateway Approach to Interconnect UMTS/WLAN Networks," in *The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, 2002, pp. 275-279.
- [26] B. Hongyang, *et al.*, "Performance Analysis of Vertical Handoff in a UMTS-WLAN Integrated Network," in *Proceedings of 14th IEEE conference on Personal, Indoor and Mobile Radio Communications (PIMRC 2003)*, Sept. 2003, pp. 187-191.
- [27] F. Siddiqui, *et al.*, "A Novel Architecture for Roaming between 3G and Wireless LANs," in *1st International Conference on Multimedia Services Access Networks*, 2005, pp. 101-105.
- [28] 3GPP, "Feasibility Study on 3GPP System to WLAN Interworking, Tech. rep. 3GPP TR 22.934 v7.0.0," Jun. 2007.
- [29] 3GPP, "Technical Specification Group Services and System Aspects; 3GPP system to Wireless Local Area Network (WLAN) interworking; System description (Release 7) - 3GPP TS 23.234 v7.4.0," ed, Dec. 2006.
- [30] M. Abu-Amara, *et al.*, "Performance of UMTS/WLAN Integration at Hot-Spot Locations Using OPNET," in *4th IEEE GCC 2007*, Bahrain, 2007.
- [31] S. Asadullah, *et al.*, "Vertical handoff characterization for SIP and mSCTP based UMTS-WLAN integration solutions," in *4th IEEE GCC*, Bahrain, 2007.
- [32] A. Mahmoud, *et al.*, "WLAN Integration For Future Generation Mobile Network Operators – A Case Study," in *18th National Computer Conference (NCC 18)*, Riyadh - Saudi Arabia, 2006, pp. 47-54.
- [33] I. F. Akyildiz, *et al.*, "A survey of mobility management in next-generation all-IP-based wireless systems," *IEEE Wireless Communications*, vol. 11, pp. 16-28, 2004.
- [34] C. E. Perkins, "Mobile ip," *Communications Magazine, IEEE*, vol. 40, pp. 66-82, 2002.
- [35] Available: <http://www.the-saudi.net/kfia/kfia.htm#GENERAL%20PARAMETERSAndSITE%20DATA>
- [36] G. Bianchi, "Performance analysis of the IEEE 802.11 distributed coordination function," *IEEE Journal on Selected Areas in Communications*, vol. 18, pp. 535-547, 2000.
- [37] A. Al-Helali, "Performance Evaluation of Mobility Solutions for Integrated WLAN/3G Networks," Master of Science, Computer Engineering, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia, Feb. 2010.
- [38] A. Al-Helali, *et al.*, "A Novel Dual-Mode User Equipment Design and Enhanced Gateway Selection Algorithm for B3G Networks," in *37th International Conference on Parallel Processing (ICPP-08)*, Portland, Oregon, USA, 2008, pp. 162-166.
- [39] A.-A. Al-Helali, *et al.*, "Permanence Evaluation and Analysis of Enhanced Gateway Selection Algorithm For B3G Networks," in *The 3rd International Conference on Modeling, Simulation, and Applied Optimization (ICMSAO'09)*, Sharjah, United Arab Emirates, 2009.

- [40] A. Al-Helali, *et al.*, "Characterization of Vertical Handoff Delay for Mobile IP Based 3G/WLAN Integrated Networks," in *IEEE 69th Vehicular Technology Conference (VTC2009-Spring)*, Barcelona, Spain, 2009, pp. 1-5.
- [41] A. Al-Helali, *et al.*, "Analysis of Handoff Delay Components for Mobile IP-Based 3GPP UMTS/WLAN Interworking Architecture," in *IEEE 23rd International Conference on Advanced Information Networking and Applications (AINA-09)*, Bradford, UK, 2009, pp. 798-803.
- [42] A. Mahmoud, *et al.*, "Comparative Performance Study for Integrated 3G/WLAN Networks Using Mobile IP, SIP, and m-SCTP Protocols," in *2010 IEEE 71st Vehicular Technology Conference: VTC2010-Spring*, Taipei, Taiwan, 2010, pp. 1-5.
- [43] *OPNET Inc.* (2009) <http://www.opnet.com>. [Online].
- [44] 3GPP, "Telecommunications and Internet Protocol Harmonization over Networks, QoS Class Specification (TS 101329-2)," ed, 2002.

## List of Acronyms:

3G	3rd Generation
3GPP	3rd Generation Partnership Project
AAA	Authentication, Authorization, and Accounting
AKA	Authentication Key Agreement
AP	Access Point
ARPU	Average Revenue Per User
ATM	Asynchronous Transfer Mode
AuC	Authentication and Care Center
BSC	Base Station Controller
BSS	Basic Service Set
BTS	Base Station Transceiver
CN	Correspondent Node
CoA	Care of Address
CS	Circuit Switched
DAR	Dynamic Address Reconfiguration
DHCP	Dynamic Host Configuration Protocol
DL	Data Link
EAP-AKA	Extensible Authentication Protocol based on Authentication and Key Agreement
EAP-SIM	Extensible Authentication Protocol based on Subscribers and Identity Module
ESS	Extended Service Set
FA	Foreign Agent
GGSN	Gateway GPRS Support Node
GIF	GPRS Interworking Function
GMSC	Gateway Mobile Switching Center
GPRS	Global Packet Radio System

GSM	Global System for Mobile Communication
HA	Home Agent
HCRAS	Hyper Coupling with Radio Access System
HLR	Home Location Register
HSS	Home Subscriber Server
IBSS	Independent Basic Service Set
ICMP	Internet Control Message Protocol
IETF	Internet Engineering Task Force
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ISDNs	Integrated Service Digital Networks
MA	Mobility Agent
MD5	Message Digest Algorithm version 5
ME	Mobile Equipment
MIP	Mobile IP
MSC	Mobile Switching Center
mSCTP	mobile Stream Control Transmission Protocol
NAI	Network Access Identity
NAT	Network Address Translation
NRO	Non Route Optimization
NSS	Network Switching Subsystem
OHG	Operator Harmonization Group
PCU	Packet Control Unit
PDG	Packet Data Gateway
PDP	Packet Data Protocol
PLMN	Public Land Mobile Network
PS	Packet Switched
PSTNs	Public Switched Telephone Networks

PWLAN	Public WLAN
QoS	Quality of Service
RADIUS	Remote Authentication Dial In User Service
RFC	Request For Comments
RO	Route Optimization
SBS	Session Border Controllers
SGSN	Serving GPRS Support Node
SIP	Session Initiation Protocol
TCWA	Tight Coupling with Wireless Access
UA	User Agent
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
USIM	UMTS Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
WAF	Wireless Adaption Function
WAG	Wireless Access Gateway
WAP	Wireless Application Protocol
WCDMA	Wide Code Division Multiple Access
WG	Wireless Gateway
WLANs	Wireless LANS



## **Appendix A:**

Sample emails and inquires showing interest in developed tools and software.

## Ashraf S. Hasan Mahmoud

---

**From:** joalarcondiaz@gmail.com on behalf of Jorge Alarcon [jalarcon@ing.uchile.cl]  
**Sent:** Monday, January 16, 2012 1:34 PM  
**To:** alhelali@kfupm.edu.sa; ashraf@kfupm.edu.sa; talalkh@kfupm.edu.sa; tarek@kfupm.edu.sa  
**Subject:** Opnet dual-mode UE

Hi,

I'm Jorge Alarcon, an Electrical Engineering student from University of Chile who is currently studying about Interworking between 3G/WLAN networks using network-based mobility protocols. For it, I'm using the OPNET Modeler software and I'm trying to develop a dual mobile station but I'm facing some problems with the model.

During my research I came across with your work "Simulation of a Novel Dual-Mode User Equipment Design" and I was wondering if there's any chance you could facilitate your models to me, in which case it'd be very useful for my research to make some simulations with it.

Hoping this mail is not a trouble for you,

Thanks in advance,  
Jorge

-----

No virus found in this message.

Checked by AVG - [www.avg.com](http://www.avg.com)

Version: 2012.0.1901 / Virus Database: 2109/4745 - Release Date: 01/15/12

## Ashraf S. Hasan Mahmoud

---

**From:** k.salvatierraleon@gmail.com on behalf of Karen Salvatierra L. [ksalvati@ing.uchile.cl]  
**Sent:** Thursday, January 05, 2012 2:59 PM  
**To:** alhelali@kfupm.edu.sa; ashraf@kfupm.edu.sa; talalkh@kfupm.edu.sa; tarek@kfupm.edu.sa  
**Subject:** UMTS/WLAN dual station for OPNET

Hi,

I'm Karen Salvatierra, an Electrical Engineering student from University of Chile who is currently studying about Interworking between 3G/WLAN networks.

I'm doing my work in OPNET Modeler software and I'm trying to develop a dual mobile station but I'm facing some problems with the model. I came across with your work "Simulation of a novel dual-mode user equipment design for B3G networks using OPNET" but I couldn't find it in the current OPNET contributed models community. So I was wondering if there's any chance you could facilitate it to me in which case it'd be very useful for my work to make some simulations with your model for comparing results later.

Hoping this mail is not a trouble for you,

Thanks in advance

Karen Salvatierra L.

--

Estudiante Ingeniería Civil Electricista 6° año  
Universidad de Chile

---

No virus found in this message.

Checked by AVG - [www.avg.com](http://www.avg.com)

Version: 2012.0.1901 / Virus Database: 2109/4723 - Release Date: 01/04/12

## Ashraf S. Hasan Mahmoud

---

**From:** wangye [wychina\_2007@hotmail.com]  
**Sent:** Tuesday, April 12, 2011 8:48 AM  
**To:** alhelali@kfupm.edu.sa; talalkh@kfupm.edu.sa; ashraf@kfupm.edu.sa  
**Subject:** hi, i really need your help!!

hi

sorry to interrupt to you

i want to simulate UMTS/WLAN INTERWORKING network by using OPNET dual-mode module

but first i should develop dual-mode user about UMTS/WLAN , but i have no any idea about it

when i found your paper "a novel dual-mode user equipment design and enhanced gateway selection algorithm for B3G networks", you provide a idea about it

but i am new beginner for opnet,

so do you have any document about how to develop this dual-mode UE? could you give me these or best suggestions?

thks so much

wang

4.12

---

No virus found in this message.

Checked by AVG - [www.avg.com](http://www.avg.com)

Version: 10.0.1209 / Virus Database: 1500/3567 - Release Date: 04/11/11

**Ashraf S. Hasan Mahmoud**

---

**From:** bixfff bixfff [bixfff@gmail.com]  
**Sent:** Wednesday, May 05, 2010 8:38 PM  
**To:** ashraf@kfupm.edu.sa  
**Subject:** Bella from Queen's university

Dear Ashraf,

Thank you for reading my letter.

I am Bella, a first-year PhD student from Queen's University Belfast, UK. My research field is about security in 3G-WLAN, and heterogeneous networks.

Recently, I have read your papers "**Analysis of Handoff Delay Components for Mobile IP-Based 3GPP UMTS/WLAN Interworking Architecture**" in 2009 International Conference on Advanced Information Networking and Applications Workshops, and "**Performance of UMTS/WLAN Integration at Hot-Spot Locations Using OPNET**". I am very interested in applying the trust models or managements for securing 3G-WLAN networks.

In your papers, I see some figures about simulation results by using OPNET. I also use OPNET to do network simulations. I plan to use OPNET to do 3G-WLAN network simulations with trust models, and quoting your results. If possible, could I have one copy of your simulation codes?

King Regards

yours  
Bella

---

No virus found in this message.

Checked by AVG - [www.avg.com](http://www.avg.com)

Version: 2012.0.1913 / Virus Database: 2114/4900 - Release Date: 03/28/12

**Ashraf S. Hasan Mahmoud**

---

**From:** wu huayang [wuhuayang@gmail.com]  
**Sent:** Thursday, May 13, 2010 3:50 PM  
**To:** ashraf@kfupm.edu.sa  
**Subject:** hi,professor

Professor,I come from China,now I'm doing a research in Vertical handoff between UMTS/WLAN, I heard that u had did this research for years and had many achievements.I have some problem in OPNET simulation,and the model which I download from your website does not work.Can u send me the project? Thank u very much!

---

No virus found in this message.

Checked by AVG - [www.avg.com](http://www.avg.com)

Version: 2012.0.1913 / Virus Database: 2114/4900 - Release Date: 03/28/12

## Ashraf S. Hasan Mahmoud

---

**From:** Juan Carlos Borda Carulla [jc.borda147@uniandes.edu.co]  
**Sent:** Thursday, April 08, 2010 2:14 AM  
**To:** alhelali@kfupm.edu.sa  
**Cc:** ashraf@kfupm.edu.sa; talalkh@kfupm.edu.sa; tarek@kfupm.edu.sa  
**Subject:** about Analysis of Handoff Delay Components for Mobile IP-Based 3GPP UMTS/WLAN Interworking Architecture

Dear Abdul-Aziz Al-Helali,

My name is Juan Carlos Borda, I'm a MS student at Los Andes University in Bogotá, Colombia. Our team is currently working on Optimizing Hand Off delay Authentication. We have read your work on Mobile IP-Based 3GPP UMTS/WLAN Handoff delays.

We would like to use your Opnet network model in order to validate our work. Is it possible for you to grant us access to this model?

Due citations and special thanks will be included in any issuing publications.

Best regards,  
Juan Carlos Borda and Research Team

---

No virus found in this message.

Checked by AVG - [www.avg.com](http://www.avg.com)

Version: 2012.0.1913 / Virus Database: 2114/4900 - Release Date: 03/28/12

## Ashraf S. Hasan Mahmoud

---

**From:** PARISA KASHI [parisa.kashi@aut.ac.ir]  
**Sent:** Thursday, April 01, 2010 10:50 PM  
**To:** ashraf@kfupm.edu.sa  
**Subject:** Request for simulation details

Dear Mr. Ashraf Mahmoud

I'm MSC student in AUT. I'm interested in research you have done in "Vertical Handoff Characterization for SIP and mSCTP Based UMTS-WLAN Integration Solutions" and "Performance of UMTS/WLAN Integration at Hot-Spot Locations Using OPNET" and i want to repeat your simulations. would you please send me back some simulation details and OPNET models you have developed?

Thank you for your time to considering this request and I'll greatly appreciate it.

Sincerely,  
Parisa Kashi.

---

No virus found in this message.

Checked by AVG - [www.avg.com](http://www.avg.com)

Version: 2012.0.1913 / Virus Database: 2114/4900 - Release Date: 03/28/12



**Dr. Ashraf S. Hasan Mahmoud**

---

**From:** Premnath [prem888@gmail.com]  
**Sent:** Saturday, February 13, 2010 4:07 PM  
**To:** taha.anwar@gmail.com; adel\_shahrani@yhao.com; rehmanda@ccse.kfupm.edu.sa;  
kaahf@yahoo.com; marwan@kfupm.edu.sa; ashraf@kfupm.edu.sa; tarek@kfupm.edu.sa  
**Subject:** A humble request from a student of Thanthai Periyar Govt Inst of Tech,India  
**Attachments:** BASEPAPER.pdf

Respected Sir,

I'm doing my Project based on your project "Performance of UMTS/WLAN Integration at Hot-Spot Locations Using OPNET ". I wish to learn OPNET Modeler but no source to learn here.Can you please help me on doing my project.Your project is my project's basepaper .Please Help me out to finish my project sir.

Thanking you

Date:13.02.2010  
Place:India

Yours faithfully  
PREMNATH D

## Dr. Ashraf S. Hasan Mahmoud

---

**From:** Abu Sayed Chowdhury Zia [S3191682@student.rmit.edu.au]  
**Sent:** Tuesday, December 02, 2008 7:53 AM  
**To:** ashraf@kfupm.edu.sa  
**Subject:** Dual mode

Dear Dr. Ashraf,

In your paper "Performance of UMTS/WLAN Integration at Hot-Spot Locations Using OPNET" you specified some of the major components that were lacking in opnet modeller and one of them is Dual mode workstation that operates under both UMTS and WLAN. Can you help me to make this dual mode workstation in Opnet. I tried to find the code (the link you have provided) but I didn't get it. I am waiting for your kind reply. Thank you for your time.

Regards,  
Sayed

**Dr. Ashraf S. Hasan Mahmoud**

---

**From:** Bashar Jabbar [mrym\_bashar@yahoo.com]  
**Sent:** Friday, November 21, 2008 4:22 PM  
**To:** tarek@kfupm.edu.sa; marwan@kfupm.edu.sa; ashraf@kfupm.edu.sa;  
Adel\_shahrani@yhaoo.com; kaahf@yahoo.com; rehmanda@ccse.kfupm.edu.sa;  
taha.anwar@gmail.com  
**Subject:** help me if you can

Dear Sir,

Wish you a good day, at first I want to introduce myself I am Bashar Jabbar H. PhD student in (University Putra Malaysia) and my topic in Doctor Degree is to integrate the Heterogeneous Wireless Network. Early I found your Paper (Performance of UMTS/WLAN Integration at Hot-Spot Locations Using OPNET), for that I will be appreciate if can you help me by sending any tutorial or simulation in the OPNET program to modify and use it in my project.

**Please give me the best attributes for the following objects in OPNET to work together :**

**RNC**

**GGSN**

**SGSN**

**ROUTER**

**SERVER**

**UMTS NODE B**

**IP\_CLOUD**

**WLAN ACCESS POINT**

**WIRELESS TERMINAL**

Sincerely,

Bashar Jabbar H.  
Wireless Communication Engineering  
Faculty of Engineering  
University Putra Malaysia  
Mobil: +60173370547  
E-mail: [mrym\\_bashar@yahoo.com](mailto:mrym_bashar@yahoo.com)

Bashar Jabbar Hamza  
Department of Communication and Computer System  
Faculty of Engineering  
University Putra Malaysia (UPM)

A-10-17, 43300, Seri Kembangan, Serdang  
Selangor  
Malaysia  
H/P: 0060173370547

## **Appendix B:**

Sample publication referenced in Table 4 of section 6 of this final report document.

# Comparative Performance Study for Integrated 3G/WLAN Networks Using Mobile IP, SIP, and m-SCTP Protocols

Ashraf Mahmoud    Abdul-Aziz Al-Helali    Marwan Abu-Amara    Talal Al-Kharobi    Tarek Sheltami  
 Computer Engineering Department  
 King Fahd University of Petroleum & Minerals  
 Dhahran, Saudi Arabia  
 { ashraf, alhelali, marwan, talalkh, tarek }@kfupm.edu.sa

**Abstract**—The 3rd Generation Partnership Project (3GPP) has adopted an interworking architecture between Universal Mobile Telecommunication System (UMTS) and Wireless Local Area Networks (WLANs). This architecture imposes a set of security requirements on subscribers connecting from within interworked WLANs to be able to access their 3G home packet-switched services. Providing seamless handoff and session continuity of ongoing communication is a critical task in UMTS/WLAN integrated networks. However, the 3GPP does not specify how mobility can be supported. This paper provides a performance evaluation for the three candidate solutions: Mobile IP (MIP), Session Initiation Protocol (SIP), and mobile Stream Control Transmission Protocol (mSCTP) that may be used to provide session continuity in the integrated network. The vertical handoff delay figure is analyzed using simulations for different WLAN speeds and its major components due to the involved signaling procedures are quantified. The results are derived from our developed OPNET based simulation model that accounts for the detailed prescribed signaling procedures as per the related standards and Request for Comments (RFCs) documents, and the main network entities in the adopted architecture. The presented analysis provides insight into the potential performance bottlenecks in the integrated network. Major findings of the work show that the security related signaling and the signaling pertaining to obtaining a new Internet Protocol (IP) address, each contribute about 40% of the total delay for all the three solutions. Enhancements targeting these procedures will help reduce the overall delay while supporting seamless handoff between the two networks.

**Keywords**- *Mobility Solutions; MIP; SIP; mSCTP; 3G/WLAN Integrated Networks; Heterogeneous Networks; Vertical Handoffs.*

## I. INTRODUCTION

Integrating 3G and WLAN networks has great advantages for both 3G operator and its subscribers. Operators can increase their networks net present value from 9-18% when integrating WLANs in hotspots [1]. On the other hand, subscribers can enjoy accessing 3G services at WLAN access speeds. Seamless handoff and session continuity is a critical issue in 3G/WLAN integrated networks. The roaming subscriber should not experience large delays that interrupt the ongoing sessions when handing off from one network to the other. The delays should not exceed 200 msec as specified by the 3<sup>rd</sup> Generation Partnership Project (3GPP) to support streaming applications [2]. Mobile IP (MIP) [3], Session Initiation Protocol (SIP) [4],

and mobile Stream Control Transmission Protocol (mSCTP) [5] are the three potential solutions that are recognized by researchers for supporting seamless handoff in wireless integrated networks.

Extensive research effort can be found focusing on identifying the needed architectures for integrating 3G/WLAN networks. Examples of these are found in [6]-[9] and the references therein. However, little research has been directed towards the study of the performance of mobility solutions in 3G/WLAN integrated networks. For example, in [10], the performance of MIP is studied in CDMA2000/WLAN integrated architecture. The evaluated architecture assumes the Internet as the interconnection point between the WLAN and the CDMA2000 network, and hence ignoring any authentication mechanism. The work in [11] tests the performance of SIP as a mobility solution in a GPRS-UMTS/WLAN integrated network using a test bed. Similarly, the work in [12] and [13] build an analytical model to evaluate the performance of SIP in Wireless Wide Area Network (WWAN) to WLAN integrated networks. The studies in [11], [12], and [13] do not account for any security requirements when handoff are executed. In [14], the performance of SCTP and its Dynamic Address Reconfiguration (DAR) extensions are tested in a UMTS/WLAN interworked at the Internet level. The study abstracts the handoff delay as a single figure and does not analyze the components of this delay. In all the aforementioned studies, the performance of mobility solutions is based on non standard architectures that assume the Internet as the interconnection point between the 3G and WLAN network. The 3GPP has recently adopted a UMTS/WLAN interworking architecture that interconnects WLAN to the packet-switched domain of the UMTS network to allow the subscribers to access 3G data services from within the WLAN [15].

To the best of our knowledge, no study prior to this work evaluates and analyzes the vertical handoff delay based on the proposed 3GPP UMTS/WLAN interworking architecture for all the major mobility solutions. In addition, this study evaluates the different components that contribute to the overall handoff delay. This work is a continuation of our earlier research conducted on MIP [16] and [17] where we extend the study to include a comparative performance evaluation of MIP, SIP, and mSCTP. A simulation model is developed to model the performance of the three mobility solutions as specified in

the corresponding standards and RFCs for the 3GPP interworking architecture. Furthermore, we propose mechanisms for WLAN layouts that enhance the performance of integrated WLANs and reduce the handoff delay by up to 50%.

The rest of this paper is organized as follows. In section II vertical handoff from UMTS to WLAN is discussed. Next, the signaling procedures for MIP, SIP, and mSCTP are presented in section III. Section IV discusses the simulation model and simulation parameters used for the evaluation while section V presents and discusses the obtained simulation results for the three mobility solutions. Finally, the main findings are summarized in section VI.

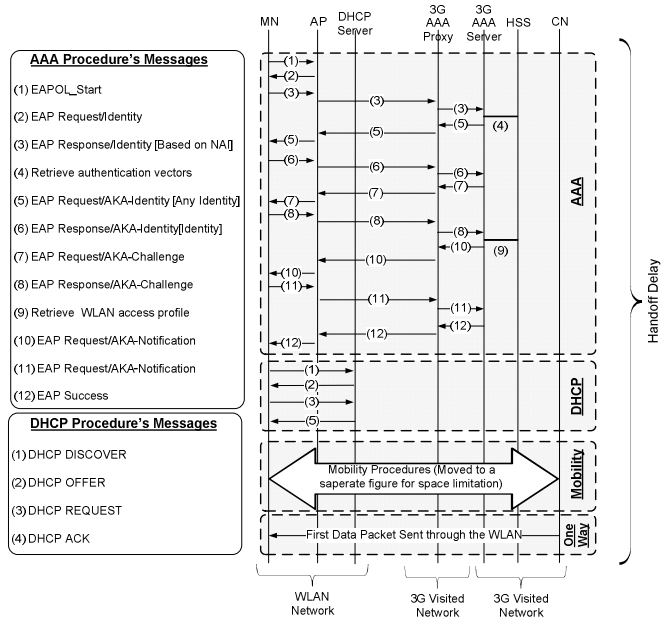


Figure 1. Vertical handoff from UMTS to WLAN based on 3GPP authentication.

## II. VERTICAL HANODOVER FROM UMTS TO WLAN

The vertical handoff delay can be defined as the time required for a Mobile Node (MN) to move all its ongoing connections from one point of attachment (UMTS) to another point of attachment (WLAN) plus the One Way (OW) delay. The OW delay is the time delay for the first packet sent from the Correspondent Node (CN) to the MN on the newly established path. The handoff delay excluding the OW delay results from executing three sets of procedures before the MN is able to handoff from UMTS to WLAN. The first procedure occurs when the MN finds WLAN coverage, at that point it starts negotiating authentication parameters with the UMTS network from within the WLAN. After successful authentication, the WLAN allows the MN to start the second procedure, the Dynamic Host Configuration Protocol (DHCP) procedure, to obtain a temporary IP from the WLAN address space. At this stage, the MN is connected to the WLAN and the third procedure commences by negotiating mobility parameters with network entities or directly with the CN depending on the mobility solution employed as shown in the next section. The CN becomes aware of the change of the point of attachment of the MN and starts forwarding new packets through the new

path. Figure 1 shows the detailed steps of all the signaling procedures except for the mobility procedures which are described in the next section. The network entities shown in Figure 1 are detailed in [1] and the associated reference model is depicted in Figure 6.2a and Figure 6.2b of [1].

## III. MOBILITY SOLUTIONS

MIP, SIP, and mSCTP are the three mobility solutions that are most suitable for solving mobility issues in UMTS/WLAN integrated networks. The three solutions differ from each other in the operation layer, supported applications, the need to modify the network, and/or the need to modify the CN protocol stack as shown in TABLE I. The signaling procedures for all the solutions are shown in Figure 2 as extracted from the related standard documents and RFCs.

TABLE I. DIFFERENCE BETWEEN MOBILITY SOLUTIONS.

	Mobility Solutions		
	MIP	SIP	mSCTP
Operation Layer	Internet Layer	Application Layer	Transport Layer
Supported Applications	HTTP/FTP/ Streaming	Streaming	HTTP/FTP/ Streaming
Network Modification	HA and FA	SIP server	No network modification
Modification to CN protocol stack	Not required	Must support SIP	Must support mSCTP

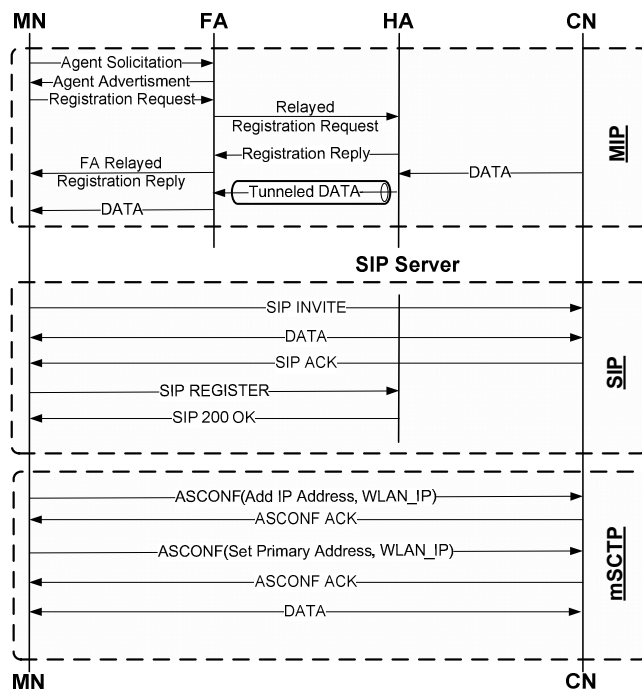


Figure 2. Signaling procedures for MIP, SIP, and mSCTP.

## IV. SIMULATION MODEL

The simulated network is based on the loose interworking architecture recommended by 3GPP [15]. The architecture shows how network entities are interconnected with each other

as shown in Figure 3. In our model we assume that T1 links are used to interconnect the Wireless Gateway (WG), the Wireless Access Gateway (WAG), and the Packet Data Gateway (PDG) located in the WLAN, the visited 3G networks, and the 3G home network, respectively, to convey data and signaling between the aforementioned networks. The 3GPP requires the MN to be authenticated using its UMTS Subscriber Identity Module (USIM) over Extensible Authentication Protocol based on Authentication and Key Agreement (EAP-AKA) or Extensible Authentication Protocol based on Subscribers and Identity Module (EAP-SIM). The 3GPP authentication requirement allows the MN to utilize the WLAN wireless connection to connect to its 3G packet based services such as multimedia. Therefore, the architecture includes a 3G AAA proxy located in the 3G visited network and a 3G AAA server located in the home 3G network. We assume that the DHCP is used to supply roaming subscribers with IPs from the WLAN address space. Since we are interested in the performance of 3G packet services supplied to the MNs during handoff, we assume that the CN is located in the 3G home network. Therefore, the HA in case of MIP and the SIP server in case of SIP are placed in the 3G home network.

OPNET [20] queues are utilized to construct a network of queues to simulate handoff from UMTS to WLAN for the prescribed interworking architecture. FIFO queues are used to represent communication links, while the service rate of the queues is set to represent the transmission speed of the links. Shared queues are used for shared media like LANs and WLANs. In the model we account for errors and retransmission effect on the communication links by reducing the raw transmission speed of the queue to an effective speed. For example, the effective speed of WLANs is 50% as reported in the literature [21].

OPNET processes are used to implement the network nodes functionalities to execute the required handoff signaling. For example, the processes of the MNs and DHCP implement the functionality of the DHCP based on the DHCP message exchange diagram as defined in [22]. A process may contribute to more than one procedure such as the MNs that contribute to all the signaling procedures.

We assume that the WLAN consists of 50 Access Points (APs) that covers a corporate building. The MNs connecting to the WLAN are split into two parts. The first part represents MNs served by one access point and is denoted as MNs. The second part corresponds to the MNs served by the remainder 49 APs and denoted as MNs\_Bulk. The total handoff delay and its components are measured as observed by MNs while the MNs\_Bulk merely generate background traffic. Therefore, there are two traffic sources that generate arrivals based on Poisson process. One source is connected to the MNs process to generate arrivals equivalent to one AP's subscribers and the other is connected to the MNs\_Bulk to generate arrivals equivalent to the traffic generated by the subscribers connecting to the remainder 49 APs.

Each arrival to MNs or MNs\_Bulk from the traffic sources triggers their process to start a handoff session to the WLAN network by executing authentication, DHCP, and mobility procedures. The size of all the messages that contributes to the

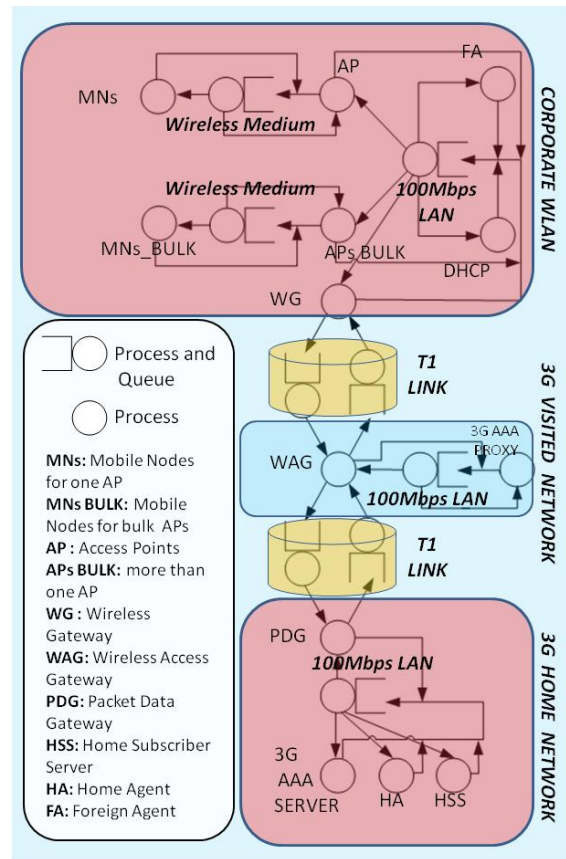


Figure 3. The Network of Queues model for 3G/WLAN integrated network[17].

handoff session procedures is obtained from related standards and RFCs to generate the load on the links they pass through. Part of the network links' capacities are reserved to account for the load generated by data streams in the network or background traffic that are not related to the handoff signaling.

## V. RESULTS AND ANALYSIS

The three mobility solutions, namely, MIP, SIP, and mSCTP are simulated in the aforementioned simulation model under the same conditions. The network is assumed to be 80% loaded and the WLAN is setup to support 2Mbps in the simulation model. The rate of handoff requests, denoted by  $\lambda$ , for roaming subscribers from UMTS to WLAN is varied from 1 to 75 requests per second. It is assumed that the roamers are evenly distributed between APs in the WLAN. The simulation model measures the delay that results from each procedure participating in the handoff. It measures the delay from the 3GPP AAA security procedure, DHCP procedure, Mobility procedure, and One Way as perceived by the MN. The total sum of these delays is the total handoff delay.

Figure 4 depicts the average handoff delay for MIP, SIP, mSCTP versus the arrival rate. It can be noticed that MIP and mSCTP produces less delays compared to SIP. SIP is an application layer protocol that uses text encoded messages to transfer control information between the peers. SIP messages



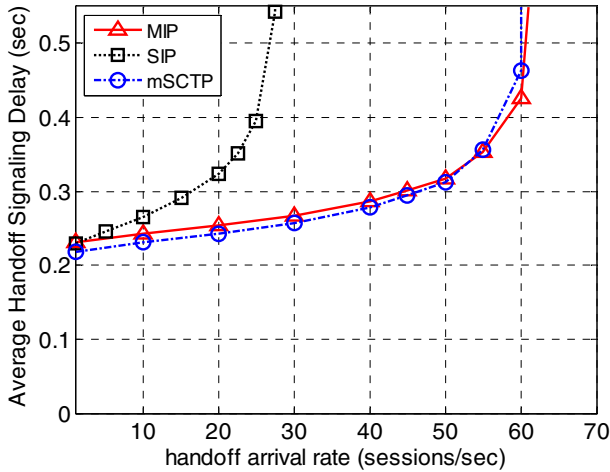


Figure 4. Handoff signaling delay utilizing MIP, SIP, and mSCTP.

are in the order of 2-3k bits. This causes an increase in the queuing and transmission times of SIP messages compared to MIP and mSCTP. For example, at  $\lambda = 20$ , the average handoff delay based on SIP is 324 msec while it is 253 msec and 242 msec for MIP and mSCTP, respectively. mSCTP produces less delay compared to MIP due to two reasons. First, mSCTP does not involve any network entities other than the communicating ends to conduct the mSCTP procedure whereas MIP relies on the FA and the HA. Second, mSCTP has only one message sent from MN to CN to inform it about its new location whereas MIP involves three messages as shown in Figure 2.

In addition, it is noticed that MIP and mSCTP show robust performance as the number of arrivals increase. At  $\lambda > 20$  SIP becomes unstable and the delay increases sharply while the delay due to MIP and mSCTP increases steadily to support up to 60 requests per second at which they become unstable. Hence, MIP and mSCTP can support more than twice the number of roamers supported by SIP while providing better service.

Figure 5 depicts the handoff delay components and their contributions for MIP, SIP, and mSCTP cases, respectively. The AAA shares starts from 42% for all the schemes. However, it increases rapidly with respect to the arrival rate in case of SIP as shown in Figure 6. Unexpectedly, the DHCP procedure also produces delays that are not less significant than those for the AAA. It generates up to 40% of the total handoff delay for all the schemes. The size of DHCP messages is in the order of 4k bits which results in generating these large delays. However, the DHCP delay remains almost constant as the number of arrivals increase since it is executed locally within the WLAN between the MNs and the WLAN DHCP server isolating it from external factors affecting the other procedures. Therefore, its share decreases as the number of arrivals increase as a result of the sharp increase in the other components shares. Other than the AAA and the DHCP components, the remainder of the handoff delay figure is distributed between the mobility solutions and the One Way delay.

One way to improve the total handoff delay is to reduce the DHCP share since it is limited to the WLAN and does not

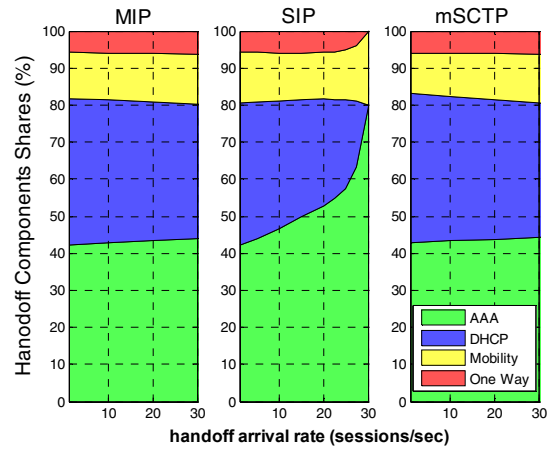


Figure 5. Weight of delay components relative to the overall handoff signaling delay for MIP, SIP, and mSCTP.

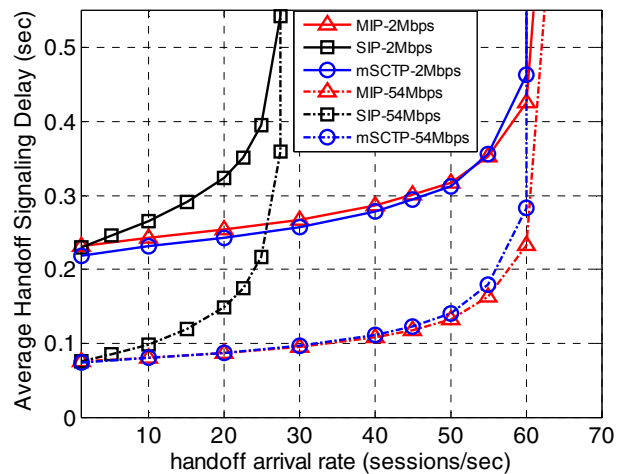


Figure 6. Comparing the total handoff delay with enhanced WLAN layout using 54Mbps WLANs

involve restrictions imposed by 3GPP. Increasing the supported AP rate at the edge of the corporate WLAN can reduce this delay significantly. This can be achieved by increasing the number of APs at the edges of the WLAN where we expect roamers from UMTS. In addition, decreasing transmission power of the AP at the edges would limit its radius and allow less number of roamers to exist at the same time. For example, when SIP is used as the mobility solution, an AP should not have on average more than one roamer every 2.5 sec. On the other hand, an AP should not have more than one roamer every 1 sec in case MIP and mSCTP are used.

Using high speed APs such as 54 Mbps, WLAN access speed reduces the DHCP delay which results in a significant decrease in the total average handoff delay as shown in Figure 6. For example, at  $\lambda=20$ , the SIP delay is reduced from 324 msec to 149 msec. Similarly, the average handoff delay for MIP and mSCTP is reduced from 253 msec and from 242 msec respectively to 86.1 msec. With such reduction in the total delay, all three solutions are able to satisfy the 3GPP 200 msec delay limit for at least low request arrival rates. Finally, Figure 7 presents the ratio of the average handoff delay to the

minimum acceptable 3GPP limit of 200 msec for 2Mbps and 54Mbps WLAN access speeds at  $\lambda = 20$  sessions per second. It can be noticed that for 54 Mbps WLAN access speed, both MIP and mSCTP produce delays that are less than the 3GPP limit whereas MIP and mSCTP using 2Mbps access produce delays that are two times the delay limit. Similarly, the ratio decreases for SIP from more than 300% with 2 Mbps to less than 150% with 54 Mbps.

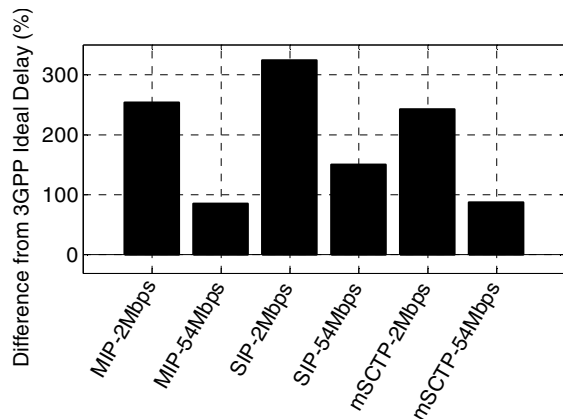


Figure 7. Ratio of handoff signaling delay based on MIP, SIP, and mSCTP relative to the 3GPP lower delay limit at  $\lambda = 20$  sessions per second.

## VI. CONCLUSION

In this paper, we analyze the performance of MIP, SIP and mSCTP as potential mobility solutions for 3G/WLAN integrated networks. The paper also quantifies the major delay components of the overall handoff delay for each of the solutions. This evaluation is obtained through the implementation of the corresponding signaling procedures from the related standards and RFCs documents for the adapted 3GPP UMTS/WLAN interworking architecture in the OPNET simulation environment. A side by side performance evaluation comparison is conducted amongst the three solutions. Simulation results show that MIP and mSCTP produce considerably less delay compared to SIP. In fact, MIP and mSCTP can support more than twice the handoff request rate that can be supported by the SIP solution for a threshold delay of 150 msec. The study provides a breakdown of the overall delay into the 3GPP AAA security component, the DHCP component, the mobility signaling component, and the One-Way delay component. The 3GPP AAA security component represents more than 42% of the total delay for all the considered configurations. Finally, it is shown that since DHCP transactions are local to the WLAN side, then a 50% reduction in the delay figure can be obtained by utilizing high WLAN access speeds.

## ACKNOWLEDGMENT

The authors acknowledge the support provided by King Fahd University of Petroleum and Minerals and the Saudi Telecom Company (STC).

## REFERENCES

- [1] I. Welling, J. Harno, F. Loizillon, K. Stordahl, D. Varoutas, "Techno-Economic Evaluation of 3G & WLAN Business Case Feasibility Under Varying Conditions", 10th International Conference on Telecommunications (ICT) 2003, vol. 1, pp. 33-38, 2003.
- [2] 3GPP, "Telecommunications and Internet Protocol Harmonization over Networks, QoS Class Specification," TS 101329-2, <http://www.3gpp.org/>
- [3] C. Perkins, "Mobile IP", *IEEE Communications Magazine*, Vol. 35, Issue 5, May 1997, pp. 84-99, 1997.
- [4] J. Rosenberg et al., "SIP: Session Initiation Protocol", IETF RFC 3261, Jun. 2002.
- [5] M. Riegel and M. Tuexen, "Mobile SCTP", Internet draft, draft-riegel-tuexen-mobile-sctp-09.txt, Nov. 2007, work in progress
- [6] G. Lampropoulos, N. Passas, L. Merakos, A. Kaloylos, "Handover Management Architecture In Integrated WLAN/Cellular Networks," *IEEE Communications Surveys & Tutorials*, vol. 7, no. 4, pp. 30-44, 2005.
- [7] Apostolis K. Salkintzis, "Interworking Techniques and Architectures For WLAN/3G Integration Toward 4G Mobile Data Networks," *IEEE Wireless Communications*, vol. 11, no. 3, pp.50-61, June 2004
- [8] S. Tsao, C. Lin, "Design and Evaluation of UMTS-WLAN Interworking Strategies", Vehicular Technology Conference 2002, vol. 2, pp. 777-781.
- [9] N. Sattari, P. Pangalos, H. Aghvam, "Seamless Handover between WLAN and UMTS", Vehicular Technology Conference 2004, vol. 5, pp. 3035-3038.
- [10] S. Park, D. Lee, S. Kim, J. Ihm, and S. Oh, "A Performance Evaluation of Handoff Method between WLAN and cdma2000 1x Ev-Do System" International Conference on Networking, International Conference on Systems and International Conference on Mobile Communications and Learning Technologies, Apr. 2006, p. 134-134.
- [11] Marc Cardenete-Suriol, Josep Mangués-Bafalluy, Marc Portoles-Comas, Manuel Requena-Esteso, Mónica Gorrioch, "VoIP Performance in SIP-Based Vertical Handovers Between WLAN and GPRS/UMTS Networks," Proceedings of The IEEE International Conference on Communications (ICC 2007), 24-28 June, Glasgow, pp. 1973-1978.
- [12] Nilanjan Banerjee, Wei Wu, Kalyan Basu, Sajal K. Das, "Analysis of SIP-Based Mobility Management in 4G Wireless Networks," *Computer Communications*, vol. 27, pp. 697-707, 2004.
- [13] Wei Wu, Nilanjan Banerjee, Kalyan Basu, Sajal K. Das, "SIP-Based Vertical Handoff Between WWANS and WLANS," *IEEE Wireless Communications*, vol. 12, no. 3, pp. 66-72, June 2005.
- [14] L. Ma, F. Yu, V. Leung, and T. Randhawa, "A new method to support UMTS/WLAN vertical handover using SCTP," *IEEE Wireless Communications*, vol. 11, no. 4, pp. 44-51, Aug. 2004.
- [15] 3GPP, Technical Specification Group Services and System Aspects; 3GPP system to Wireless Local Area Network (WLAN) interworking; System description (Release 7), 3GPP TS 23.234 v7.4.0 Dec. 2006.
- [16] A. Al-Helali, A. Mahmoud, T. Al-Kharobi, and T. Sheltami, "Analysis of Handoff Delay Components for Mobile IP-Based 3GPP UMTS/WLAN Interworking Architecture", The IEEE 23rd International Conference on Advanced Information Networking and Applications (AINA-09), Bradford, UK, May. 2009.
- [17] A. Al-Helali, A. Mahmoud, T. Al-Kharobi, and T. Sheltami, "Characterization of Vertical Handoff Delay for Mobile IP Based 3G/WLAN Integrated Networks", 2009 IEEE 69th Vehicular Technology Conference (VTC2009Spring), Barcelona, Spain, Apr. 2009.
- [18] Seamless Internetworking of WLANs and Cellular Networks: Architecture and Performance Issues In A Mobile IPv6 Scenario," *IEEE Wireless Communications*, vol. 12, no. 3, pp. 73-80, June 2005.
- [19] Sherali Zeadally, Farhan Siddiqui, "An Empirical Analysis of Handoff Performance for SIP, Mobile IP, and SCTP Protocols," *Wireless Personal Communications*, vol. 43: pp. 589-603, 2007.
- [20] OPNET Inc. <http://www.opnet.com>.
- [21] Av Jacob Benesty, M. Mohan Sondhi, Yiteng Huang,, "Springer Handbook of Speech Processing," in , p. 311.
- [22] IETF RFC 1541, "Dynamic Host Configuration Protocol," Mar. 1997.

## Analysis of Handoff Delay Components for Mobile IP-Based 3GPP UMTS/WLAN Interworking Architecture

Abdul-Aziz Al-Helali

Ashraf Mahmoud

Talal Al-Kharobi

Tarek Sheltami

Computer Engineering Department

King Fahd University of Petroleum &amp; Minerals

Dhahran, Saudi Arabia

{alhelali, ashraf, talalkh, tarek}@kfupm.edu.sa

**Abstract**—The integration of the widely spread 3rd Generation (3G) Universal Mobile Telecommunication System (UMTS) with the Wireless Local Area Networks (WLANs) has recently attracted considerable attention. However, addressing seamless and transparent handoff during mobility between these networks is still the biggest challenge to overcome. This paper evaluates the components of the handoff delay for the 3GPP UMTS/WLAN interworking architecture. We analyze the handoff delay components due to security procedures, Dynamic Host Configuration Protocol (DHCP), Mobile IP, and the one-way or data transfer delay. This study utilizes a simulation model comprised of network of queues to model the integrated networks at the packet level taking into account both signaling traffic and background loads. Simulation results show that the handoff delay component due to security procedures is the dominant relative to other components under the considered network parameters. In addition, results also reveal that this former component specifically, and the total handoff delay in general, are very sensitive to background load in the network.

**Keywords**- 3G/WLAN Integrated Networks; Heterogeneous Networks; Vertical Handoffs.

### I. INTRODUCTION

The 3rd Generation (3G) Universal Mobile Telecommunications System (UMTS) [1] and Wireless Local Area Networks (WLANs) [2] are spreading very rapidly. UMTS provides wide and continuous coverage but with low data rates. On the other hand, WLAN provides high data rates but with limited coverage. Although, they are heterogeneous wireless access networks, they possess complementary characteristics that can be exploited to the advantage of both UMTS and WLAN network operators and their subscribers. To achieve full integration between UMTS and WLANs, subscribers should be able to access UMTS data services such as streaming and multimedia from within the WLAN without sacrificing their security and privacy. In addition, UMTS operators must control subscribers' access from WLAN to UMTS data services based on their profiles and calculate usage charges as if the user is connecting from a UMTS network. To solve the diversity in the two technologies, the 3rd Generation Partnership Project (3GPP) has recently approved an interworking architecture between the UMTS and public WLANs which specifies the addition of new components and security procedures that

must be implemented in the UMTS and WLAN networks to support such integration [3]. UMTS subscribers must execute this security procedure when they connect from WLAN. Then, the users obtain an IP address from the WLAN address space through running the Dynamic Host Configuration Protocol (DHCP) [4] procedure. After that, the Mobile IP procedure works to transfer any ongoing sessions from the old connection point, i.e. the UMTS, to the new one, i.e. the WLAN. Therefore, roaming subscribers between UMTS and WLAN execute these procedures each time they switch from UMTS to WLAN. Unfortunately, these requirements increase the delay during handoff from UMTS to WLAN resulting in service deterioration and probably resetting any ongoing sessions if the delay is unacceptably high. This increased delay may render some internet services such as VoIP or interactive gaming infeasible.

Consequently, handoff delay is one of the main challenges to provide seamless roaming that can meet service requirements. Extensive investigations have been conducted to study the handoff delay due to Mobile IP in homogenous networks such as those in [5], [6], and [7]. Conversely, only few research efforts focused on the handoff delay in UMTS to WLAN interworked networks. In [8] and [9] the performance of a non standard interworking architectures between UMTS and WLAN is evaluated. The first architecture is based on Mobile IP while the latter does not require any mobility solution because the WLAN is considered as a micro cell in the UMTS coverage. Salkintzis *et al.* quantified the maximum number of UMTS roamers that the WLAN can service while maintaining the same UMTS QoS level in the WLAN [10]. In [11], an experimental set up is used to evaluate the handoff delay for Mobile IP and other mobility solutions but for a General Packet Radio Service (GPRS) / WLAN integrated network. Furthermore, the some of the performance figures related to Mobile IP are missing as indicated by Fig. 6 and Fig. 7 of [11].

All the previous research efforts either abstract the handoff delay as one component and/or analyze the performance of non standardized interworking architectures focusing only on mobility management overhead. In this paper we analyze the handoff delay for a standardized 3GPP UMTS/WLAN integrated network. We model the exact signaling procedures as prescribed by the corresponding

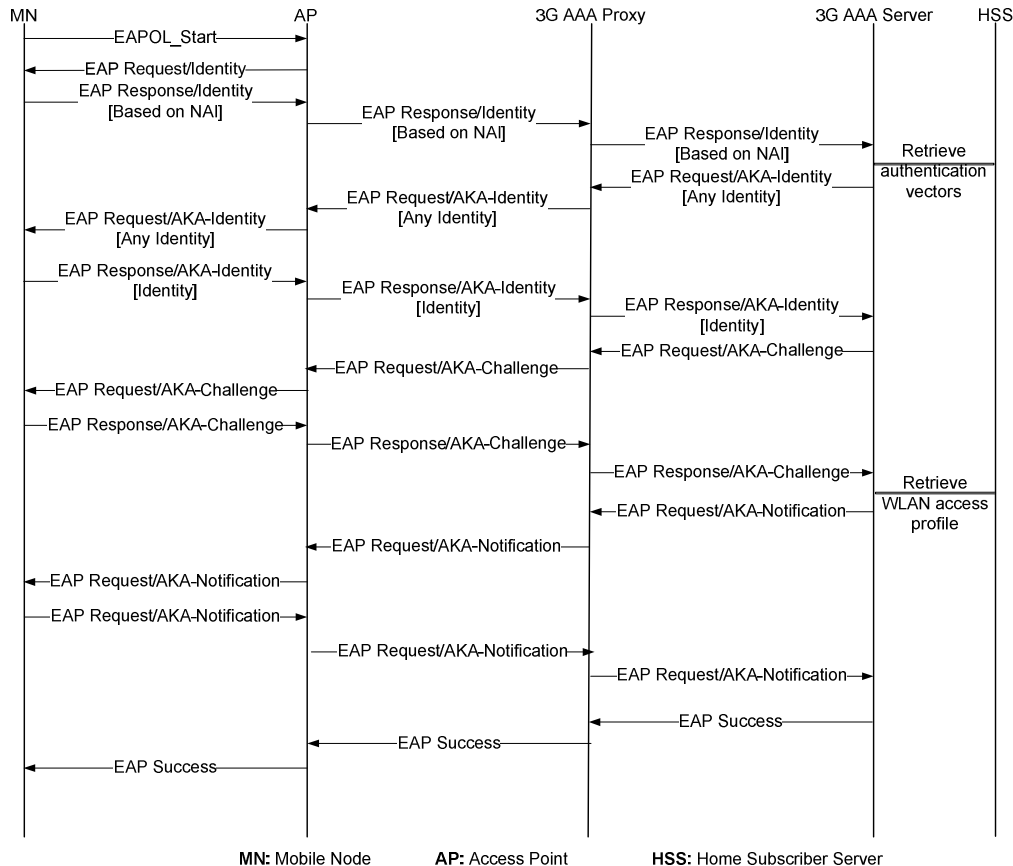


Figure 1: Security Signaling (AAA) Procedure.

protocols and provide a breakdown of the overall handoff delay figure into its individual components. To the best of the authors' knowledge, no previous study has analyzed the handoff delay components with the detailed signaling required for the security procedures as specified by 3GPP. To this end, we develop a simulation model that enables the evaluation of the handoff delay components due to security, DHCP and Mobile IP procedures as specified by the related protocols standards and Request For Comments (RFCs). The developed model can be extended to analyze the performance of other mobility solutions that may be considered in future studies.

The paper is organized as follows. Section II summarizes the UMTS to WLAN vertical handover with the relevant and implemented procedures. Section III details the network model used to evaluate the network performance as well as the parameters of the simulation setup, while section IV presents and analyzes the results obtained from the model. Finally, conclusions are presented in section V.

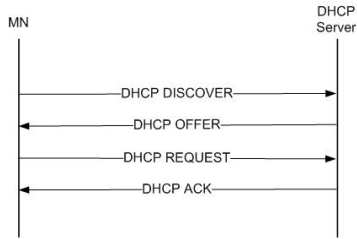
## II. UMTS TO WLAN VERTICAL HANDOVER

Roaming users from UMTS to WLAN need to execute a set of procedures to conduct a smooth handoff. Once in the coverage of the WLAN and before obtaining an IP, the Authentication, Authorization, and Accounting (AAA) security procedure commences on the WLAN as specified by the 3GPP. After a successful AAA procedure the WLAN

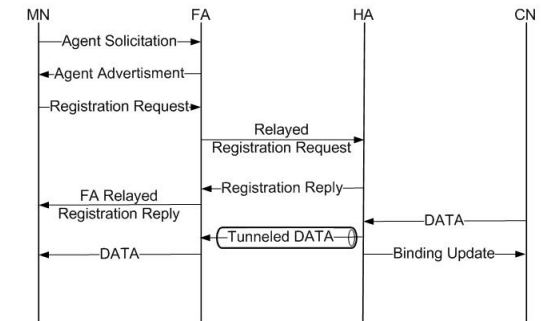
allows the Mobile Node (MN) to request a new IP using DHCP. When the MN obtains an IP from the WLAN address space, it establishes the Mobile IP procedure to transfer all the ongoing sessions to new point of attachment. The following elaborates on each of these procedures and shows the corresponding message sequence diagrams as specified in the related protocols' standards and RFCs.

### A. Authentication, Authorization, and Accounting Procedure.

In contrast to UMTS, WLANs are designed to provide simple wireless access that works as a wireless extension to Local Area Networks (LANs). Hence, they do not enforce the use of security or billing protocols by nature. In order to allow subscribers to access UMTS based services through WLANs, very strict authentication procedures are needed. The 3GPP has adopted the Extensible Authentication Protocol based on Authentication and Key Agreement mechanism (EAP-AKA) [12] or the Extensible Authentication Protocol based on Subscribers and Identity Module (EAP-SIM) [13] mechanism as the authentication methods for 3G and 2G subscribers, respectively. These protocols are prescribed for usage for authenticating subscribers connecting from WLANs [3]. However, EAP-AKA and/or EAP-SIM cannot be used as standalone protocols as these procedures need the services of other protocols for the authentication process to be completed.



MN: Mobile Node  
DHCP: Dynamic Host Configuration Protocol  
**Figure 2: DHCP Procedure**



MN: Mobile Node FA: Foreign Agent HA: Home Agent CN: Correspondent Node  
**Figure 3: Mobile IP Procedure**

Figure 1 shows the AAA signaling where EAP-AKA/SIM messages are exchanged between the MN and the authentication server over EAP [14]. The EAP-AKA/SIM messages are carried in an 802.1x special frame called EAP over LAN (EAPOL) between the MN and the access point. This allows EAP messages to be sent over the LAN using the data link layer protocol since the MN may not possess an IP from the WLAN address space at this stage.

### B. DHCP

The MN needs an IP address in order to be able to send and receive packets from the WLAN. DHCP [4] is utilized for this purpose. After the MN is authenticated and its access is authorized from the 3G network, it sends a DHCP discover message to find any available DHCP servers in the WLAN network. The DHCP server in the WLAN will offer its services to the MN through a DHCP OFFER message. Subsequently, the MN requests an IP address from the DHCP server and the DHCP server assigns an IP address for the MN which can now communicate with the external networks. Figure 2 details the DHCP related transactions.

### C. Mobile IP

Mobile IP [15] works at the network layer. It allows mobility changes to be transparent for upper layers and therefore insure continuity of ongoing sessions. The MN should have a long term IP address on a home network which is the UMTS network in our scenario. This IP address is used as the source address of all IP datagrams going out of the MN. On a foreign network, the WLAN in our scenario, the source IP address is not used. But rather a new IP address, referred to as the Care-of-Address (CoA), is acquired from the foreign network. To handle mobility functions between two networks, Mobile IP defines two new

components which are the Home Agent (HA) and the Foreign Agent (FA). The former is anchored in the home network while the latter may be a router in the foreign network.

Once the MN in WLAN coverage, it sends a solicitation to find out if there is a FA in the network as shown in Figure 3. The FA provides its IP address to the MN in an advertisement message to be used as CoA. The MN sends a registration request to the FA which in turn forwards it the HA. The HA replies to the FA which relays the reply message to the MN. Using Mobile IP, the MN sends datagrams to Correspondent Nodes (CNs) using its home address as the source address, while CNs sends datagrams to the MN using its home address as the destination address. These datagrams will arrive to the home network of the MN where the HA will intercept and tunnel them to the CoA of the MN. Typically, the FA will decapsulate the datagrams and forwards them to the MN via layer two addressing.

## III. MODELING AND SIMULATION SETUP

This paper attempts to evaluate the following delay components:

**AAA Delay:** the time required for the MN to complete the AAA procedure.

**DHCP Delay:** the time required for the MN to complete the DHCP procedure.

**Mobile IP Delay:** the time required for the MN to complete the mobile IP signaling procedure.

**One Way Delay:** the time needed for the first packet sent by the CN to arrive to the MN through the new enabled interface after the MN completed the handoff procedures.

**Total Handoff Delay:** It is the cumulative sum of all the delay components mentioned above.

In order to simulate a realistic case, we assume a corporate WLAN network that is integrated with a UMTS network as specified by the loose interworking architecture accepted by 3GPP [16]. With this integration scheme, UMTS subscribers can access their home network services from the WLAN via another UMTS operator's network referred to by the 3G visited network. Therefore, the interworking architecture consists of three networks as shown in Figure 4: the corporate WLAN, the visited 3G network, and the home 3G network. The model assumes that the former two networks are connected to each other via a T1 links.

The corporate WLAN consist of 50 access points connected to 100Mbps LAN. In addition, a DHCP server is attached to the WLAN to provide WLAN users with IP addresses from the WLAN address space. To support user mobility between UMTS and WLAN, a Foreign Agent (FA) is connected to the LAN. The corporate WLAN is interfaced to the UMTS network through the Wireless Gateway (WG).

The model depicted in Figure 4 considers only the UMTS or WLAN entities that are relevant to the vertical handover evaluation. Hence, we include a WAG and a 3G AAA proxy in the 3G visited network, and a Home Subscriber Server (HSS), an HA, a 3G AAA server, and a Packet Data Gateway (PDG) in the 3G home network. The distribution media that connects these components in both networks is assumed to be 100Mbps LANs.

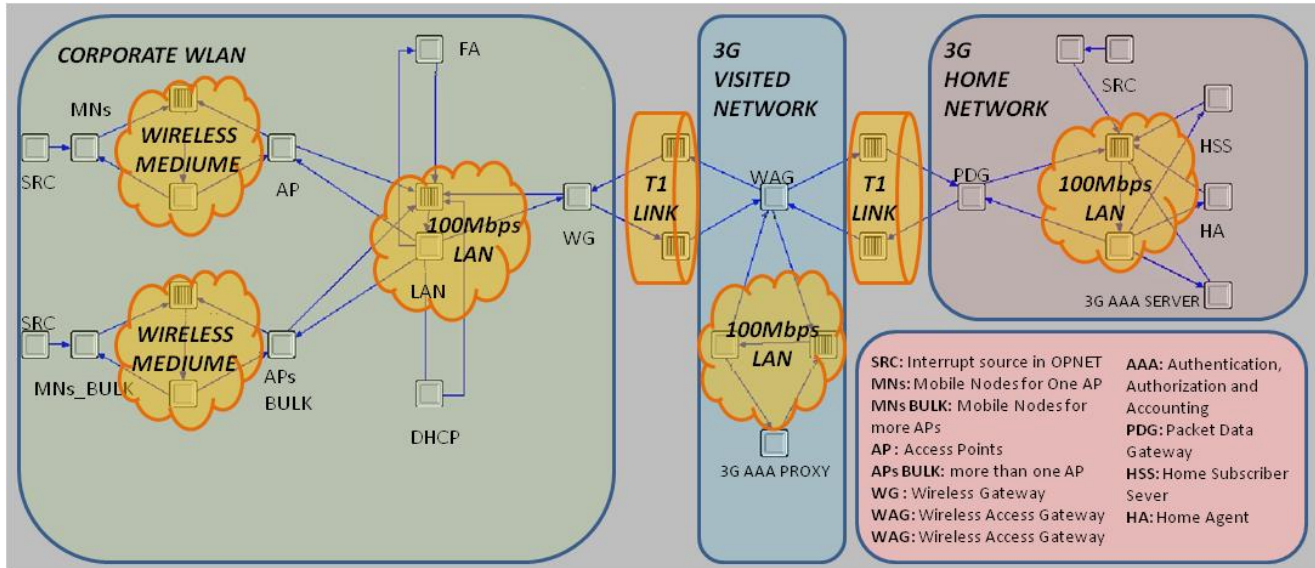


Figure 4 : The OPNET model implementation using network of queues for 3G/WLAN integrated network.

To facilitate execution of the simulation model, we restrict the analysis to be at the packet level by abstracting the details of the lower layers. However, we compensate for this by reducing the transmission rate of each link by a factor.

The model is built utilizing OPNET Modeler 11.5[17] where we construct a network of queues and processes to represent the interworking architecture as shown in Figure 4. In the model, there are nodes and links. The nodes are the communicating ends that initiate and reply to incoming packets based on the prescribed procedures that they participate in. For example, the mobile nodes denoted by MNs in Figure 4 represent a set of users that are served by the access point (AP). To control the handoff arrival rate to the WLAN, the MNs process generates handoff sessions according to a Poisson process with arrival rate  $\lambda$ . Each handoff session consists of a AAA procedure, a DHCP procedure, and a mobility procedure. These procedures correspond to the actual protocols and standards found in the literature. The packets are created and exchanged between nodes based on these procedures. The packets' sizes are calculated to reflect the load that a transaction will present to the network as it is exchanged between the communicating nodes. Each transaction will introduce a load in the network based on the packet size which is the sum of the all the headers and control data from the data link layer and above. Hence, each node decides the size of the packet to be transmitted based on the procedure, the carrying protocols and the link type. That is the same packet will have different sizes as it traverses across different link types along the prescribed path.

The links are implemented using FIFO queues with infinite capacity. The service rate of each queue is a function of the link speed and type. For example, a LAN is represented by a shared queue that has a service rate of 100Mbps. In the same manner, the wireless medium provided by access points is represented by a queue that has

a service rate of 2, 11, or 54Mbps based on the scenarios considered in this study.

Given that each AP can serve only a limited number of users, we divided the WLAN into two parts: the first is represents by a single access point and its served users. This is denoted by AP in Figure 4. The second part corresponds to Bulk access points and their served users. This part is denoted by AP\_Bulk in Figure 4. Finally, we assumed that all access points are equally loaded on average which is a valid assumption in a very well designed WLAN. The AP\_Bulk is used to generate the background traffic that corresponds to 49 APs in the WLAN. This is done to improve the accuracy of delay modeling and decrease the simulation running time.

#### IV. RESULTS AND ANALYSIS

In this section, we discuss the performance results for our simulation model of the 3GPP UMTS/WLAN integrated network. For all the results, we assume that the WLAN is 802.11b due to its wide deployment in access points and user equipments. Therefore, the WLAN data rate is set to 11Mbps.

To analyze the effect of the network load and handoff rates on delay, the simulation is run under network background loading of 20, 50, and 80 percent while varying the arrival rate of handoff sessions,  $\lambda$ , from 5 to 200 arrivals per second. Figure 5 shows the average total handoff delay versus the handoff arrival rates. It is clear that the total handoff delay increases as the handoff arrival rate increase. The total handoff delay increases exponentially when the network load is 50 percent and 80 percent as the handoff arrival rate reaches 160 and 60 arrivals per second, respectively. Since the acceptable handoff delay values ranges from 100 ms to 200 ms [18], for the specified configuration the interworked networks can serve up to 160 roamers per second for moderate background load of 50%. However, under high network background load, i.e. 80%,

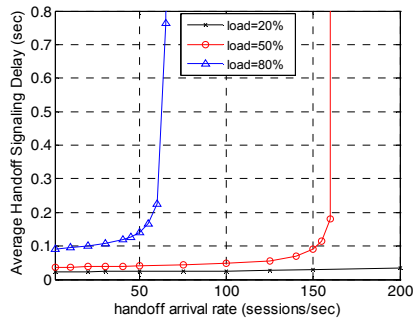


Figure 5: The Total Handoff Delay under Different Network Utilizations.

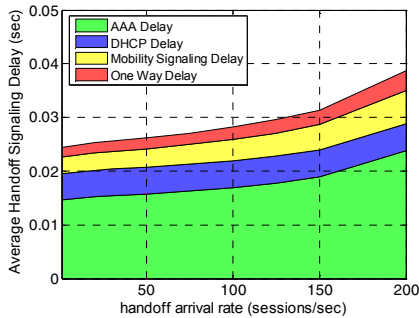


Figure 6: Break Down of Total Handoff Signaling Delay When Network Load is 20%

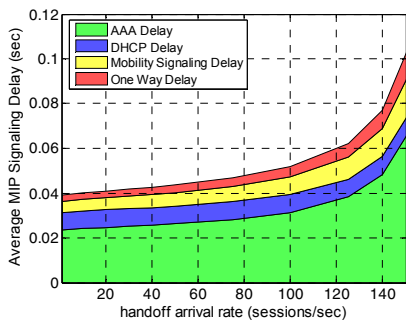


Figure 7: Break Down of Total Handoff Signaling Delay When Network Load is 50%

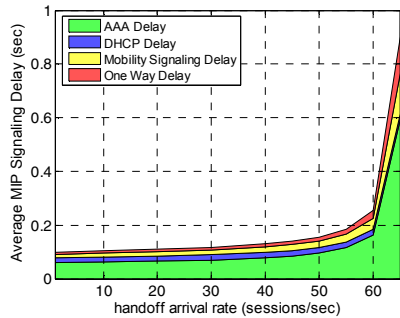


Figure 8: Break Down of Total Handoff Signaling Delay When Network Load is 80%

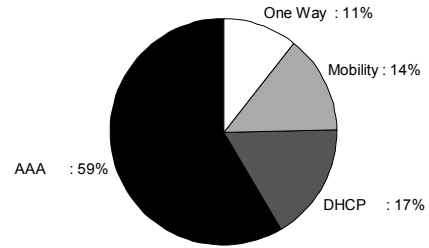


Figure 9: Comparing the Components of the Total Handoff Delay for Mobile IP for 802.11b WLAN at  $\lambda=30$  and load=80.

only 60 roamers per second can be admitted without exceeding the handoff delay threshold.

Figures 6, 7, and 8 present the handoff delay breakdown for network background loads of 20, 50, and 80 percent, respectively. The components are presented in all the figures from bottom in the following order: AAA delay, DHCP delay, Mobility delay, and the one-way delay. It is noticed that the AAA delay dominates all the other delay components. In addition, it is the most sensitive component to the arrival rate especially at high network background load. On the other hand, the other delay components appear to be less affected. This is due to the fact that numerous exchanged packets for the AAA procedure have to cross from the corporate WLAN all the way through the T1 links to and from the 3G home network. On the other hand, all the signaling for DHCP is confined to the corporate WLAN, while only two of the four messages for Mobile IP signaling have to pass by the aforementioned T1 links.

For further insight into the relative size of different delay components, Figure 9 shows the relative composition of the handoff delay figure for an arrival rate of 30 requests per second while the network background load is at 80%. The AAA signaling delay comprises 59% of the total handoff delay, while DHCP, Mobile IP, and one-way delay produce 17%, 14%, and 11%, respectively, of the overall figure. The obtained breakdown of delay components serve not only to depict the procedures that contribute the most to the overall handoff delay, but also to identify potential enhancements to the handoff procedure. For example, one can reduce the overall delay by about 17%, for parameters of Figure 9, if the DHCP release time is extended.

## V. CONCLUSION

Handoff is a critical process in UMTS/WLANs integrated networks. Handoff delay in the 3GPP UMTS/WLAN interworking architecture is analyzed in this paper with the goal to provide a comprehensive understanding of the handoff delay components when considering the 3GPP requirements. The different components have been described and their corresponding message sequence diagrams are extracted from related protocols, standards, and RFCs. Four components are identified and described that contributes to the total handoff delay which are the security, DHCP, Mobile IP and data

transfer. A simulation model is developed to study the delay due to these components. In addition, the effect on the delay due to the increase in network load and number of roamers is analyzed. Simulation results show that the AAA delay is the dominant compared to the other components. In fact it can cause up to 59% of the overall handoff delay at some configurations. Moreover, we found that the total handoff delay is very sensitive to the capacity of the link connecting the 3G visited network with the Corporate WLAN.

#### ACKNOWLEDGMENTS

The authors acknowledge King Fahd University of Petroleum and Minerals for support in the course of this research.

#### REFERENCES

- [1] B. Walke, P. Seidenberg, and M. Althoff, *UMTS - the fundamentals*, Wiley, 2002
- [2] *Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, IEEE standard 802.11, edition 1999.
- [3] 3GPP, Technical Specification Group Services and System Aspects; 3GPP system to Wireless Local Area Network (WLAN) interworking; System description (Release 7), 3GPP TS 23.234 v7.4.0, Dec. 2006.
- [4] IETF RFC 1541, "Dynamic Host Configuration Protocol", Mar. 1997.
- [5] S. Sharma, Z. Ningning and C. Tzi-cker, "Low-latency mobile IP handoff for infrastructure-mode wireless LANs", *IEEE Journal on Selected Areas in Communications*. vol. 22, iss. 4, pp. 643-652, May 2004.
- [6] M. Dell'Abate, M. De Marco and V. Trecordi, "Performance evaluation of mobile IP protocols in a wireless environment", *IEEE International Conference on Communications*, pp. 1810 – 1816, Jun. 1998.
- [7] N. Fikoura *et al.*, "Performance of TCP and UDP During Mobile IP Handoffs in Single-Agent Subnetworks", *IEEE Wireless Communications and Networking Conference*, pp. 1258- 1262, Sep. 1999.
- [8] S. Tsao and C. Lin, "Design and Evaluation of UMTS-WLAN Internetworking Strategies", *Proceedings of IEEE Vehicular Technology Conference*, vol. 2, pp. 777-781, 2002.
- [9] S. Tsao and C. Lin, "VGSN: a gateway approach to interconnect UMTS/WLAN networks", *The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, vol. 1, pp. 275-279, Sep. 2002.
- [10] A.K. Salkintzis *et al.*, "Seamless Continuity of Real-Time Video Across UMTS and WLAN Networks: Challenges and Performance Evaluation", *IEEE Wireless Communications*, vol. 12, pp. 8-18, Jun. 2005,
- [11] S. Zeadally, F. Siddiqui, "An Empirical Analysis of Handoff Performance for SIP, Mobile IP, and SCTP Protocols," *Wireless Personal Communications*, vol. 43: pp. 589-603, 2007.
- [12] IETF RFC 4187, "Extensible Authentication Protocol Method for 3rd Generation Authentication and Key Agreement (EAP-AKA)", Jan. 2006.
- [13] IETF RFC 4186, "Extensible Authentication Protocol Method for Global System for Mobile Communications (GSM) Subscriber Identity Modules (EAP-SIM)", Jan. 2006.
- [14] IETF RFC 3748, "Extensible Authentication Protocol (EAP)", Jun. 2004.
- [15] C. Perkins, *Mobile IP Design Principles and Practices*, Addison-Wesley, 1998.
- [16] 3GPP, "Feasibility Study on 3GPP System to WLAN Interworking," Tech. rep. 3GPP TR 22.934 v7.0.0, Jun. 2007.
- [17] OPNET Inc. <http://www.opnet.com>.
- [18] 3GPP, "Telecommunications and Internet Protocol Harmonization over Networks, QoS Class Specification," TS 101329-2, 2002.



# Characterization of Vertical Handoff Delay for Mobile IP Based 3G/WLAN Integrated Networks

Abdul-Aziz Al-Helali

Ashraf Mahmoud

Talal Al-Kharobi

Tarek Sheltami

Computer Engineering Department

King Fahd University of Petroleum &amp; Minerals

Dhahran, Saudi Arabia

{alhelali, ashraf, talalkh, tarek}@kfupm.edu.sa

**Abstract**—Mobile IP is one of the popular mobility solution and a viable candidate for the Beyond 3rd Generation (B3G) networks such as the integrated 3rd Generation Universal Mobile Telecommunications System (UMTS) and the Wireless Local Area Networks (WLANs). Mobile IP has many configuration and enhancements that are proposed by IETF such as the Care-of-Address (CoA), Collocated CoA, Mobile IPv6, and route optimizations. In this paper, we present a side-by-side performance evaluation and comparisons of the UMTS to WLAN handoff delay that results from using each configuration in the lately adopted UMTS/WLAN interworking architecture by 3GPP. In addition, we analyze the delay components due to 3GPP security and Internet protocol integration requirements. Simulation results show that under low network loading all configurations yield similar performances. However, Mobile IP with IPv6 configuration is more sensitive for network loads and wireless access speeds. In fact, it produces the highest delay figures at high load. Moreover, 3GPP security procedures contribute to more than 60% of the handoff delay for all the configurations.

**Keywords** - 3G/WLAN Integrated Networks; Heterogeneous Networks; Vertical Handoffs.

## I. INTRODUCTION

The accelerated deployment of Universal Mobile Telecommunications System (UMTS), a third generation (3G) network, and the widespread use of wireless local area networks (WLANs) present an ideal opportunity to integrate these two technologies to exploit the best of them as they complement each other [1]. UMTS provides an always available coverage with limited data rates and charged services. On the other hand, WLANs provide very high data rates, almost free of charge but with restricted coverage. Hence, the two technologies form a perfect pair.

A large body of literature has presented solutions for interworking such heterogeneous networks as the studies in [2]-[5] and the references therein. These studies mostly focus on the network architecture and the technology identified for solving the mobility issue. A critical issue for any interworking solution is the support of session continuity and seamless connectivity as perceived by the user. A user moving from the 3G network to the WLAN or vice versa should be able to switch established sessions from the old point of attachment to the new one, and should not experience unacceptable handoff delays that result from security and mobility requirements. Three dominant solutions have been recognized as potential solutions for handling user mobility. These solutions are:

Mobile IP (MIP), Session Initiation Protocol (SIP), and mobile Stream Control Transmission Protocol (mSTCP). Due to its compatibility and wide acceptance, Mobile IP is considered a viable solution for Beyond 3<sup>rd</sup> Generation (B3G) networks.

Few studies in the literature have focused on the performance of integrated networks and even fewer attempted to characterize the corresponding handoff delay based on Mobile IP and analyze its components. Examples of such recent studies can be found in [6]-[9]. The study in [6] and [7] provides an analytic model for characterizing the handoff delay utilizing a simplistic one-branch feed-forward network of M/M/1 queues focusing on the performance of the General Packet Radio Service (GPRS) air interface as a function of frame error rates. The study shows that wireless access, one component of handoff delay, is mainly constant as the study abstracts the Internet by a single fixed delay number. Again, Cardenete-Suriol et al. in [8] show that delays associated with the air interface switching are no more than 8% of the total handoff delay for the UMTS case. In [10] and [11] handoff delay is analyzed for UMTS to WLAN interworking architecture. However, the study assumes a general interworking architecture that is not standardized and does not fulfill the 3GPP interworking requirements. For example, in [9] and [10] the evaluation is conducted for Mobile IP while in [11] the proposed architecture does not use any mobility solution as it considers the WLAN cell as a micro cell inside the UMTS coverage.

The work in this paper evaluates the performance of Mobile IP (MIP) as a viable option for handling mobility in integrated networks utilizing the 3GPP approved 3G/WLAN interworking architecture as specified by [12]. A roaming scenario is considered in this work, while we evaluate different MIP configurations such as MIP with Care-of-Addresses (CoA), MIP with Collocated Care-of-Addresses (CCoA), MIP over IPv6, and MIP with and without route optimizations [13]. Unlike the aforementioned performance studies, this study considers the 3GPP requirements for the mobile authentication, authorization and accounting (AAA) to provide such integration. In addition, to best of authors knowledge, no study thus far provides analysis of the handoff delay where major components other than the two indiscriminate air interface and non-air interface components are identified. Therefore, the main motivation of this paper is to evaluate handoff delays taking into account all different MIP configurations and all the required signaling procedures, especially those pertaining to the

handoff signaling involving the authorization and authentication process.

The rest of this paper is organized as follows. In section II vertical handoff delay is discussed. Next, Mobile IP configurations and enhancements are presented in section III, while we elaborate on the simulation model used for the performance evaluation in section IV. Section V presents and analyzes the obtained simulation results. Finally, the paper is concluded in section VI.

## II. VERTICAL HANDOFF DELAY

The total handoff delay is the sum of four delay components, namely the AAA, Dynamic Host Configuration Protocol (DHCP), Mobile IP (MIP), and the One-Way (OW) delay. That is:

$$\text{Total handoff delay} = \text{AAA} + \text{DHCP} + \text{MIP} + \text{OW} \quad (1)$$

The AAA delay results from executing the mandatory security procedure shown in Fig. 1 each time the mobile node (MN) wishes to switch to WLAN. The procedure is a major requirement by 3GPP [12]. The delay due to DHCP procedure enables the MN to obtain a temporary IP from the WLAN address space and to start IP connectivity with the WLAN network. The MIP delay is the time required to perform the Mobile IP signaling procedure. The last component of the total handoff delay is the one-way delay which is the time needed for the first data packet sent by the Correspondent Node (CN) to reach the MN through the new path.

## III. MOBILE IP CONFIGURATIONS AND ENHANCMENTS

IP Routing requires that the node's IP uniquely identifies its point of attachment such that packets can be routed properly. Since mobile devices tend to change their point of attachment from 3G to WLAN and from WLAN to 3G, all ongoing sessions may be disconnected. Mobile IP is proposed by Internet Engineering Task Force (IETF) as an extension to Internet Protocol (IP) to address the routing problem due to change of IP while roaming between networks with different subnets. It realizes user mobility without the need to disseminate host-specific routes all over the Internet routing fabric.

Mobile IP associates with the MN a permanent IP address from the home network, the 3G network in our scenario, and a temporary address, called Care-of-Address that is obtained from the foreign network, which is the WLAN in our scenario. To manage Mobile IP functions in home and foreign networks, Mobile IP identifies two new entities: the Home Agent (HA) and the Foreign Agent (FA). Fig. 2, Fig. 3, and Fig. 4 present the messages sequence diagrams for the three standardized Mobile IP configurations: the MIP with CoA, MIP with CCoA, and MIP with IPv6. In this section we highlight the differences between these configurations and also Mobile IP enhancements. Interested readers may refer to [13] for more details.

In MIP with CoA configuration, the FA provides its IP address to MNs in the advertisement message to be used as a CoA. This mechanism is suitable for large networks where

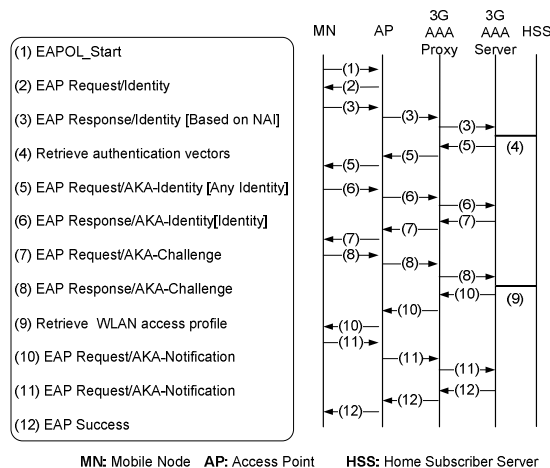
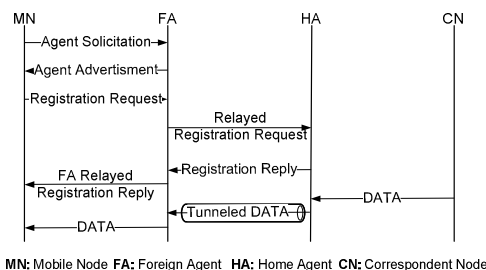
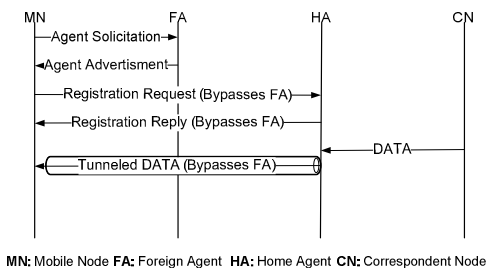


Figure 1. WLAN access authentication and authorization signaling procedure.



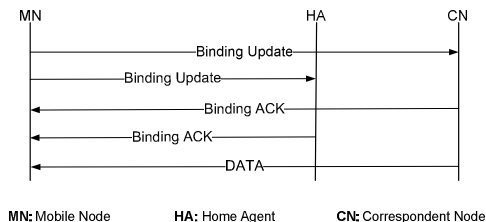
MN: Mobile Node FA: Foreign Agent HA: Home Agent CN: Correspondent Node

Figure 2. MIP with CoA signalling procedure.



MN: Mobile Node FA: Foreign Agent HA: Home Agent CN: Correspondent Node

Figure 3. MIP with CCoA signalling procedure.



MN: Mobile Node HA: Home Agent CN: Correspondent Node

Figure 4. Mobile MIP with IPv6 signalling procedure.

scalability matters. In this case the FA will be the end of the tunnel, where it has to de-encapsulate all the tunneled datagrams from the HA and forward them to the MN via layer 2 addressing as shown in Fig. 2. On the other hand, the MN uses its temporary IP obtained from the foreign network as CoA in the MIP with CCoA Configuration. This IP could be an IP assigned to MN by DHCP. Here, as depicted in Fig. 3, the MN will be the end of the tunnel where it has to take care of de-encapsulating all the datagrams and forwarding them to the

upper layer. In this case there is no need for a FA. Considering Fig. 2 and Fig. 3, we notice that the MN saves some time in the CCoA configuration by bypassing the FA. Similarly, the MN can reduce the delay of data packets coming from the CN by utilizing the route optimization extensions. Route optimization extensions are part of mobile IP to solve the triangular routing problem. This occurs when the CN sends datagrams to a MN that is not in its home network and the HA has to intercept the datagrams and to tunnel them to the current CoA of the MN. The route optimization extensions minimize this problem by providing means for CNs to maintain a binding cache that contains a list of CoAs of the MNs that it is communicating with. The HA sends a binding update carrying the new MN's CoA to the CN when it intercepts the first datagram sent by the CN to the MN. The CNs then tunnels datagrams to the current CoA of the MN in the same manner as the HA. In contrast to previous configurations that run on top IPv4, IETF has designed a new version of Mobile IP called Mobile IPv6 that utilizes the capabilities of the new Internet Protocol version 6 (IPv6) and attempts to resolve the shortcomings of its predecessor. FAs are eliminated in Mobile IPv6 since their functions can be performed with help of IPv6 in both of the MNs and CNs [13].

#### IV. SIMULATION SETUP

The 3GPP UMTS/WLAN loose interworking architecture with roaming scenario [12] is adopted in our simulations as shown in Figure 5. The network consists of three integrated networks: a corporate WLAN, a visited 3G network, and a home 3G network with a 100 Mbps LAN as distribution media. In the simulation we consider all the UMTS and WLAN entities that contribute to the handoff process being studied. The Wireless Gateway (WG) in the WLAN, the Wireless Access Gateway (WAG) in the visited 3G network, and the Packet Data Gateway (PDG) interface the three networks to each other via T1 WAN links with 1.54 Mbps. The authentication, accounting, and authorization (AAA) is accomplished by cooperation between the APs, the 3G AAA proxy, the 3G AAA server, and the Home Subscriber Server (HSS) to allow the UMTS subscribers to access their home 3G network services from within the WLAN via another 3G operator. The IP management in the WLAN is done by the DHCP. To support mobility, the WLAN is considered as the foreign network and installs a FA server. On the other hand, the home 3G network is assumed to be the home network and provides Mobile IP home services via an HA server.

A simulation model is developed that closely matches the main core network entities and their connecting links involved in the handoff procedure for integrated networks. The model is implemented in OPNET using a network of queues and servers where exchanged messages are represented by packets that traverse prescribed paths. The model aims to approximate the average handoff delay and its various components described in the section II. Network entities are implemented using OPNET processes. Packet arrivals to a process causes an interrupt that awakes the process from the waiting state and forces it to enter the active state. The active state defines how an entity processes the packet arrival and also specifies the

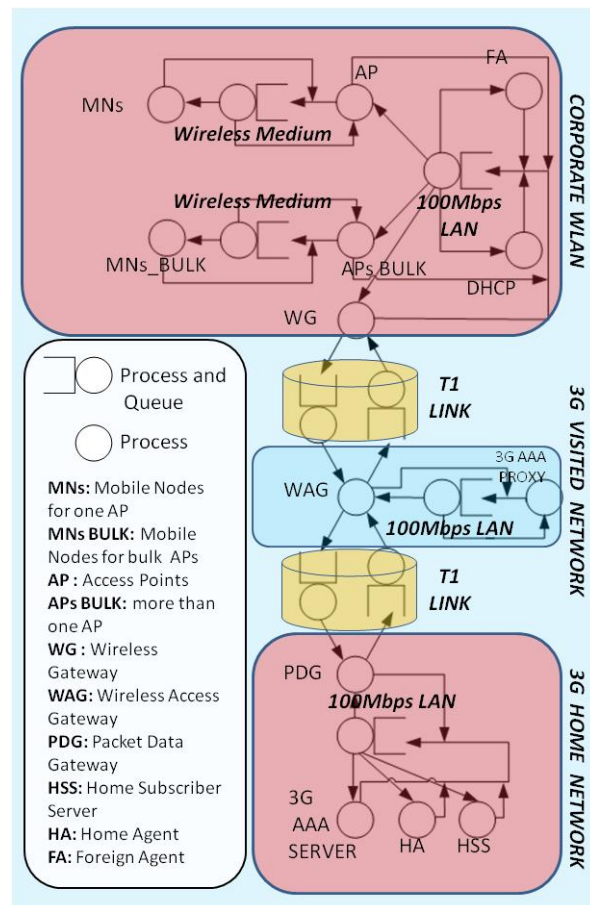


Figure 5. The Network of Queues model for 3G/WLAN integrated network.

subsequent transactions. For example, the process for a router entity may just route packets to the proper output port after it extracts the old Data Link (DL) headers and adds the new DL headers as is the case for the WG entity. However, for more complex entities such as the 3G AAA server node, it will select the proper response message based on the message sequence diagram. For all exchanged messages, the true sizes in bytes, as defined by the corresponding RFCs and standards documents, are used in the simulation to manifest the offered load by handoff requests. Finally, OPNET queues and servers are used to model links. A link is implemented using a FIFO queue with infinite capacity and fixed service rate that reflects the transmission speed of that link. Shared queues are used to represent shared links such as LANs and wireless media.

The handoff sessions are generated by the MNs and the MNs\_Bulk according to a Poisson Process with arrival rate  $\lambda$ . The arrival rate reflects the number of roaming subscribers joining the WLAN per second where we assume that the MNs are distributed evenly among access points. Each handoff session is composed of the execution of authentication procedure, DHCP procedure, and Mobile IP procedure in sequence. In our simulation model, we study the performance metrics as experienced by mobile nodes served by one access point denoted by MNs and AP, respectively, in Fig. 5. However, the rest of the MNs and APs in the corporate WLAN

are represented by  $MNs\_Bulk$  and  $APs\_Bulk$ , respectively, and generate a background handoff traffic equivalent to 49 access points' traffic. The data flows in the network other than the handoff sessions signaling data is represented by a background data traffic for which we reserve network capacity. The reservation is done for 20, 50, and 80 percent of network capacity to reflect variable network loading. Finally, to estimate the one-way delay, a real-time streaming application is assumed to run between the CN and the MN with a constant arrival rate of 1 packet per second. This allows the estimation of the one-way delay without loading the network. This approach is also used to evaluate delay components for the route optimization enhancements.

### V. RESULTS AND ANALYSIS

In this section, we compare the handoff delay from UMTS to WLAN based on different Mobile IP configurations under the same load conditions. The handoff arrival rates are varied from 1 to 200 arrivals per second, while the network loading (for background data traffic) is varied as low, moderate, and high and specified by 20%, 50%, and 80%, respectively.

The handoff delay for different configurations: MIP CoA, MIP CCoA, and MIP with IPv6 is shown in Fig. 6 assuming 11 Mbps WLANs. All three configurations produce roughly the same delay under the same network loading for low arrival rates, but MIP with IPv6 produces significantly higher delays for moderate and high arrival rates of requests. This is due to the larger packet header sizes associated with MIP IPv6 as opposed to that for IPv4 which is used in MIP CoA and MIP CCoA. Although MIP with IPv6 is carefully designed to avoid shortcomings of its predecessor, the large headers of IPv6 cause this increase in the delay. It is worth mentioning that the use of MIP IPv6 forces the MN to use IPv6 as the underlying internet protocol. As a result, all handoff signaling is conducted over IPv6 including the numerous AAA messages of the security procedure imposed by 3GPP.

Fig. 7 shows the corresponding handoff delay for all the schemes for various WLAN speeds as a function of the handoff requests arrival rate. The figure shows delays are around 100 msec for 11 Mbps and 54 Mbps WLANs, while it is 200-250 msec for low and moderate arrival rates assuming a network loading of 80%. The 3GPP has recommended that delays should ideally be less than 100 msec and should not exceed 200 msec [14]. Therefore, from Fig. 7 we can see that a 2 Mbps WLAN rate cannot fulfill this requirement even for very low handoff arrival rates. On the other hand, a 54 Mbps WLAN provides the optimal handoff delay compared to the other 11 Mbps which hardly allows 100 ms delay.

To explore the composition of the total handoff delay and the relative weight of the various delay components specified in (1), Fig. 8 plots the proportion of the AAA, DCHP, MIP, and OW delay components. The breakdown is done as a function of handoff request rate for the 11 Mbps WLAN access utilizing the MIP with IPv6 configuration under network loading of 80%. The figures corresponding to the breakdown for the other configurations, namely, the MIP with CoA and MIP with CCoA for the same 80% loading follow the same pattern of Fig. 8. The AAA procedure constitutes the major portion, ranging from 60% to 67% of the total delay for all the schemes.

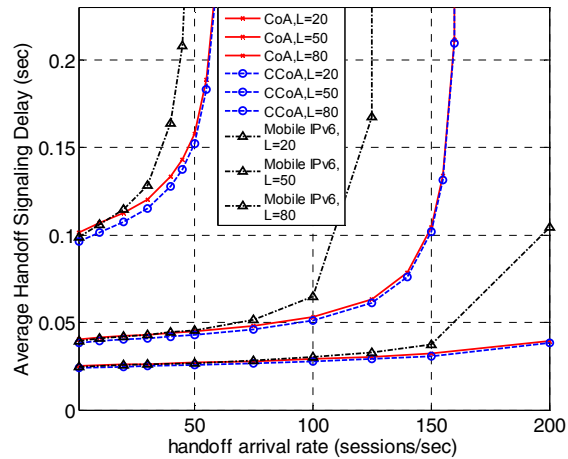


Figure 6. Handoff signaling delay utilizing Mobile CoA, CCoA and IPv6 configurations and for different network loads with 11 Mbps WLAN access.

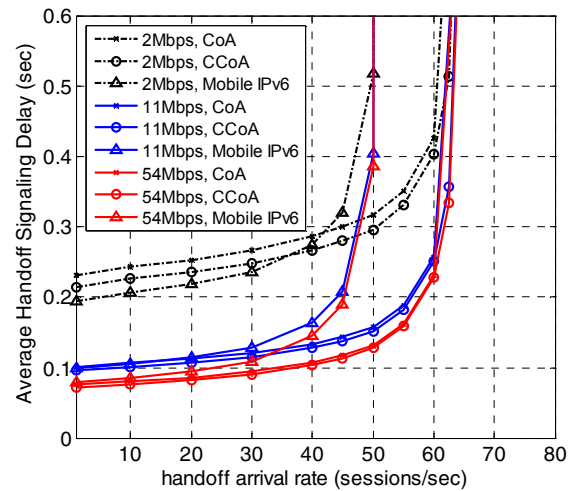


Figure 7. Handoff signaling delay utilizing Mobile CoA, CCoA and IPv6 configurations and for different WLAN speeds and network load of 80%.

Surprisingly, the DHCP constitutes up to 20% of the total handoff delay when the arrival rates are low although all its transactions are restricted to the local corporate network. This is due to the fact that some DHCP packets are very large, in the order of 4 kbits, such as the DHCP discover and request messages. However, the DHCP portion shrinks as the handoff arrivals increase due to the faster increase in the other delay components. For example, in Fig. 8 it reaches as low as 3% for 50 handoff arrivals per second. The MIP and the one-way delays start from 10% and 7%, respectively, at low arrival rates, but may contribute up to a maximum of 16% and 12%.

Finally, the effect of route optimization techniques when the CN is assumed to be in the MNs home network (i.e. 3G home) is shown in Fig. 11. The figure plots the one-way delay versus the handoff arrival rate as a function of handoff arrival rate when route optimization (RO) and non route optimization (NRO) configurations are used. The results show that the RO

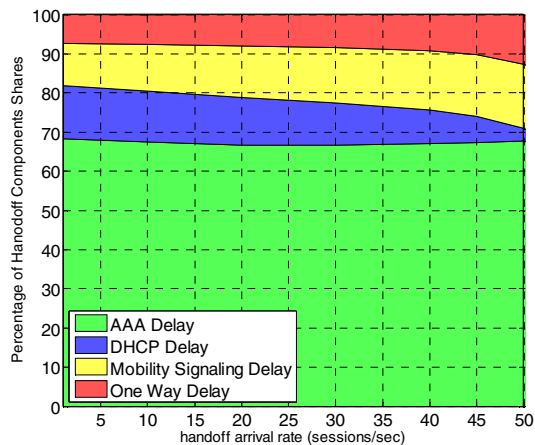


Figure 8. Weight of delay components relative to the overall handoff signaling delay for Mobile IP (IPv6 configuration) and with 11 Mbps WLAN access and network load is 80%.

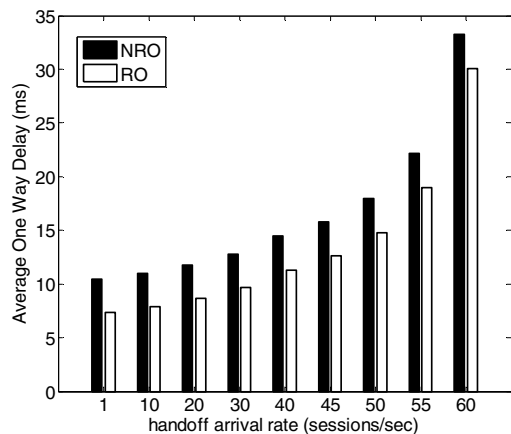


Figure 9. The one-way delay (OW) for route optimization (RO) and non route optimization (NRO) techniques for network load of 80% and 11 Mbps WLAN access.

technique is better than the NRO by about 3 msec which is anywhere from 3% to 1.2% of the total handoff delay. Hence, there is no significant impact on the one-way delay reduction on the total handoff signaling delay. However, when the CN node is to be outside the MN's home network, the one-way delay is expected to be more significant. Furthermore, route optimizations leading to reduced one-way delay improve the latency for the subsequent data packets flow from the CN to the MN.

## VI. CONCLUSION

This work quantifies the vertical handoff delay from UMTS to WLAN based on Mobile IP under various configurations and enhancements, namely, the MIP with CoA, MIP with CCoA, MIP with route optimization, and MIP with IPv6 configurations. Handoff delays for each configuration are compared to find the optimal Mobile IP configuration for 3GPP UMTS/WLAN integrated networks. In addition, we analyze the authentication and DHCP components that participate in the handoff delay. Simulation results show that all the

configurations produce similar handoff delays under low network loads. However, MIP with IPv6 is the most sensitive to network loading and high handoff arrival rates where it produces significantly higher delays as the load increases. In addition, the delay due to the imposed 3GPP security procedures constitutes more than 60% of the total handoff delay and reaches to 67% in the case of MIP with IPv6. Finally, the WLAN with 2 Mbps access speed cannot fulfill the 3GPP delay requirements of 100 msec even for very low arrival rates of handoff requests.

## ACKNOWLEDGMENT

The authors acknowledge King Fahd University of Petroleum and Minerals for its support.

## REFERENCES

- [1] I. Welling, J. Harno, F. Loizillon, K. Stordahl, D. Varoutas, "Techno-Economic Evaluation of 3G & WLAN Business Case Feasibility Under Varying Conditions", 10th International Conference on Telecommunications (ICT) 2003, vol. 1, pp. 33-38, 2003.
- [2] Apostolis K. Salkintzis, "Interworking Techniques and Architectures For WLAN/3G Integration Toward 4G Mobile Data Networks," *IEEE Wireless Communications*, vol. 11, no. 3, pp.50-61, June 2004
- [3] N. Sattari, P. Pangalos, H. Aghvham, "Seamless Handover between WLAN and UMTS", Vehicular Technology Conference 2004, vol. 5, pp. 3035-3038.
- [4] S. Tsao, C. Lin, "Design and Evaluation of UMTS-WLAN Interworking Strategies", Vehicular Technology Conference 2002, vol. 2, pp. 777-781.
- [5] G. Lampropoulos, N. Passas, L. Merakos, A. Kaloxylas, "Handover Management Architecture In Integrated WLAN/Cellular Networks," *IEEE Communications Surveys & Tutorials*, vol. 7, no. 4, pp. 30-44, 2005.
- [6] Nilanjan Banerjee, Wei Wu, Kalyan Basu, Sajal K. Das, "Analysis of SIP-Based Mobility Management in 4G Wireless Networks," *Computer Communications*, vol. 27, pp. 697-707, 2004.
- [7] Wei Wu, Nilanjan Banerjee, Kalyan Basu, Sajal K. Das, "SIP-Based Vertical Handoff Between WWANS and WLANS," *IEEE Wireless Communications*, vol. 12, no. 3, pp. 66-72, June 2005.
- [8] Marc Cardenete-Suriol, Josep Mangués-Bafalluy, Marc Portoles-Comeras, Manuel Requena-Esteso, Mónica Gorriacho, "VoIP Performance in SIP-Based Vertical Handovers Between WLAN and GPRS/UMTS Networks," Proceedings of The IEEE International Conference on Communications (ICC 2007), 24-28 June, Glasgow, pp. 1973-1978.
- [9] Sherali Zeadally, Farhan Siddiqui, "An Empirical Analysis of Handoff Performance for SIP, Mobile IP, and SCTP Protocols," *Wireless Personal Communications*, vol. 43, pp. 589-603, 2007.
- [10] S. Tsao and C. Lin, "Design and Evaluation of UMTS-WLAN Internetworking Strategies", Proceedings of IEEE Vehicular Technology Conference, vol. 2, pp. 777-781, 2002.
- [11] S. Tsao and C. Lin, "VGSN: a gateway approach to interconnect UMTS/WLAN networks", The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, vol. 1, pp. 275-279, Sep. 2002.
- [12] 3GPP, Technical Specification Group Services and System Aspects; 3GPP system to Wireless Local Area Network (WLAN) interworking; System description (Release 7), 3GPP TS 23.234 v7.4.0 Dec. 2006.
- [13] C. Perkins, "Mobile IP", *IEEE Communications Magazine*, vol. 35, Issue 5, May 1997, pp. 84-99, 1997.
- [14] 3GPP, "Telecommunications and Internet Protocol Harmonization over Networks, QoS Class Specification," TS 101329-2, <http://www.3gpp.org/>

## A Novel Dual-Mode User Equipment Design and Enhanced Gateway Selection Algorithm for B3G Networks

Abdul-Aziz Al-Helali Ashraf Mahmoud Talal Al-Kharobi Tarek Sheltami  
 Computer Engineering Department, King Fahd University of Petroleum and Minerals  
 {alhelali, ashraf, talalkh, tarek}@kfupm.edu.sa

### Abstract

*As wireless Internet applications are proliferating and becoming the main driver for the exploding growth of wireless access technologies, integrating third generation (3G) systems with Wi-Fi networks allows combining the strengths of these two technologies. In this paper, we present a novel design for a dual-mode user equipment (UE) model that supports both 3G and Wi-Fi access and provide one implementation using the OPNET simulation tool. The proposed UE model should be capable of supporting all the integrated network architectures depending on the deployment scenario. The modular model is equipped with two air-interface modules that allow communication with 3G and Wi-Fi networks, but the rest of the protocol stack is the standard IP protocol stack to satisfy the compatibility requirement. The design also includes needed functionalities to support vertical handoff across the two networks. The paper also presents an example algorithm that may be implemented into the proposed UE for enhanced gateway selection.*

### 1. Introduction

Currently, wireless technologies have different overlapping coverage with each other to provide the users with great experience and verity of choices to connect with. For example, UMTS provides the users with wireless access to the Internet utilizing the WCDMA air interface [1]. Alternatively, users can use the WLAN IEEE 802.11 air interface to access the Internet [2]. While UMTS provides a large coverage with high mobility support and low data rates up to 384 kbps, the WLAN covers smaller areas but provides greater data rates that may reach up to 54Mbps.

Although this provides the users with the opportunity to switch to the most suitable network, it

complicates the process when considering mobile users who move between these networks in and out frequently. This requires a mechanism that makes the network selection efficient and transparent to the user. This mechanism should take into consideration when to switch and based on what. It also must know the users preferences like cost, QoS, and privacy. Moreover, it should handle the handoff of the ongoing sessions when handing off from one wireless technology to the other.

In the literature, there is a lot of research done on the interworking architectures between the UMTS and WLAN [3-6]. However, only few conducted research on the structure of the UE. In [8] and [10], a framework for UE that is compatible with the tight coupling scheme was proposed where the protocols of the access points (APs) has to be modified. Moreover, the tight coupling is not adopted by the third generation partnership project (3GPP) which is responsible about the standardization of UMTS. Siddiqui and et al. in [7] proposed a UE design that works with a specific interworking architecture where the WLAN is connected to the UMTS core network at the Gateway GPRS Support Node (GGSN). In order to route the packets to the UE when it moves to the WLAN, this architecture requires that the UE should update the GGSN with its new IP that is obtained from the WLAN. This requires a modification in a major component in the UMTS core network which is the GGSN.

In this paper, we propose a UE model and provide its implementation in OPNET. It should be noted that the proposed model is applicable for a wide range of WLAN/UMTS interworking architectures. We discuss our implantation of the UE which has two interfaces one UMTS and the other is WLAN. In addition, we provide an enhanced gateway selection algorithm for optimized vertical handoff delay.

The rest of the paper is organized as follows: Section 2 briefly provides basic information about WLAN/UMTS interworking types. Section 3 details the design and functionalities of different components

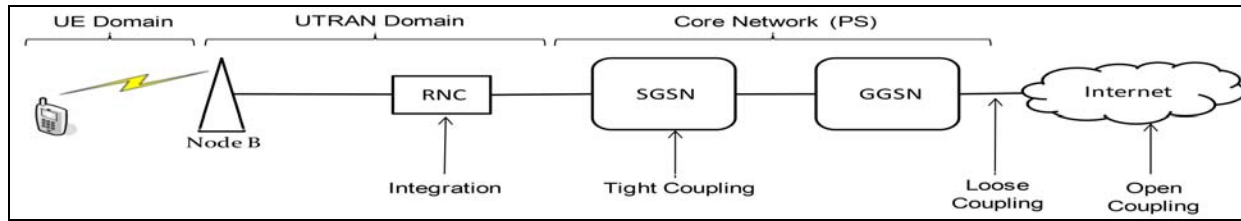


Figure 1: WLAN/UMTS interworking Types

of the 3GPP loose interworking architecture. Section 4 discusses our proposed multi-homed user equipment OPNET model. Section 5 points out several options of how handoff can be supported in our UE OPNET Model. Section 6 concludes the paper.

## 2. WLAN/UMTS interworking

The different interworking architectures between UMTS and WLAN are defined depending on where the WLAN is coupled with UMTS network. Based on that, there are four possible architectures as shown in Figure 1. These are the open, loose, tight, and integration coupling.

For the open coupling, the UMTS and WLAN networks are considered as two independent networks that share common billing and customer care to subscribers. In contrast, loose coupling provides subscribers the access to 3G based packet services by accomplishing the authentication, authorization, and billing through the UMTS network. However, it does not make any changes to the protocols used in WLAN or UMTS. Although the tight and integration coupling provide better services they are more complex since they require major changes in the protocols used in the WLAN. This complexity makes them inconvenient to interwork the widely spread public WLANs with UMTS.

Due to the simplicity, flexibility, and security of the loose coupling, 3GPP has recently approved a loose interworking architecture between the WLAN and UMTS [9]. The following subsection will elaborate more on this architecture and required components that satisfy the loose coupling requirements.

## 3. 3GPP Loose Interworking Architecture

The UE model we propose is compatible with any coupling architecture. However, we concentrate here on the loose coupling architecture since it is being adopted by 3GPP [9]. Figure 2 shows the loose coupling architecture that is approved by 3GPP. This interworking architecture requires new network entities to be added to the WLAN and the 3G network (UMTS) in order to satisfy the loose coupling

requirements. These required interworking components to join the WLAN and UMTS networks are: AAA Server, Wireless Access Gateway, 3GPP AAA Proxy, 3GPP AAA Server, and the Packet Data Gateway.

The AAA server, 3GPP AAA Proxy and 3GPP AAA Server cooperate to insure authentication, authorization and accounting of the subscribers coming from the WLAN. The AAA server is added to the WLAN network to apply authentication procedures for the WLAN users. It forwards the authentication information to the 3GPP AAA Proxy which in turn relays them between the WLAN network and the 3GPP AAA Server to authenticate the users. On the other hand, the WAG and PDG work together to provide the WLAN 3G users access to the 3GPP Packet Switched (PS) services based on their profiles.

## 4. User Equipment (UE) Protocol Stack

Modularity and Flexibility is a major requirement in any design. We built our user equipment in a modular way such that we reuse OPNET built in components and added our modifications in a separate components that can be easily separated, tested, analyzed, and developed.

The UE consists of the standard Internet protocol stack layers. They are the application, the transport, the Internet, the data link, and the physical layers. However, there is separate data link and physical layers stack for each of the air interfaces: UMTS and WLAN. In addition to the standard layers, we propose new Handoff Logic (HL) to handle handoff and support network selection. The HL consists of two components, the Monitoring and Reporting Unit (MRU) and the Interface Selection Unit (ISU). The HL component controls when and how handoff is accomplished. They provide flexibility to modularly integrate, test, and simulate handoff schemes without modifying the other components. We will elaborate more on these components in section 5. Figure 3 shows our designed OPNET Dual Mode User Equipment Model. The upper two layers: application and transport layers are used as provided by OPNET Modeler 11.5 [11] without any modification. However, the data link

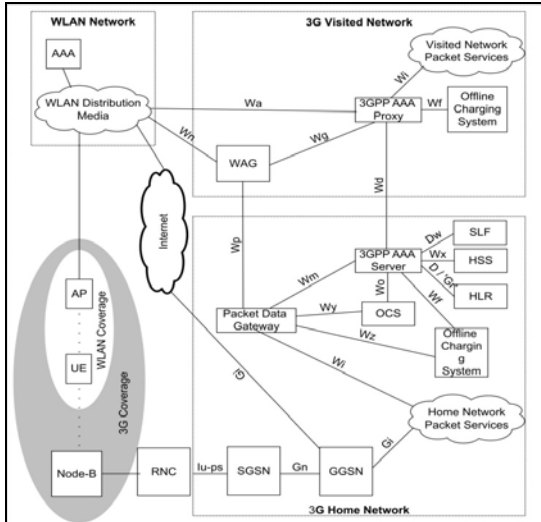


Figure 2: 3GPP Loose Interworking Architecture

layer and the Internet layers are modified to provide the UE with the ability to switch to different access networks transparently.

Thus, the data link layer consists of three parts, the WLAN DLL, UMTS DLL and MRU. Whereas the physical layer of the WLAN interface consists of a standard OPNET ARP and the MAC components, The physical layer of the UMTS interface consists of the GMM, RLC/MAC, and the Layer manager. The GMM (GPRS Mobility Management) is responsible about the functions of mobility management, session management, and radio resource control. For example, it is responsible about the GPRS attach PDP Context activation and establishment/release of radio bearers [11].

The RLC/MAC consists of the implantation of the radio link control and the media access control logic. This layer handles data flow with priority, the three types of RLC modes, and higher layer segmentation and reassembly. The management layer is responsible about the reporting measurements to the GMM Layer.

## 5. The Handoff Logic

This section will discuss a possible implementation of the handoff mechanism (Handoff Logic HL). HL can be easily integrated with our OPNET Dual Mode User Equipment Model. The HL consists of two main units:

- The Monitoring and Reporting Unit (MRU) which resides in the Data Link Layer.
- The Interface Selection Unit (ISU) which is located in the Internet Layer.

The details of each unit will be discussed in sections 5.1 and 5.2.

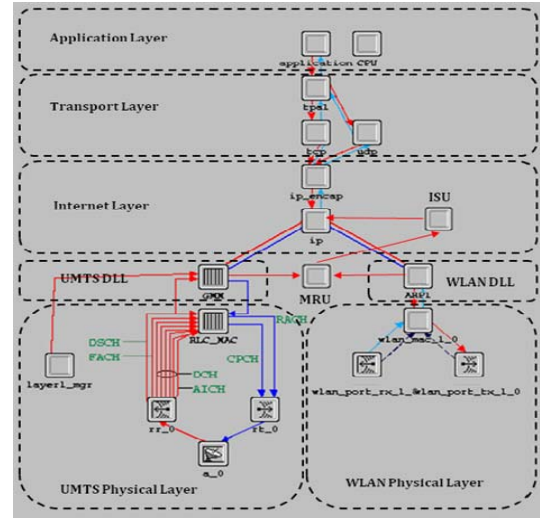


Figure 3: Our OPNET Dual Mode User Equipment Model

### 5.1. The Monitoring and Reporting Unit (MRU)

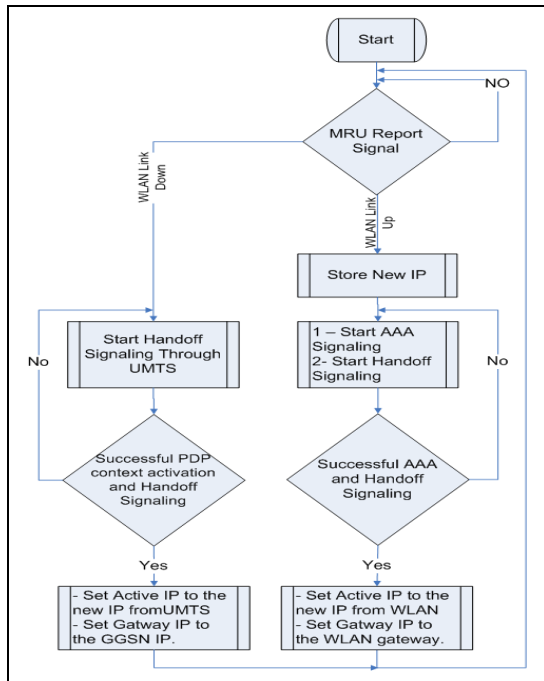
The Monitoring and Reporting Unit (MRU) monitors the events happening at the data link layer of the WLAN and UMTS interfaces. It analyzes these events and reports its findings to the (ISU). The MRU is located in the data link layer.

The process of the monitoring and reporting in the MRU works as follows. The MRU looks for the events at the data link layer of the WLAN interface and if it finds an Association Success or Re-association Success it reports a WLAN Link Up signal to the ISU. The reported signal carries the UE IP in the WLAN, IP of the WLAN gateway, the WLAN BSSID and SSID. In addition, it looks for the UMTS data link layer events and if it finds a PDP context Activation Success, it informs the ISU with a UMTS Link Up signal with new IP and the IP of the associated GGSN. Figure 3, shows how the MRU and the ISU interact with each other and with the other layers.

### 5.2. The Interface Selection Unit (ISU)

The activation of an interface to be used for sending and receiving packets is done by the ISU. The ISU is located in the Internet layer. It receives reports from the MRU about the interface's status. Based on that, it applies the algorithm shown in Figure 4 to select an interface. After the algorithm starts it enters a waiting state for a report from the MRU. There are four types of MRU reports: the WLAN Link Up, the WLAN Link Down, UMTS Link Up, and the UMTS Link Down. For the current implementation, we assume the UMTS





**Figure 4: Interface Selection Algorithm**

coverage is always available. Upon the reception of a WLAN Link Up, the algorithm stores the new obtained IP and start the AAA and handoff signaling. If the AAA and Handoff signaling is successful, the new IP obtained from the WLAN is set as the active IP and the IP of the WLAN access point is set as the default gateway of the UE, otherwise the AAA and Handoff signaling has to be repeated. After that, the UE enters a waiting state again waiting for Link Down event. When the MRU send a Link Down report the handoff process should be started through the UMTS interface using the UMTS IP.

After the completion of the handoff signaling the UE IP is set to the new IP from the UMTS and the default gateway is set to the GGSN's IP. We emphasize that during this process the MN continues sending and receiving through the other interface.

## 6. Conclusion

In this paper, we proposed and briefly presented a new dual-mode user equipment design and described the functionality of its modules focusing on the newly added entities to support the various integration architectures. In addition, we also present an OPNET implementation of the design that will aid in future simulation exercises and evaluations. The needed functionality for supporting vertical handoff is located in two proposed entities referred to herein by MRU and ISU. The modular UE model allows the

experimentation of the various integration schemes and various handoff algorithms with no or minimal change to the rest of standard 3G or Wi-Fi functional entities. This paper also presents an example algorithm for enhanced gateway selection for the integrated network. Finally, the proposed model will be made available at [www.opnet.com](http://www.opnet.com) in the contributed models section for researchers around the world to test, evaluate, and probably enhance the proposed model.

## 7. Acknowledgments

The authors would like to thank King Fahd University of Petroleum and Minerals for their support in the course of this research.

## 8. References

- [1] H. Kaaranen et al, *UMTS Networks, Architecture, Mobility, and Services*, Wiley, 2005.
- [2] IEEE, *Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, IEEE standard 802.11, edition 1999.
- [3] S. Tsao and C. Lin, "Design and Evaluation of UMTS-WLAN Internetworking Strategies", *Proceedings of IEEE Vehicular Technology Conference, VTC 2002*, vol. 2, pp. 777-781, 2002.
- [4] Buddhikot M. et al, "Design and Implementation of a WLAN/CDMA2000 Internetworking Architecture", *IEEE Communications Magazine*, vol. 41, pp 90- 100, November 2003.
- [5] S. Tsao and C. Lin, "VSGN: A Gateway Approach to Interconnect UMTS/WLAN Networks", *The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC 2002.*, vol. 1, pp. 275-279, 2002.
- [6] B. Hongyang, H. Chen, L. Jiang, "Performance analysis of vertical handoff in a UMTS-WLAN integrated network", *Proceedings of 14th IEEE conference on Personal, Indoor and Mobile Radio Communications, PIMRC*, vol. 1, pp. 187-191, Sept. 2003.
- [7] F. Siddiqui, S. Zeadally, S. Fowler, "A Novel Architecture for Roaming between 3G and Wireless LANs". *1st International Conference on Multimedia Services Access Networks, MSAN*, 2005, pp.101 – 105, 2005.
- [8] A.K. Salkintzis, C. Fors, R. Pazhyannur, "WLAN-GPRS integration for next-generation mobile data networks" *IEEE Wireless Communications*, vol. 9, no. 5, pp. 112 – 124, Oct. 2002.

- [9] 3GPP, Technical Specification Group Services and System Aspects; 3GPP system to Wireless Local Area Network (WLAN) interworking; System description (Release 7), 3GPP TS 23.234 v7.4.0 Dec. 2006.
- [10] N. Vulic, I. Niemegeers, S.H. de Groot, " Architectural options for the WLAN integration at the UMTS radio access level ". Vehicular Technology Conference, 2004. VTC 2004-Spring, vol. 5, 2004.
- [11] OPNET Inc. <http://www.opnet.com>

# Vertical Handoff Characterization for SIP and mSCTP Based UMTS-WLAN Integration Solutions

Syed Asadullah, Ashraf S. Mahmoud, Marwan Abu-Amara, Tarek Sheltami  
 Computer Engineering Department  
 King Fahd University of Petroleum and Minerals  
 Dhahran 31261, Saudi Arabia  
 Email: {sasad, ashraf, marwan, tarek}@kfupm.edu.sa

**Abstract** — It is desirable to integrate 3G Universal Mobile Telecommunication System (UMTS) and 802.11 wireless local area networks, especially at hot-spot locations such as hotels and airports. The efficiency of wireless data services can be maximized if the integration provides users with seamless roaming across the two types of networks. Seamless handoff between these two networks to maintain session continuity is a major challenge in WLAN-3G integration. To achieve this goal, integration architectures together with mobility solutions such mobile stream control transmission protocol (mSCTP) and session initiation protocol (SIP) have been proposed in the literature. In this paper, we implement through simulations an integration architecture and characterize the vertical handoff delay for both mobility solutions mSCTP and SIP as a function of network parameters. This study finds that mSCTP perform better in terms of handoff delay compared to SIP for the assumptions specified in this paper.

**Index Terms** — WLAN, 3G, UMTS, mSCTP, SIP handoff, mobility.

## I. INTRODUCTION

The proliferation of wireless local area networks (WLANs) has provided network service providers with an option of integration with third-generation (3G) wireless wide area networks, such as Universal Mobile Telecommunications System (UMTS). Such integration allows mobile users to move among these heterogeneous networks in a seamless manner. However, the integration of 3G networks and WLANs presents some considerable challenges which include the demand for seamless handoff, continuity of data traffic and multimedia sessions across the two networks, central authentication system, billing, security etc. To deal with these challenges and to support this type of integration several 3G/WLAN interworking architectural scenarios have been proposed [1]. These architectures differ in terms of the extent of interoperability or services they provide.

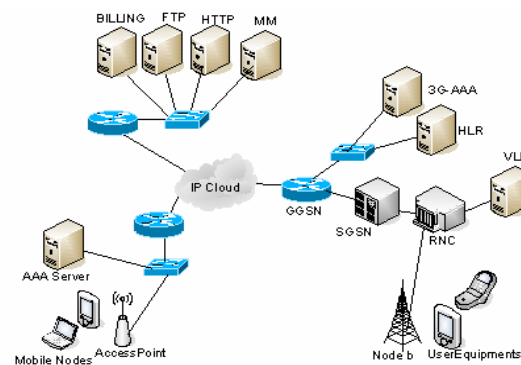
Vertical handoff is a major factor in any UMTS/WLAN integration. Vertical handoff refers to the handoff between two heterogeneous networks such as UMTS-to-WLAN or WLAN-to-UMTS. It is desired that the data sessions that a mobile user maintains during handoff stay alive, that the handoff is seamless, and that the handoff spans only a very short period of

time. To achieve seamless handoff, several mobility protocols have been proposed. The paper considers two mobility protocols; SIP and mSCTP. SIP is an application layer protocol while mSCTP works at the transport layer.

The paper is outlined as follows. In section 2 we briefly review the WLAN and UMTS integration architecture. In section 3 we discuss UMTS-to-WLAN vertical handoff and how it is handled using SIP and mSCTP. Similarly, we discuss WLAN-to-UMTS handoff scenario in section 4. In Section 5 we define the simulation setup and the parameters used. The simulation results and analysis for vertical handoff using SIP and mSCTP are presented in section 6. In section 7 we present the conclusions.

## II. NETWORK ARCHITECTURES

The UMTS-WLAN integration architecture adopted in this paper is shown in Figure 1. The network clearly consists of the UMTS network, the WLAN network and the Internet service provider network. The following presents a brief description of the WLAN and UMTS networks and their main components.



**Figure 1: Integrated UMTS-WLAN network architecture.**

**WLAN Architecture:** The 802.11b/g/a WLAN architecture basically consists of one or more Basic Service Sets (BSSs) also called access points (APs) and

client devices. The traffic for all the client devices that are associated with one AP flows through the particular AP. All the APs are connected to the network backbone through a switch or a hub.

**UMTS Network Architecture:** The basic UMTS architecture consists of three domains: The User Equipment (UE), the UMTS Terrestrial Radio Access Network (UTRAN) and the Core Network (CN). The UE consists of the equipment used by the user to access UMTS services. The UTRAN consists of one or more Radio Network Sub-systems which can further have one or more Node Bs connected to one Radio Network Controller (RNC). The coverage area of Node B is called a cell. CN consists of Circuit switched networks for providing voice and circuit switched services, Packet Switched network (PS) for providing packet based services, and optionally a Home Location Register (HLR). HLR stores subscribers' location and maintains a list of services allowed for each subscriber.

Among several functional entities, the PS network consists of a Serving GPRS Support Node (SGSN) responsible for routing packets inside the PS as well as for mobility management, logical link management, and authentication and charging functions, and a Gateway GPRS Support Node (GGSN) acting as a gateway towards external packet switched networks. The external network could be a LAN, WAN, GPRS, ATM network etc.

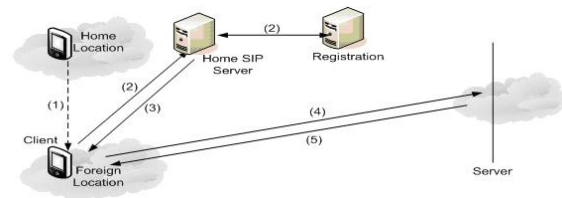
### III. UMTS-TO-WLAN VERTICAL HANDOFF

When a mobile node (MN) enters a foreign (WLAN) network, it identifies the presence of a WLAN by receiving the characteristic beacons from an AP. To start using the services of the new network, the MN has to authenticate itself with the WLAN. Many authentication methods exist and can be employed depending on the agreement between the UMTS/WLAN service providers. The paper uses authentication, authorization and accounting (AAA) authentication and extensible authentication protocol (EAP) signaling for WLAN authentication which is briefly discussed next.

**WLAN Authentication:** During the EAP signaling [2] for MN authentication and key exchange, the MN initially sends a request to the AP to connect to the WLAN and receives a response for authentication type from the AP. The MN submits an authentication request to the AP that is forwarded to the AAA server. The AAA server processes the request and sends challenge back to the client. The client submits its credentials to the AAA server that the AAA verifies and allows or denies access based on local user database or contacting an external user database. This is implementation dependent and can be EAP-MD5, EAP-MSCHAP v2

etc. AAA also sends a session key to the MN along with the response. The authentication is valid as long as the client is associated with the same AP. If the MN moves from one AP to another it re-authenticates itself during handoff. After successful authentication the MN begins to acquire an IP address from the WLAN network through dynamic host configuration protocol (DHCP) registration. Thus, any client that enters WLAN network needs to authenticate and acquire an IP address before it triggers its protocol specific handoff procedures. Two such procedures, SIP and mSCTP, are discussed next.

**SIP:** Session Initiation Protocol (SIP) [3] is basically a signaling protocol that offers a number of benefits, including extensibility and provision for call/session control. It is mainly used to establish, modify, and terminate multimedia sessions. Apart from the signaling function, SIP is an application layer protocol which inherently supports terminal mobility. SIP users are addressed using email-like addresses, sip:user@domain for example. The logical entities in SIP communication are user agents which are the nodes communicating using SIP, registrar server which is responsible for maintaining user agent access information, redirect server that keeps track of the user's location so as to redirect requests in case of location change, and proxy server responsible for relaying the messages. The proxy server can be Outbound, Inbound or Intermediate. The standard methods defined in SIP for setting up sessions between user agents are SIP — INVITE, ACK, BYE, OPTIONS, CANCEL and REGISTER. Figure 2 shows the SIP-based mobility management solution.



**Figure 2: SIP-based mobility management solution.**

When an MN moves into the coverage area of the foreign WLAN network, step (1), it authenticates itself with the new network, obtains a new IP address, and triggers the SIP message exchange. The MN then sends a location update to the home SIP server, step (2), so that new invite requests can be redirected to the correct address. The registrar processes the update message and forwards it to the location service, which stores the information. The home SIP server responds to the MN with an acknowledgment, step (3). In step (4), the MN sends a new SIP-INVITE request to the Correspondent Host's (CH) user agent using the same call identifiers as in the original connection setup. The request contains

the new address. Any new message from the server to the MN is sent to this new address. The CH's user agent acknowledges the request, step (5), and this completes the handoff procedure. The combined delay due to WLAN authentication, DHCP registration and SIP Location Update and INVITE procedures constitute the UMTS-to-WLAN handoff delay.

**mSCTP:** Mobile Stream Control Transmission Protocol (mSCTP) [4] is an extension of SCTP [5] with the addition of the Dynamic Address Reconfiguration (DAR) feature that is also referred to as ADDIP. The mSCTP protocol provides mobility management at the transport layer. An mSCTP enabled node has the provision of acquiring and holding multiple IP addresses while keeping the end-to-end connection intact. During initiation of the connection, a list of addresses is exchanged between the endpoints. One address (primary) is used as the destination for normal transmission and the other addresses are used for retransmissions only. With mSCTP nodes can add, delete and change the primary address dynamically while still being connected. The major advantage of mSCTP over other mobility protocols is that it does not require any additional infrastructure but the entities communicating at both ends must support mSCTP. The Address Configuration (ASCONF) message transactions for mSCTP mobility management are shown in Figure 3.

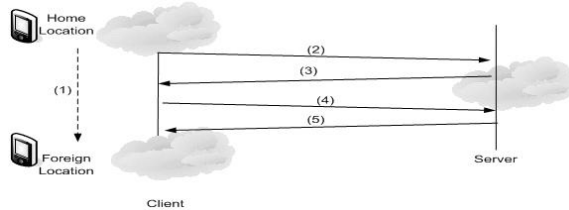


Figure 3: mSCTP Mobility Management.

When a Mobile Node moves into the coverage area of the foreign WLAN network, step (1), it authenticates itself with the new network and obtains an IP address from the local DHCP server through standard registration procedure. The MN then informs the entity at the other end (CH) about the new IP address through the ASCONF message ADD-IP, step (2). The CH updates this IP address in the list and sends an acknowledgement, step (3). The MN further informs the CH to set the newly assigned IP address to the primary IP address, step (4), which the CH responds to with an acknowledgment, step (5). The new primary IP address now becomes the destination address for further communication. With this the handoff procedure is complete and the time required to complete the ASCONF messages (steps 2 to 5) constitutes the UMTS-to-WLAN handoff delay. Due to the dual homing feature of mSCTP, the MN continues to

communicate with the CN through its UMTS IP while it is authenticating itself with the WLAN and acquiring an IP address from the DHCP server in the new location. Hence, the WLAN authentication and DHCP registration delay does not add to the handoff delay in UMTS-to-WLAN handoff using mSCTP.

#### IV. WLAN-TO-UMTS VERTICAL HANDOFF

When an MN moves from a WLAN to a UMTS network, it is required to perform two key functions prior to initiating a handoff [6], namely the GPRS Attach and the Packet Data Protocol (PDP) Context Activation [7][8]. This establishes a data connection setup used to carry protocol specific handoff messages. The GPRS attach is analogous to the WLAN authentication and PDP Context Activation is analogous to the DHCP registration in the UMTS-to-WLAN handoff. The messages involved in the GPRS Attach and PDP Context Activation procedures are shown in Figure 4.

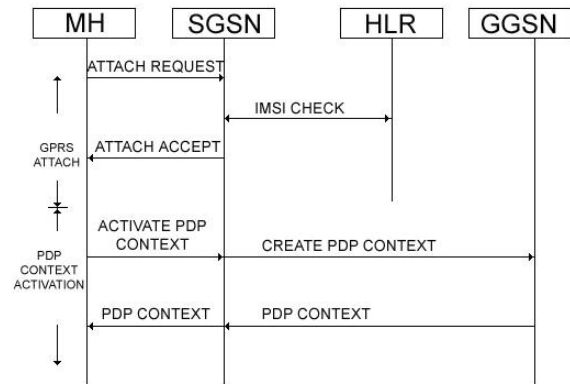


Figure 4: GPRS Attach & PDP Context Activation.

**GPRS Attach:** As part of the GPRS Attach procedure [7], the MN sends an Attach Request message to the SGSN with the MN's international subscriber identifier (IMSI). The SGSN uses the IMSI to authenticate the MN with its HLR. Successful authentication is followed by the SGSN sending a location update to the HLR. The SGSN finally completes the procedure by sending an Attach Accept message to the MN. This establishes a logical association between the MN and the SGSN.

**PDP Context Activation:** After the GPRS attach, the MN must activate a PDP address (or IP address) to begin packet data communication. Activation of a PDP address creates an association between the MN's current SGSN and the GGSN that anchors the PDP address. A record of such an association is known as the PDP context. PDP context transfer is initiated by the MN by sending a PDP Context Activation message to the SGSN. After receiving the Activation message, the

SGSN discovers the appropriate GGSN & selects a GGSN capable of performing the function. The SGSN and GGSN create special paths for the transfer of the respective mobility protocol messages. Once the MN gets attached to the UMTS network and activates its PDP context, then dependent on the type of handoff procedure used, the MN triggers either a SIP handoff procedure or an mSCTP handoff procedure similar to what was discussed in section 3. If a SIP handoff procedure is triggered, then the time required for GPRS Attach and PDP context activation plus the delay due to SIP REGISTER/UPDATE messages constitute the handoff delay for WLAN-to-UMTS handoff. On the other hand, if an mSCTP handoff procedure is triggered, then the handoff delay for WLAN-to-UMTS handoff is the delay due to the ASCONF messages.

## V. SIMULATION SETUP & PARAMETERS

A SIP-based integration architecture is design and implemented using Opnet Modeler as shown in Figure 5. For handoff between heterogeneous networks it is required that the mobile node has a dual mode network interface which supports both UMTS and WLAN networks. As Opnet does not support such interface we have built custom tasks to simulate the handoff instances. A custom task is a collection of communication transactions between network entities. In our simulation we have customized tasks for AAA Authentication, DHCP address lease, SIP Handoff, mSCTP handoff, and UMTS Authentication. The exact transactions, as stated by the corresponding RFCs, required to perform these tasks were built into the simulation code.

The handoff task is simulated as follows. Two separate nodes are used in WLAN and UMTS network which serve the purpose of one MN having dual mode network interface. Suppose a node is moving from UMTS to WLAN network, the first set of handoff transactions are initiated between UMTS node and the Correspondent Host. Once the MN moves into the WLAN area the remaining transactions are carried out between the corresponding WLAN node and correspondent host. Hence in this work we interested in quantifying the time required to complete the transactions that take place over the network and is recorded using the above mentioned tasks. These transactions vary depending on the mobility protocol being used and hence we compare the delay incurred using different mobility protocols. In our simulation the packet sizes for mSCTP and SIP transactions, WLAN and UMTS authentication etc. were taken from related sources [2][3][4][9][10]. The implemented architecture includes entities such as the mobile nodes, DHCP server, SIP servers, interconnecting routers and switches etc. For our analysis, the correspondent host is the HTTP\_Server.

Comparison of handoff delays at protocol level does not require actual simulation of physical layer and hence Ethernet nodes were used as mobile nodes to save simulation time and support higher traffic.

For handoff delay comparison the simulations were run with WLAN and UMTS users using the services from their respective domains. One node was selected to initiate the handoff when it moves from UMTS to WLAN network or vice versa. Mobility in both directions was considered. For each traffic load the handoff delay was noted at five different instances during simulation and the average of these five values is considered to be the effective handoff delay for the load.

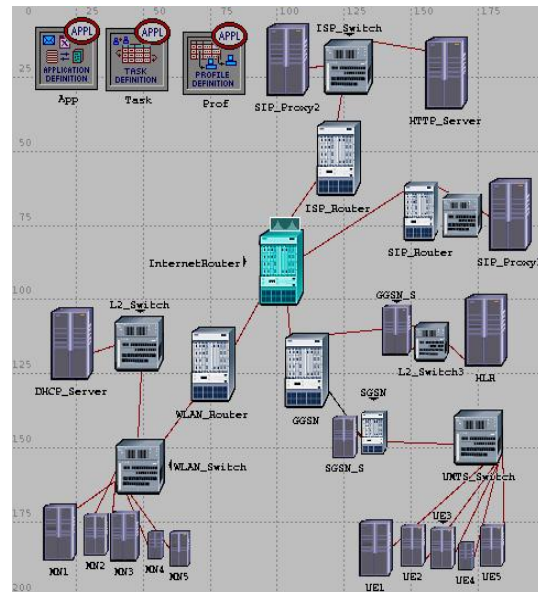


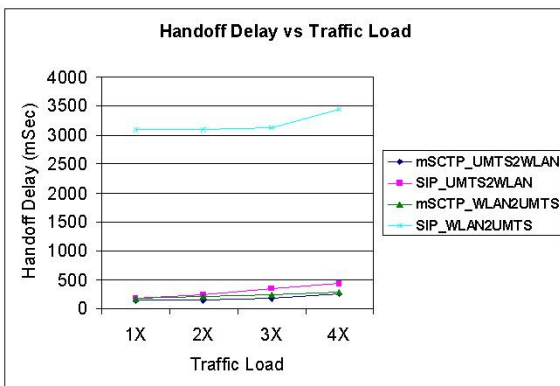
Figure 5: SIP-based integration architecture implementation using Opnet Modeler.

## VI. HANDOFF DELAY COMPARISON

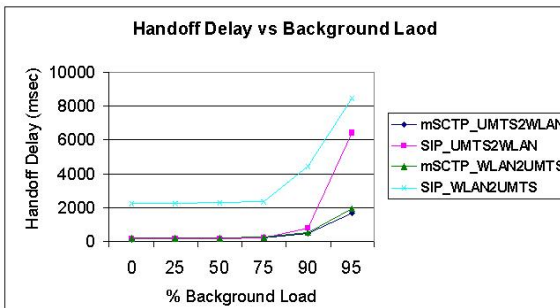
Figure 6 shows the comparison of handoff delay vs traffic load for mSCTP and SIP. Figure 7 shows effect of background load on the handoff delay. Results are presented in this section for mobility in both directions.

**WLAN-UMTS:** The top curve in the Figure 6.1 is the handoff delay for WLAN-UMTS using SIP where the values for handoff delay are around 3 – 3.5 seconds. The delay for mSCTP is much less than in SIP. This can be attributed to the fact that when the Mobile node moves into the UMTS network requires GPRS attach and PDP context activation which consumes considerable amount of time. An mSCTP enabled node also goes through these steps but with a difference that it still maintains connectivity through its WLAN IP. Hence the GPRS attach and PDP context activation do not add to the handoff delay in case of mSCTP.

**UMTS-WLAN:** Even in the case of a UMTS-WLAN handoff mSCTP performs better than SIP as mSCTP requires fewer transactions than SIP for handoff completion. It can also be noted from the results presented below that the difference between the handoff times (SIP and mSCTP) is not significantly high initially but with increase in the traffic on the network the performance of SIP handoff degrades fast. This is mainly due to the additional communication and signaling between SIP entities viz. SIP Proxy, Registrar etc. for location update and registration. With increasing load this communication takes longer time to traverse through the network. The background load figures also indicate that SIP handoff time increases dramatically with increase in the background traffic on the network.



**Figure 6: Handoff Delay vs Traffic Load comparison for mSCTP and SIP.**



**Figure 7: Handoff Delay vs Background Load comparison for mSCTP and SIP.**

## VII. CONCLUSION

It is quite evident that there are still several challenges to be addressed to enable seamless integration of wireless LAN and UMTS networks. Various architectures have been proposed to meet these challenges. This paper provides an implementation using simulation platform (Opnet) for an integration architecture that supports two mobility schemes:

mSCTP and SIP. We also use our implementation to quantify the vertical handoff delay for such network. Based on the results, we can also conclude that with respect to mobility mSCTP provides faster vertical handoffs than SIP. Moreover SIP also requires additional entities at various levels like SIP proxy server, registration server and intermediate proxy servers while mSCTP does not have any of these requirements. However end nodes must be mSCTP enabled to support dual homing feature and achieve faster handoffs.

## REFERENCES

- [1] Apostolis K. Salkintzis, "Interworking Techniques and Architectures For WLAN/3g Integration Toward 4g Mobile Data Networks," *IEEE Wireless Communications*, June 2004
- [2] RFC 3748 - Extensible Authentication Protocol (EAP)
- [3] RFC 3261 - SIP: Session Initiation Protocol
- [4] SCTP Extensions for Dynamic Reconfiguration of IP Addresses and Enforcement of Flow and Message Limits Network Working Group, *INTERNET-DRAFT*, June 6, 2001
- [5] Seok Joo Koh, Moon Jeong Chang, and Meejeong Lee, "mSCTP for Soft Handover in Transport Layer," *IEEE COMMUNICATIONS LETTERS*, Vol. 8, No. 3, March 2004
- [6] Farhan Siddiqui, Sherali Zeadally, "Mobility management across hybrid wireless networks:Trends and challenges," *Computer Communications* 29, 2006, 1363 - 1385
- [7] Wei Wu, Nilanjan Banerjee, "SIP-Based Vertical Handoff Between WWANs and WLANs," *IEEE Wireless Communications*, June 2005
- [8] Nilanjan Banerjee, Arup Acharya, T. J. Watson, "Seamless SIP-Based Mobility for Multimedia Applications," *IEEE Network*, March/April 2006.
- [9] RFC 4187 - Extensible Authentication Protocol Method for 3rd Generation Authentication and Key Agreement (EAP-AKA)
- [10] RFC 2960 - Stream Control Transmission Protocol