Performance of UMTS/WLAN Integration at Hot-Spot Locations Using OPNET

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ABSTRACT — **Due to the many benefits provided by both the third-generation (3G) mobile networks and the IEEE 802.11 wireless local area networks (WLANs), it is desirable to integrate both types of networks. While studies specifying generic integration architectures are abundant, there are little or no studies that are dedicated for applications performance over such heterogeneous networks. Using simulations, this paper evaluates the performance of two 3G/WLAN integration schemes: loose and open coupling, together with two mobility management schemes: Mobile IP and mobile stream control transmission protocol (mSCTP) for an airport as a typical example of a hot-spot location. In addition, the evaluation is carried out for a wide range of application mixes consisting of FTP, HTTP and multimedia. Utilizing OPNET as the simulation platform and incorporating the required protocols to support our implementation of the Mobile IP and mSCTP, we generate a large matrix of performance figures for the 4 network configurations under all applications mixes considered. The results summarized in this paper indicate that integration methods considered have little impact on the application mixes studied in terms of delay but show that FTP and HTTP throughput is better with loose coupling scheme. Further, quantifying the handoff delay between the 3G and WLAN networks, the results indicate that a loose-couple integration solution together with Mobile IP provides the best performance.**

***Index Terms* — Mobile Networks, Mobile IP, mSCTP, Handover.**

I. INTRODUCTION

The recent evolution and successful deployment of Wireless Local Area Networks (WLANs) worldwide has yielded a demand to integrate such networks into third-generation (3G) mobile networks, such as Universal Mobile Telecommunications Systems (UMTS). The key goal of the integration is to develop heterogeneous mobile data networks, capable of supporting ubiquitous data services with very high data rates in hotspots. The effort to develop such heterogeneous networks, also referred to as fourth-generation (4G) mobile data networks, is linked with many technical challenges including seamless vertical handovers, security, common authentication, unified accounting and billing, WLAN sharing by several 3G networks, consistent QoS and service provisioning, etc.

To properly integrate a WLAN into a 3G mobile network the optimum combination of an integration scheme [1][2] and a mobility management scheme [13][14][15] must be selected. Hence, the performance of two integration and two mobility management schemes is studied for integrating a WLAN into a UMTS network at an airport as a typical example of a hot-spot location. Further, the study considers different application mixes and traffic loads.

The studies in [1] and [2] already define six possible scenarios for service integration between 3G networks and WLANs. These scenarios range from the simplest form of integration, common billing and customer care, to the most complex form of integration, where access to 3G circuit-switched-based services with seamless mobility is allowed from the WLAN system. Of interest to this study are the 3rd and 4th integration scenarios where 3G packet-based services and service continuity is supported in the heterogeneous network.

While studies from an architecture point of view are abundant [3][4][5][6][7][8], very few, if any, studies can be found on performance of these heterogeneous networks for various Internet applications. For example, the study in [9] attempted to quantify the performance of a loose coupling Mobile IP based solution. In specific the study focuses on the optimization of the handoff latency figure measured at the transport layer for a generic traffic type that is not specified in the paper. A second example of such performance studies is the study in [10] where the authors measure the performance of loose coupling architecture with regard to the continuity of real-time video traffic for UMTS connections. The study does not specify the mobility solution employed and only considers handoffs from the UMTS network to the WLAN network. Finally, Song and Jamalipour [11] focus on the performance of a network selection algorithm, rather than traffic sessions.

In this paper we attempt to evaluate the performance of four network integration solutions: open coupling with mSCTP, open-coupling with Mobile-IP, loose-coupling with mSCTP, and loose-coupling with Mobile-IP. In addition, the evaluation is conducted using simulations for a varying range of traffic loads and mixes for three Internet applications; FTP, HTTP, and multimedia streaming. The purpose is to characterize the performance of applications and the network as a whole in terms of delay and throughput figures with respect to the four different integration solutions. We also quantify the handoff delay for the assumed traffic session to gauge the suitability of each of these solutions for supporting service continuity.

II. BACKGROUND

A. UMTS Network Architecture

The architecture of a UMTS network consists of two basic components: The UMTS core network (UCN), and the UMTS terrestrial radio access network (UTRAN). The UCN consists of two networks: circuit-switched and packet-switched. In particular, the packet-switched network consists of the serving GPRS support node (SGSN), the gateway GPRS support node (GGSN), and other functional entities. On the other hand, the UTRAN provides the wireless access to the UMTS network and consists of a collection of radio network controllers (RNC), and base stations, referred to as Node B. Node B provides the immediate wireless access for mobile subscribers, while the RNC assumes the management and control tasks within the UTRAN, and interfaces with the rest of the UMTS network [12].

B. General WLAN Architecture

The IEEE 802.11 defines the standard for WLANs. The WLAN operates in either ad-hoc mode or infrastructure mode. The latter is relevant to the integration with wireless networks. In infrastructure mode, an access point (AP) coordinates the transmission among nodes within its radio coverage area. A mobile node (MN) can only associate with one AP at a time. A number of APs can be interconnected through an IP routed network to form a WLAN IP network.

C. Integration Schemes

To facilitate integration of a WLAN network into a UMTS network four levels of coupling are proposed [1][2]. The first level is open coupling where the UMTS and the WLAN networks make use of two separated access and transport networks while having a common billing. Note that the UMTS and the WLAN networks maintain separate authentication mechanisms. The second level is loose coupling which enables the use of common authentication mechanisms by providing a link between the authentication, authorization and accounting (AAA) server in the WLAN network and the Home Location Register (HLR) in the UMTS network. The third level is tight coupling where the WLAN AP is connected as an RNC to the UMTS SGSN to support the handover between WLAN and UMTS networks. The fourth level is very tight coupling where the WLAN AP is connected to the RNC using the same interface used by a Node B to connect to an RNC. The latter two coupling schemes are not considered in this paper as they require major modifications in the protocol stacks of the WLAN AP, the UMTS RNC, and/or the UMTS SGSN for such coupling schemes to work. Furthermore, the integration architectures outlined in this subsection only highlight the generic network structure and do not specify the solution details. Other solution components are still required and the most important component is the mobility management solution which is an essential part of the service continuity requirement. The paper considers two mobility solution candidates: Mobile IP [13] and mSCTP [14]. Other solutions such as session initiation protocol [15] and IPv6 remain of interest and subject to future research.

III. METHODOLOGY OVERVIEW, NETWORK DESIGN, AND SIMULATION ASSUMPTION

In this section we describe the simulation model and assumptions used to evaluation the four integration solutions of interest. The simulation model is designed using OPNET™ Modeler 11.5 and the simulation parameters were selected to accurately model an interworked WLAN-UMTS system supporting a "hot spot." To compare the performance of loose and open coupling schemes simulations are performed in both architectures with the same simulation parameters: number of nodes, traffic loads and mixes, etc. Thus, the network design shown in Fig. 1 depicts the model used for simulation. The design consists of three major parts; the WLAN network, the UMTS network, and the Internet Service Provider (ISP) network. The ISP network hosts the applications' servers available for customer access as well as the customer care and billing system (CC&BS). It should be pointed that the network design depicted in Fig. 1 is valid for both the open coupling and the loose coupling integration schemes. The difference between the two integration schemes is that in the case of the open coupling scheme the HLR is used for authentication by the UMTS network only, whereas in the case of the loose coupling scheme the HLR will be used for authentication by both the WLAN and the UMTS networks.

The simulation model incorporates several custom made components (network entities and procedures) that were developed during this study and that were lacking from the OPNET™ Modeler 11.5. Some of the major components that were lacking include:

1) Support for AAA, HLR, and VLR.
2) Support for mSCTP under both UMTS and WLAN models.
3) Support for Mobile IP under UMTS model.

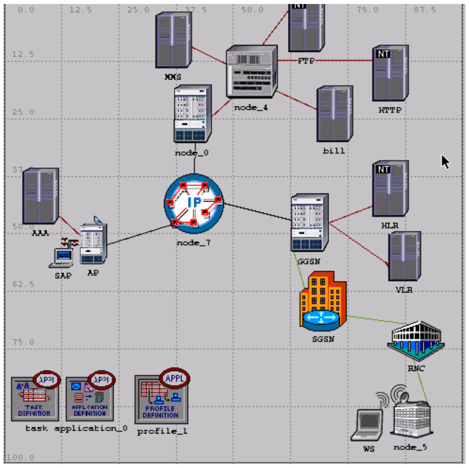

Fig. 1. Simulated network design.

4) Support for a dual mode workstation that operates under both UMTS and WLAN.

A. Traffic Model

Using the designed simulation model shown in Fig. 1 a series of simulation runs were conducted under the following assumptions. A maximum of 7,000 simultaneous users at any time are using the wireless network. The figure is derived using statistics of a reasonably sized airport with a maximum of 38,000 visitors and a 20% wireless service penetration. In addition, the network traffic load was varied from 1,000 to 7,000 simultaneous users, in steps of 1000 users. The objective of the assumption is to study the effect of loading on the different performance metrics. All UMTS users are assumed to move to the WLAN network with each user requiring a peak rate of 1 Mbps. In regard to applications, three different types of applications are supported, FTP, HTTP, and Multimedia Audio/Video Streaming (MMS). The MMS traffic is simulated as video conferencing session. The distribution of each user's traffic among the three different applications is varied as shown in Table 1. For the aspect of mobility, the users will start moving from the home network (i.e. UMTS) to foreign network (i.e. WLAN) after five minutes from starting the simulation.

Table 1: Applications distribution

Type	% of user traffic (scenario)						
	1	2	3	4	5	6	7
FTP	20	10	40	35	10	35	10
HTTP	40	45	30	10	60	55	30
MMS	40	45	30	55	30	10	60

IV. Simulation Results

As stated earlier, the major focus of the paper is to study the performance of the integrated network given the two types of integration schemes and the two mobility management schemes. The performance metrics that the paper is concerned with are: WLAN delay, WLAN throughput, each application response time, each application throughput, and the handover delay. As such, several simulation runs were conducted taking into account the assumptions outlined in section III, the different traffic loads, and the different application mixes of Table 1. The result is a large matrix of performance figures of more than 200 different simulation points for the different network architectures: mSCTP with open coupling, Mobile IP with open coupling, mSCTP with loose coupling, and Mobile IP with loose coupling. However, due to lack of space, the paper presents only two samples of the results. Namely, the results for the application mix FTP/HTTP/MMS being 20/40/40 as an expected application mix for most users, and for the application mix FTP/HTTP/MMS being 10/30/60 as an extreme case of MMS usage by the users and its impact on the performance. For both types of application mixes, the paper shows the WLAN delay and throughput in Fig. 2 and Fig. 3, as well as each application's response time and throughput in Fig. 4–Fig. 9.

A. Traffic Load

From Fig. 2–Fig. 9, it can be observed that increasing the traffic load increases the WLAN delay, and each application's response time and throughput. Further, it is clear that increasing the traffic load is less significant on the MMS response time than on both the FTP and the HTTP response times. For example, Fig. 6 shows that the MMS response time is between 1 microsecond and 1.2 microseconds irrespective of the traffic load.

B. Open vs. Loose Results

Using Fig. 2 and Fig. 3, and considering the same mobility management scheme, it can be observed that the different integration schemes have no significant impact on the WLAN delay and throughput. Performance figures for the WLAN are the average across the various applications considered in this study. On the other hand, when considering Fig. 4–Fig. 9, it is evident that both FTP and HTTP have higher throughput when the loose coupling scheme than when the open coupling scheme is used. For example, Fig. 4b and Fig. 7b show that the FTP throughput under loose coupling is 2 to 8 times larger than the FTP throughput under open coupling. Similarly, Fig. 5b and Fig. 8b show that the HTTP throughput under loose coupling is 1 to 6 times larger than the HTTP throughput under open coupling. In summary, the loose coupling scheme is preferred over the open coupling scheme since the loose coupling scheme provides for higher throughput for FTP and HTTP than the open coupling scheme.

C. mSCTP vs. Mobile IP Results

From Fig. 2 and Fig. 3, and considering the same integration scheme, it can be observed that the WLAN delay and throughput are insensitive to the different types of mobility management schemes. Similarly, from Fig. 4–Fig. 9, it is evident that the different mobility management schemes have no significant impact on the different applications' response times and throughputs.

D. Handover Delay Calculations

In order to collect the handover delay in the case of mSCTP and Mobile IP, the *TotalHandoverDelay* was computed as the sum of *HandoverTrafficResponseTime* and *ReauthorizationResponseTime*.

Simulation runs were conducted for different integration settings. As shown in Table 2 the Mobile IP provides faster handover than mSCTP since mSCTP handover traffic is performed with application server. In addition, mSCTP over loose coupling produce very high handover delay when compared to other settings. Also, Mobile IP over loose coupling has higher delay than Mobile IP over open coupling due to authentications traffic between the AAA server and the HLR. However, the difference between both delays is very small (i.e. about 7 msec).

Table 2: Handover delay calculations.

Mobility Scheme	Integration Solution	Total Handover Delay (msec)
Mobile IP	Loose Coupling	467
Mobile IP	Open Coupling	404
mSCTP	Loose Coupling	4,066
mSCTP	Open Coupling	1,069

V. CONCLUSION

While generic integration solutions for 3G/WLAN networks are abundant in the literature, very few, if any, studies present performance evaluation for Internet applications for such heterogeneous networks. This paper attempts to bridge the gap and present a summary of performance figures obtained for four integration solutions. Using simulations the paper evaluates the performance of integrating a WLAN into a UMTS network in a hot-spot location such as an airport. The paper considers two integration schemes, open coupling and loose coupling, and two mobility management schemes, Mobile IP and mSCTP. Furthermore, the paper took into account varying both the traffic load and the application mix when conducting the simulations. The performance metrics considered in the paper include WLAN delay, WLAN throughput, each application response time, each application throughput, and the handover delay. The results show that the loose coupling integration scheme together with Mobile IP provides the best performance.

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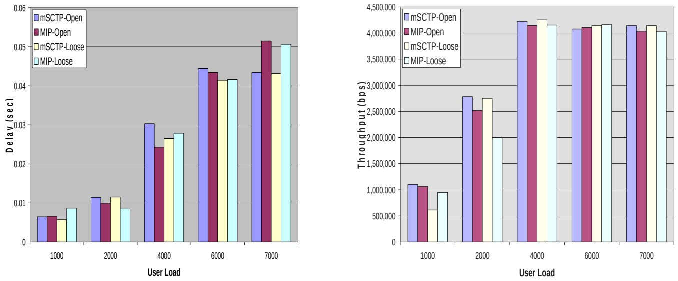

a) b)

Fig. 2. Performance of WLAN for traffic mix of 20/40/40: a) delay, b) throughput.

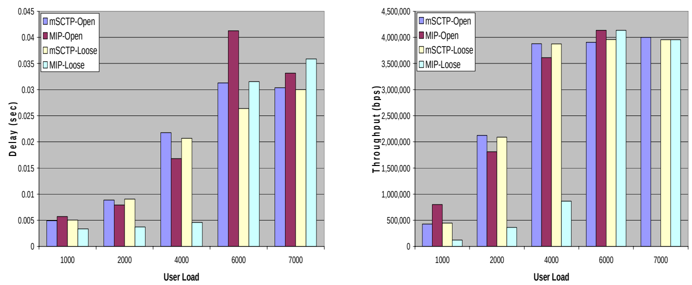

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Fig. 3. Performance of WLAN for traffic mix of 10/30/60: a) delay, b) throughput.

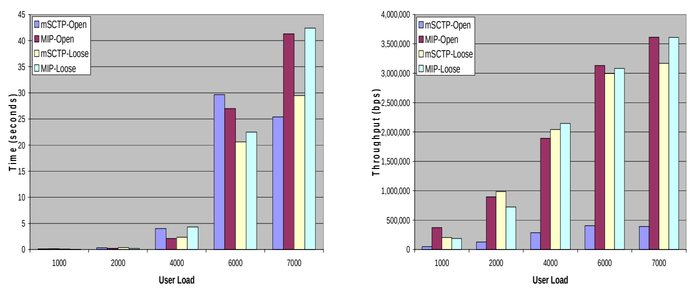

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Fig. 4. FTP traffic performance for 20/40/40 mix: a) response time, b) throughput.

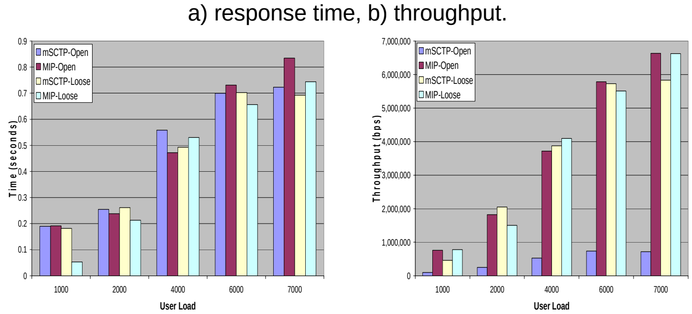

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Fig. 5. HTTP traffic performance for 20/40/40 mix: a) response time, b) throughput.

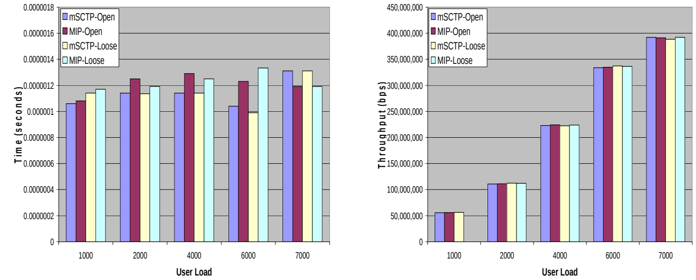

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Fig. 6. MMS traffic performance for 20/40/40 mix: a) response time, b) throughput.

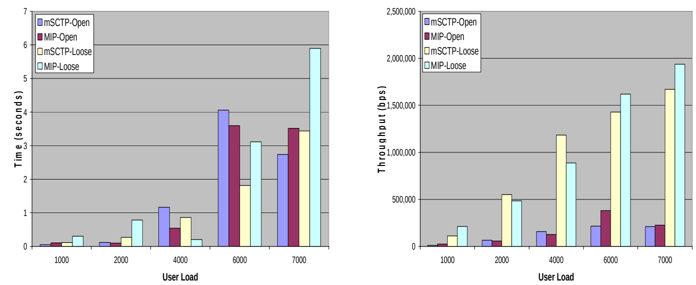

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Fig. 7. FTP traffic performance for 10/30/60 mix: a) response time, b) throughput.

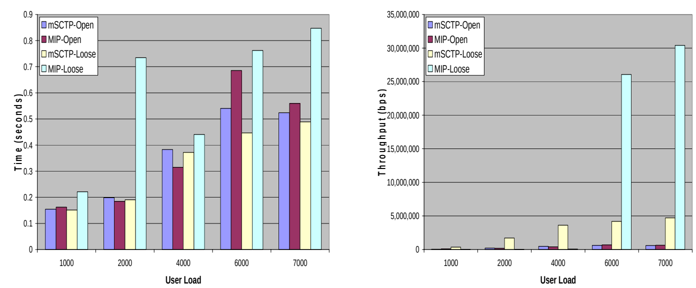

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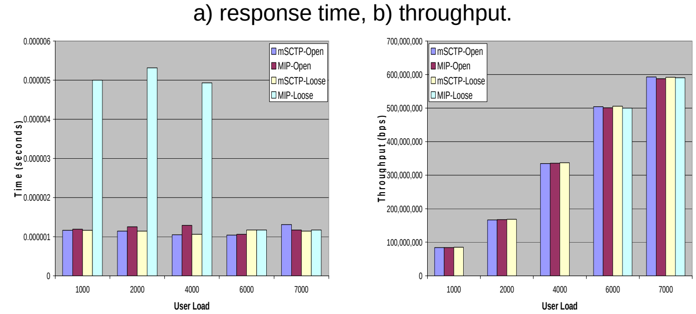
Fig. 8. HTTP traffic performance for 10/30/60 mix: a) response time, b) throughput.



a) b)

Fig. 9. MMS traffic performance for 10/30/60 mix: a) response time, b) throughput.