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

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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 3rd 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 UTMS 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

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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.

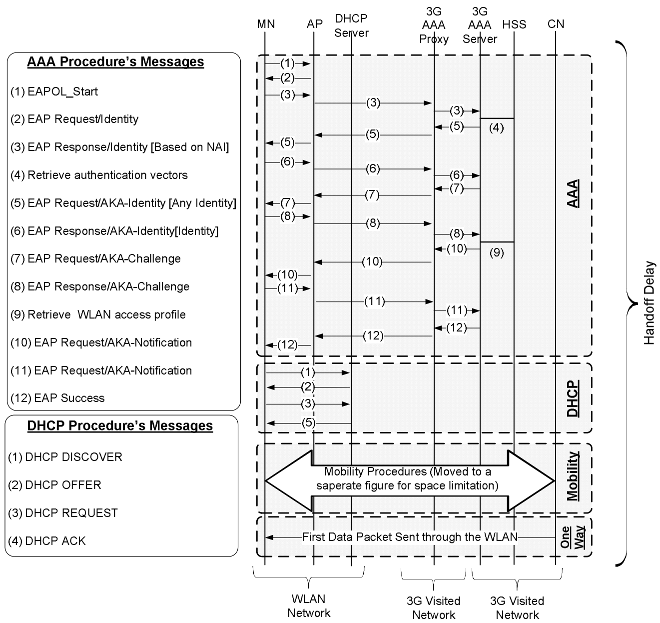

Figure 1. Vertical handoff from UTMS to WLAN based on 3GPP authentication.

II. VETICAL 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

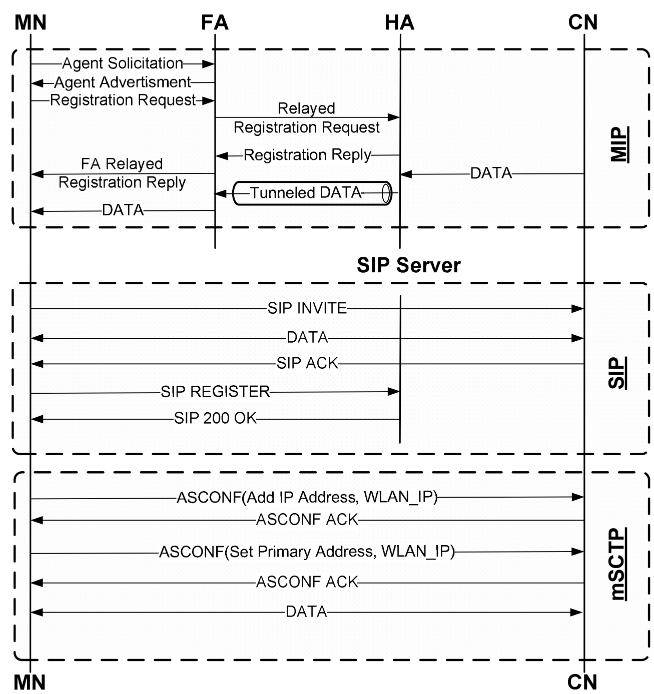

Figure 2. Signaling procedures for MIP, SIP, and mSCTP.

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].

OPENT 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, DCHP, and mobility procedures. The size of all the messages that contributes to the

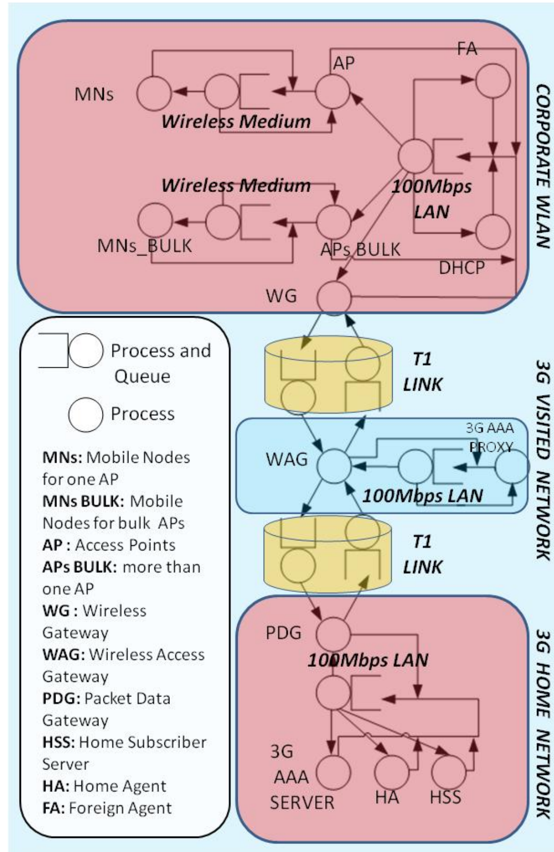

Figure 3. The Network of Queues model for 3G/WLAN integrated network[17].

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 λ, 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

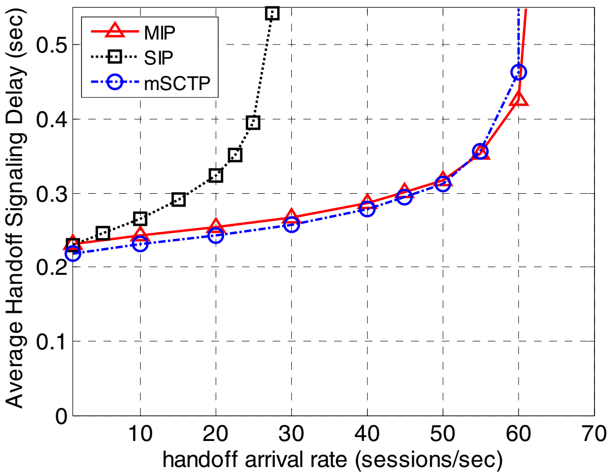

Figure 4. Handoff signaling delay utilizing MIP, SIP, and mSCTP.

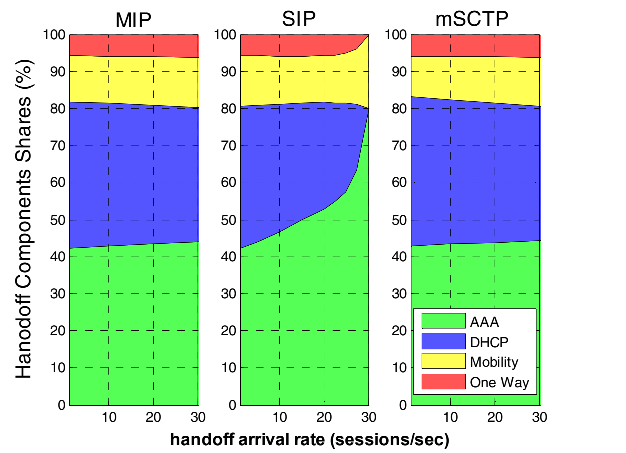

Figure 5. Weight of delay components relative to the overall handoff signaling delay for MIP, SIP, and mSCTP.

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 where as 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

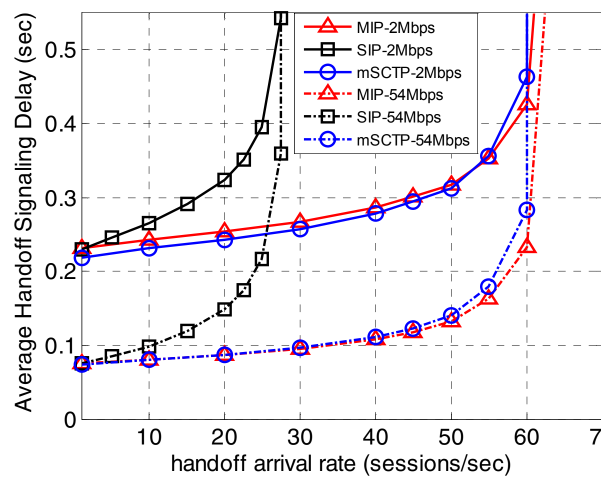

Figure 6. Comparing the total handoff delay with enhanced WLAN layout using 54Mbps WLANs

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 λ = 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.

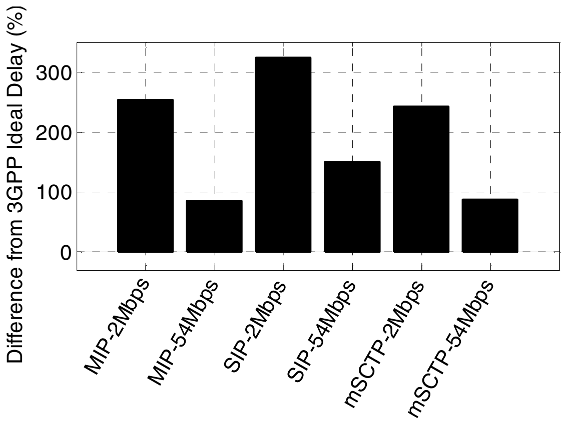

Figure 7. Ratio of handoff signaling delay based on MIP, SIP, and mSCTP relative to the 3GPP lower delay limit at λ = 20 sessions per second.

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.

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