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Research Article

SSVHOP: A Simple and Seamless Vertical Handoff Protocol for Loosely Coupled Integrated UMTS/WLAN Network

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Abstract: To provide anywhere at any time services in an integrated wireless networking environment, seamless mobility is one of the most important and challenging issues. Recent literature shows that the seamless mobility can be achieved by performing significant modifications in existing network designs and protocol architectures. However, such intensive modification increases the network implementation complexity and deployment cost. In this study , we have proposed a Simple and Seamless Vertical Handoff Protocol (SSVHOP) to attain the seamless mobility without implementing any major modification in the existing network topology or protocol architecture. The foundations of the underlying principle of the SSVHOP are based on a proactive RSS handoff triggering mechanism and multi-homing capabilities of mobile terminal. In addition, SSVHOP reduces the signaling and processing cost of the network to achieve low handoff delay and packet loss during upward and downward vertical handoff scenarios. Moreover, it has been observed that the proposed design also improves the data session performance by routing the data packets on the optimal route and by introducing an overhead free mechanism for data transportation in an integrated UMTS/WLAN network. We evaluated and compared the SSVHOP with the tight coupling mechanism. By analyzing mathematical modeling and simulation results, it is evident that the SSVHOP performs better than the tight coupling mechanism for all tested applications and measurement parameters.

Keywords: Heterogeneous wireless networks, loose coupling, seamless mobility, tight coupling, UMTS/WLAN integration, vertical handoff

INTRODUCTION

When the wireless terminal moves between the coverage regions of different access points, its ongoing session needs to be handed over from one access point to another access point. This mechanism is known as Handoff. If the handoff is performed in between the access networks which are representing the same technology (for example, WLAN to WLAN), this handoff is known as Horizontal handoff. On the contrary, if the handoff is executed in between the access networks which are representing different technologies (for example, UMTS to WLAN or vice versa), such kind of handoff is called Vertical Handoff (VHO) (Rizvi *et al*., 2010).

It is desired that the Next Generation Wireless Heterogeneous Networks (NGWHN) will provide seamless VHOs. A handover is considered seamless when it provides both i.e., smooth (no or very little packet loss) and fast (low latency) switching of active connection between the heterogeneous access networks (Barja *et al*., 2011; Dunmore and Pagtzis, 2005). Along with seamless VHOs, the ease of implementation of internetworking system to support seamless mobility is one of the most important parameters to bring the integrated network architecture design into reality.

In order to prevent service disruptions and to achieve a seamless handover during the movement of the mobile nodes, various standard mobility management techniques have been developed at different layers of the TCP/IP protocol stack. The European Telecommunications Standards Institute (ETSI) has divided internetworking approach into two coupling mechanisms; Tight and loose (Salkintzis *et al*., 2002). The tight coupling mechanism operates on layer 2, whereas, above layer 2 all the integration designs come under the category of loose coupling.

In general loose coupling mechanism suffers from the high handoff latencies and packets losses; however, it provides an independent integration mechanism for the existing networks without significant modifications (Liu *et al*., 2010), which consequently leads to the ease of deployment. In contrast to the loose coupling mechanisms, the tight coupling mechanism provides the best solution in terms of handoff latency and packet loss. Nevertheless, tight coupling is the most complex approach to be implemented in an integrated network design as it requires major modification in the existing

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network protocols. Moreover, tight coupling introduces additional network component emulators to establish compatibility among different networks (Liu *et al*., 2010; Nguyen-Vuong *et al*., 2007). Since, the internet service providers/ telecommunication operators all over the world have already invested an enormous amount to the fully functional legacy networks; significant modifications in existing protocols, additional mobility management components or a global roll out with a new technology would not be easily accepted.

This study proposes a novel Simple and Seamless Vertical Handoff Protocol (SSVHOP) which is capable to provide the seamless mobility in an integrated UMTS/WLAN network during upward (WLAN to UMTS) and downward (UMTS to WLAN) handoffs. Logically, this protocol can be considered as a cross layer protocol that performs the handoff functionalities over network layer by receiving the inputs from data link layer. The main contribution of SSVHOP is twofold. First, for a user roaming across the UMTS and WLAN coverage regions, we have proposed a proactive RSS based mechanism. These data link layer hints are used to trigger an early handoff decision on network layer. Furthermore, an optimized signaling and processing cost mechanism has been designed and evaluated to reduce the handoff latency and packet loss. Second, for the stationary mobile user's data session with the internet server via WLAN access network of integrated UMTS/WLAN network, an optimal routing mechanism is proposed which reduces the number of network hops to send data packets to the destination node. In addition to the optimal routing mechanism, an overhead free technique is used which consequently enhances the data service experience of the mobile user in terms of faster email, FTTP and HTTP service response time.

INTEGRATION MECHANISMS

Loose coupling: In the loose coupling internetworking, networks are independently deployed and interconnected. From the UMTS network point of view, as illustrated in the Fig. 1, this interconnecting point exists after the Gateway GPRS Support Node (GGSN), i.e., at the Gi interface (Salkintzis *et al*., 2002; Tom *et al*., 2006). Therefore, WLAN network bypasses the UMTS core network for the establishment of a direct connection with the external Packet Data Networks (PDNs) and at the same time maintains an indirect connection with the UMTS network. For the mobility management, networks often use the Mobile IP mechanism (Nguyen-Vuong *et al*., 2007; Liu *et al*., 2010).

In order to achieve seamless mobility and to prevent service distribution while wireless client is roaming in an overlaid wireless heterogeneous access network, Internet Engineering Task Force (IETF) has proposed several mobility management protocols at different layers of TCP/IP protocol stack. The Mobile IPv4/6 (MIPv4/6) (Perkins, 2002; Johnson *et al*., 2004) along with its several extensions like Fast Mobile IPv4/6 (FMIPv4/6) (Koodli, 2005) and Hierarchical Mobile IPv4/6 (HMIPv6) (Soliman *et al*., 2008) are suggested for the network layer mobility management. The mobile Stream Control Transmission Protocol (mSCTP) (Koh *et al*., 2005) and Session Initiation Protocol (SIP) (Rosenberg *et al*., 2002) are proposed for the transport and application layer mobility management, respectively. However, none of the aforementioned protocol can be considered as the complete feasible solution for the seamless mobility.

The MIP and SIP based mobility management requires the introduction of several network nodes in the existing network infrastructure. For example, in case of MIP and SIP, Home Agent (HA) and SIP servers are needed to be installed in the core network to perform the vertical handoffs, respectively. Furthermore, handoff latency is very high which is not acceptable to fulfill the requirements of NGWHNs. Unlike techniques based on Mobile IP or SIP, the SCTP-based vertical handover scheme does not require any additional network components (Ma *et al*., 2004). Nevertheless, the well established and strong competitor i.e., TCP/UDP transport protocol is the major obstacle in the deployment of the mSCTP protocol. Since the global roll out of SCTP by replacing widely deployed TCP and UDP based devices are extremely difficult, if not impossible.

Tight coupling: In the tight coupling internetworking approach, WLAN is connected directly to the UMTS core network i.e., either with UMTS Serving GPRS Support Node (SGSN) or Gateway GPRS Support Node (GGSN). Since the WLAN data traffic traverse to the internet via UMTS network, therefore, the UMTS mobility management features are applied to the integrated networks. Consequently, an intra-domain equivalent handoff performance can be achieved by using tight coupling mechanism. However, as depicted in Fig. 1, the main drawback is the introduction of the additional components, i.e., the SGSN Emulator (SGSNE) and the RNC Emulator (RNCE) or gateway devices, for the protocols conversion and data routing between UMTS and WLAN networks. Such operations require intensive modifications in the existing protocols and network architecture (Nguyen-Vuong *et al*., 2007; Liu *et al*., 2010). Moreover, it increases the operational complexities and overall cost of network deployment.

Integration at the GGSN: The GGSN based integration mechanism has been widely studied and suggested by several researchers in the literature (Tsao and Lin, 2002a; Benoubira *et al*., 2011; Varma *et al*., 2003; Altwelib *et al*., 2007; Altwelib and Ashibani, 2005; Tsao and Lin, 2002b; Buddhikot *et al*., 2003). When GGSN is the integration point, SGSNE or gateway is required to perform the internetworking. In this type of integration, Gn interface is the integration point of two networks (Tom *et al*., 2006). The SGSN

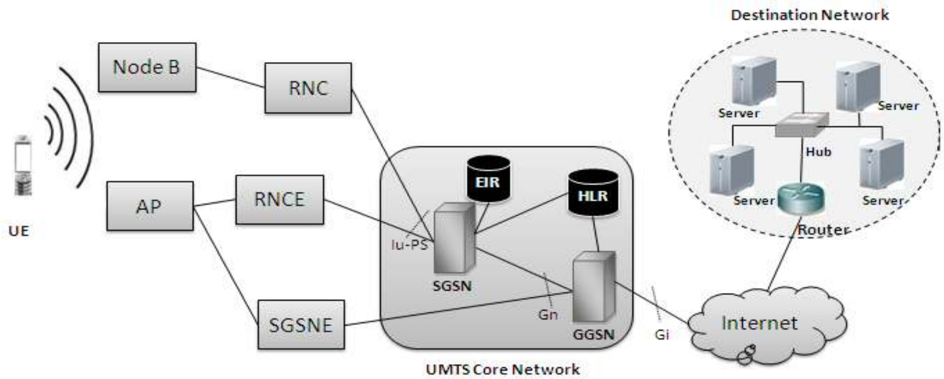

Fig. 1: UMTS/WLAN tight and loose coupling approaches

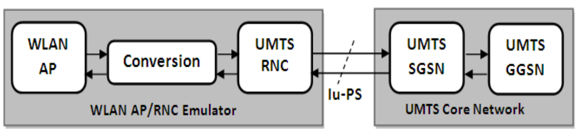

Fig. 2: RNC emulator internetworking with the UMTS core network

emulator/gateway hides the WLAN access network from UMTS network and performs the functionalities as it were another UMTS SGSN (Buddhikot *et al*., 2003). Hence, the UMTS considers the WLAN AP region as its own UMTS routing area.

Integration at the SGSN: When the integration point is SGSN, as illustrated in the Fig. 1, an RNC emulator is required to perform the internetworking between UMTS and WLAN networks. As presented by Pries *et al*. (2008, 2006), logically an RNC emulator can functionally be divided into 3 sub-functional entities. As shown in Fig. 2, an RNC emulator integrates the WLAN access point and standard UMTS RNC operations. Moreover, to establish the compatibility between the WLAN and UMTS networks, a conversion module is introduced which basically performs the packet translation from WLAN format to UMTS and vice versa.

The UMTS and WLAN integration is achieved by connecting the WLAN access network with the Iu-PS interface (Salkintzis *et al*., 2002). In such an internetworking scenario, WLAN access point/RNC emulator is connected to the UMTS network in the similar manner as it is another UMTS Radio Access Network (RAN). A UMTS network deals with WLAN as it is its own RAN and finds no difference between UMTS and WLAN access networks. The SGSN based integration mechanism can be found in Pries *et al*. (2008) and Kaur and Singh (2012).

In Pries *et al*. (2008), to maintain the service continuity with the seamless mobility, the authors introduced a vertical handoff protocol based on the tight coupling approach. In addition to the RNC emulator, a vertical handoff management module is introduced at the Mobile Equipment (ME) that operates below the IP and above the UMTS GMM layer in the ME protocol stack. Moreover, in order to initiate/continue the packet data sessions from WLAN to external PDNs via UMTS, a WLAN GMM module has been introduced below the IP and above the WLAN_MAC module. This WLAN GMM module works in a similar way as the UMTS GMM does. Therefore, GMM attach and PDP context messages can be sent to UMTS network through WLAN network. It was observed that the handoff blackout time (i.e., when the ME is neither connected to the UMTS nor to the WLAN network) is fast enough to support the real time services.

In Lampropoulos *et al*. (2007), the authors proposed a session based VHO mechanism in which, instead of a single network, each active connection of mobile terminal can be served by different access networks. However, to achieve this, extensive modifications have been made by introducing protocol layers in existing RNC and SGSN components. Moreover, they suggested a new network component; termed as Emulated Radio Network Controller (ERNC) for the internetworking of UMTS/WLAN networks. Similarly, Patil (2011) introduced a WAG component to establish compatibility between UMTS and WLAN networks. The handover delay was found to be few hundred mili-seconds.

It is worth mentioning here that even in case of heterogeneous networking environment, the tight coupling mechanism provides as low handoff delays as the handoff were performed among the AP points of the same wireless access network. This kind of intra-domain handoff performance can be achieved by reducing the signaling and processing cost during the handoff. This simply advocates that if more signals are exchanged and more nodes are participated to perform a handoff, subsequently the HO delay will be higher. Similarly, if less signaling is performed and less number of nodes taking part in the handoff process, a faster handoff can be executed. For example, as proposed by Pries *et al*. (2008), the HO triggers by exchanging just three signaling message between ME and SGSN node.

Analytically, the total handoff delay of tight coupling mechanism (D_{TC}) can be expressed by summing the total Signaling (S_{COST}) and nodes Processing (P_{COST}) cost:

$$D_{TC} = S_{COST} + P_{COST}$$

The S_{COST} is proportional to the distance between communicating nodes and type of media signals traverse to. However, the P_{COST} depends on the characteristic and functionalities of the network component. Let $D_{ME\text{-}RNCE}$ and $D_{RNCE\text{-}SGSN}$ be the hop distances between ME to RNC emulator and RNC emulator to SGSN, respectively. These hop distances remains same in both direction i.e., ME to SGSN or SGSN to ME communication cases. The $PRNC$, P_{RNCE} and P_{SGSN} represent the processing cost required by the RNC, RNC emulator and the SGSN to act in accordance with the received signaling message. These processing delays occurred because the SGSN has to establish a GTP tunnel with the RNC and RNC emulator to send and receive the Packet Data Units (PDUs), in case of WLAN to UMTS and UMTS to WLAN switching. Therefore, the total HO delay equation can be expressed as:

For UMTS to WLAN:

$$D_{TC} = 3\left(D_{ME-RNCE} + D_{RNCE-SGSN}\right) + P_{SGSN} + P_{RNCE}$$

For WLAN to UMTS:

$$D_{TC} = 3\left(D_{ME-RNCE} + D_{RNCE-SGSN}\right) + P_{SGSN} + P_{RNC}$$

THE PROPOSED MECHANISM

The Proposed mechanism, Simple and Seamless VHO protocol (SSVHOP) mainly accomplishes the two most fundamental requirements of the NGWHNs. Namely; these are ease of implementation and seamlessness of VHOs. Ease of implementation is achieved by introducing an integration mechanism that does not require significant protocol alteration or introduction of additional network components in existing UMTS and WLAN networks. This simplicity and straightforwardness were the main challenging issue in case of tight coupling mechanism. As discussed earlier, loose coupling provides an independent protocol engineering and network deployment mechanism. Consequently, it reduces the network deployment and operational complexities. Nevertheless, it is unable to provide seamless VHOs. In contrast, the proposed SSVHOP attains the seamless VHOs by introducing proactive multi-homed VHO triggering mechanism in Dual Mode Mobile Terminal (DMMT). Therefore, an efficient VHO is performed by sending most of the VHOs signaling messages to the target network in parallel with the already established data session with the previous network. Thus, only few messages will influence the overall VHO performance.

The SSVHOP operates when the WLAN AP is connected with the UMTS GGSN. However, unlike the techniques aforementioned which connect WLAN AP on Gn interface, the SSVHOP operates when WLAN AP is connected with the GGSN at Gi interface. The Gi interface has been chosen as the point of integration because when the two networks are integrated through Gi interface, the WLAN network appears as an external PDN to the UMTS. Consequently, such integration allows the independent deployment and traffic engineering of WLAN and UMTS networks. This permits the network service providers to take advantage of other providers' existing deployed networks. As no emulator/gateway is required for the integration, as a result, only minimal alterations in existing network infrastructure are needed to be performed. Hence, integration does not require major investments.

When the UMTS and WLAN clients are located in the UMTS cell and WLAN AP coverage regions, respectively and accessing the Internet Servers (ISs) then UMTS and WLAN network will be operated completely independent and transparent to each other. No protocol or traffic engineering alteration would be required. In this case, both networks will operate as no integration is performed. The UMTS user will send requests and receive responses to ISs through its UMTS core network without any modified procedure. Similarly, the WLAN client will send requests and receive responses via its WLAN network. In this instance, GGSN appears as a normal router which is routing the packets to/from the internet servers to the WLAN network.

However, in case of a roaming user minor modifications in the existing GGSN mechanism and signaling procedure are required, which has virtually no significance when compared with the overall performance improvements and reduction in the telecommunication service providers' capital investment. Therefore, we advocate the aforementioned integration design as a preferred architecture for the UMTS/WLAN network integration and, consequently, use it for the analysis of proposed SSVHOP mechanism for the rest of the study.

In addition, the authors proposed a Dual Mode Mobile Terminal (DMMT) in Rizvi and Saad (2012) for the integrated UMTS/WLAN network design. Interested readers are referred to Rizvi and Saad (2012) for detailed design consideration and operations of DMMT. However for the completeness few functionalities of DMMT are described here.

Actually in the case of integrated networks, a mobile client is required to have UMTS and WLAN interfaces to maintain the session continuity during

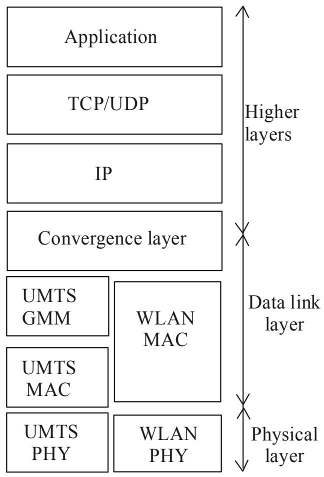

Fig. 3: DMMT protocol stack

handover between heterogeneous networks. For example, consider a user is located in UMTS cell and initiates a session with the internet server with its UMTS interface, when it moves to a region where it receives beacon messages of the WLAN access network; it must switch its active connection to the WLAN to enjoy the high bandwidth and low cost service. Similarly, when it is moved away to the WLAN network coverage, it must switch its active connection to the UMTS to keep its session alive.

In practice, the main difference in WLAN and UMTS workstations exist after the higher layers. Therefore, the proposed DMMT contains the MAC and Physical layer of both i.e., UMTS and WLAN technologies, as shown in Fig. 3.

Furthermore, if the packets are coming from the upper layers, a Convergence Layer (CL) was designed which provides the intelligence to the DMMT to switch the packets to the intended UMTS or WLAN link layer module. Functionally, this CL operates below the IP layer. From UMTS and WLAN network perspectives, this layer operates above the UMTS GMM and WLAN MAC layers, respectively. That is why, we called this CL as 2.5th layer which not only performances the functionalities of routing packets and dealing with the IP address allocation like a network layer, moreover, it keeps on monitoring the link layer RSS value of the WLAN interface for efficient and proactive network switching decisions.

SIMULATION DESIGN ARCHITECTURE

In this section, we are defining our simulation network design and parameters for the integration of UMTS and WLAN networks. The simulation scenarios were designed on OPNET Modeler tool. The network design consists of three major network parts: UMTS network, WLAN network and Internet Service Provider (ISP). In this network design, only PS domain is considered and CS domain of the UMTS network is neglected for simplicity. This simulation scenario is illustrated in Fig. 4. A UMTS network is composed of Node-B, Radio Network Controller (RNC), SGSN and GGSN. A WLAN network is composed of WLAN AP router, which is connected with the GGSN. The voice, email, HTTP and FTP servers are located at the back of the internet cloud to facilitate the data services to the DMMT. The WLAN AP is located within the UMTS coverage area. This simulation design reflects a real-world scenario where WLAN is operated as a hotspot under the coverage of UMTS cell. Such hotspots serve airports, campuses, buildings, train stations, hotels, etc.

In the simulation scenario, the RNC is connected with the Node-B and SGSN with the ATM OC-3 link that supports data rate up to 155.52 Mbps. The GGSN is connected to the SGSN with the PPP DS-3 bi-directional link that supports data up to 44.736 Mbps. As illustrated in Fig. 4, the WLAN AP is connected to the GGSN with the PPP DS-3 bi-directional link that reflects the loose coupling architecture used for the proposed SSVHOP evaluation. For comparison purposes, in addition to the loose coupling design, a tight coupling architecture has been designed and simulated separately. This tight coupling design contains a WLAN AP/RNC emulator, which is capable to process the UMTS messages and performs the GMM and PDP functionalities. Here, the RNC emulator is connected with the SGSN with the PPP DS-3 bi-directional link. The UMTS and WLAN access networks support 2 and 11Mb/s, respectively.

UMTS to WLAN switching: In this simulation scenario, initially the DMMT is located inside the coverage region of Node-B. After the successful establishment of UMTS data session, the DMMT starts moving towards the WLAN AP coverage region. A detailed UMTS connection establishment procedure has been presented in Rizvi and Saad (2012). Even the data session is ongoing via UMTS network; the DMMT continuously scans the nearby wireless networks for the possibility of connection establishment with other high speed wireless network. In this case, it is WLAN. As illustrated in Fig. 5, when the WLAN_MAC module of DMMT starts receiving the beacon frames from the WLAN AP, it notifies the CL module about the existence of WLAN network by sending Beacon Received message. On receipt, the CL module gives direction to the WLAN_MAC for the association with the WLAN AP by sending a WLAN Activation Required message. For the association with the WLAN, a three way handshake procedure is taken place between the WLAN_MAC and WLAN AP. The WLAN_MAC sends an Association Request message to the WLAN AP, which is replied back with the Association Response. Finally, the WLAN_MAC sends an Association Acknowledge message to WLAN AP and then DMMT connects to the WLAN network. This successful association information is forwarded to the CL module by the WLAN_MAC with the WLAN Activation Reply.

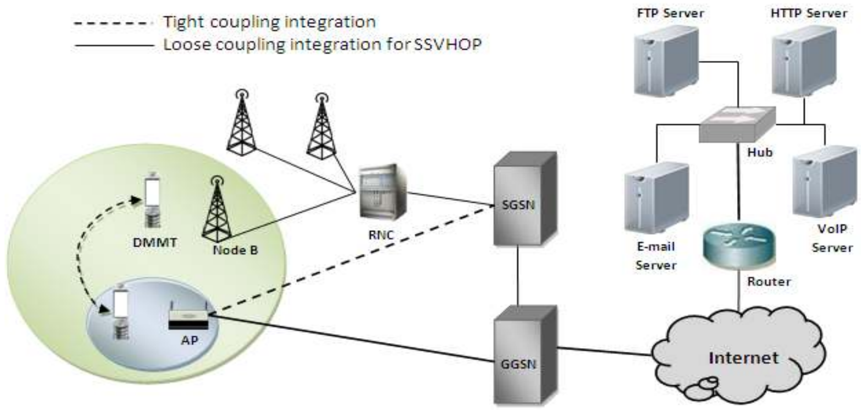

Fig. 4: Simulation network design for SSVHOP and tight coupling mechanism

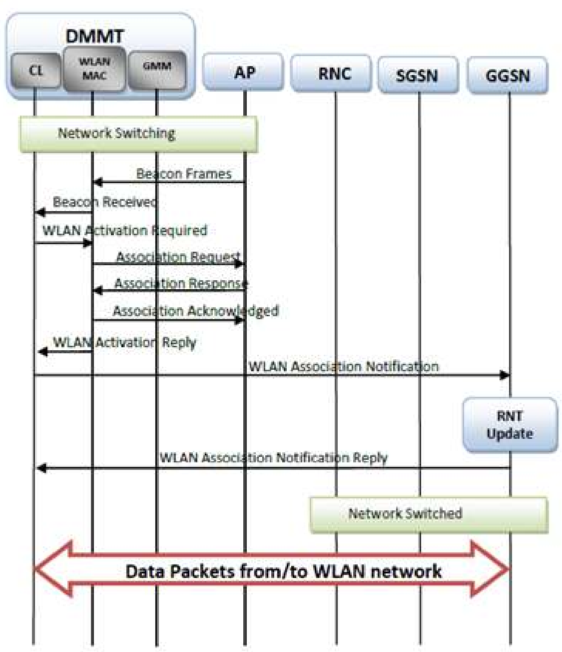

Fig. 5: SSVHOP for UMTS to WLAN switching

Now, the DMMT is connected to the WLAN network with the IP address assigned by the WLAN network. However, to route the internet servers PDUs not from the UTRAN but from the WLAN network, the DMMT will have to notify the GGSN about its relocation. For this, the DMMT CL module will send a WLAN Association Notification message to the GGSN. This notification message contains the WLAN and UMTS IP addresses. Actually, by this double entry IP address message the GGSN will be notified that this is the same terminal, who initiated the session in the UTRAN with the dynamically assigned UMTS IP address, now moving to the WLAN with the notified WLAN IP address. On receipt of this notification, the GGSN will keep this entry in a "Roaming Notification Table (RNT)". This relocation process is completed when the GGSN sends a WLAN Association Notification Reply message to the CL. Henceforth, all the PDUs for the DMMT UMTS IP address will be routed to the mapped WLAN IP. Therefore, instead of sending the PDUs towards SGSN via Gn interface, the GGSN will start sending the PDUs on its Gi interface, which is connected to the WLAN network. From the Fig. 5, the total handover delay can analytically be computed as:

$$D_{SSVHOP} = D_{L2} + S_{NOTIFICATION} + P_{GGSN}$$

where, D_{L2} represents the WLAN link establishment delay. The $S_{Notification}$ is the signaling cost required to send the WLAN association notification to the GGSN ($D_{DMMT\text{-}GGSN}$) and receive back the acknowledgement ($D_{GGSN\text{-}DMMT}$). The P_{GGSN} shows the processing delay required by the GGSN to update its RNT with the double IP address entry provided by the DMMT so that all the subsequent PDUs can be sent to the roamed DMMTs without any service interruption. Therefore, the above expression can be written as:

$$D_{SSVHOP} = D_{L2} + 2D_{GGSN-DMMT} + P_{GGSN}$$

It is worth mentioning here that in the proposed SSVHOP mechanism, we enabled the multi-homing functionalities in DMMT. Therefore, when the DMMT is located in an overlapping zone meanwhile establishing link layer connection with the WLAN network by WLAN_MAC module and sending the WLAN association notification to the GGSN, the DMMT will keep alive its session from the UTRAN by its RLC_MAC module and continuously receiving the PDUs without any service interruption. Consequently, the handoff delay will depend on the time required by the GGSN to update its RNT and the signaling cost associated with the WLAN association notification reply.

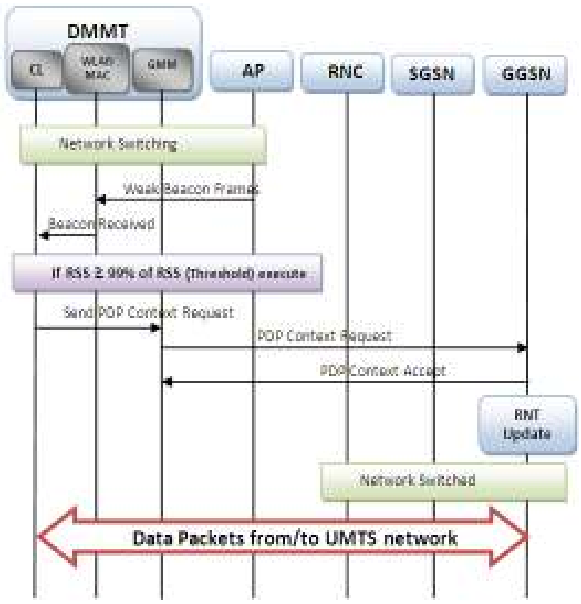

Fig. 6: SSVHOP for WLAN to UMTS switching

Therefore, by omitting the D_{L2} and dividing the $S_{Notification}$ cost into the half, the total handoff delay of the proposed SSVHOP mechanism can be expressed as:

$$D_{SSVHOP} = D_{GGSN - DMMT} + P_{GGSN}$$

WLAN to UMTS switching: When the DMMT starts moving away from the WLAN AP, the RSS value will be decreasing accordingly. These regular RSS dropping will be informed to the CL module by the WLAN_MAC so that CL can be notified that the DMMT is moving away to the AP. These early notifications of RSS deterioration are essential because if no such an early notification mechanism is present then DMMT may cross the WLAN coverage region and lost its connectivity with the WLAN AP, even without establishing its connectivity with the UMTS network. Since, in case of WLAN to UMTS network switching, situation can relate to a non-overlapping region and a Break-before-Make event will take place. Consequently, an abrupt service disruption or a call break event can be experienced. Therefore, to avoid such events and to adopt a Make-before-Break mechanism, we designed a proactive approach to avoid the Break-before-Make situations. When CL is constantly notified by the deteriorated RSS signals then, instead of establishing UMTS connectivity after losing WLAN connectivity, an early decision of HO will be made by the CL. As a result of this proactive approach, a PDP context request will be sent to UMTS network by the GMM module at:

$$RSS \geq 99\% RSS_{Thershold}$$

Consequently, as shown in Fig. 6, before breaking the active connection with the WLAN network, the DMMT will start establishing its active session with the UMTS network by sending PDP context request.

As explained in Rizvi and Saad (2012), in order to initiate or continue a data session via UMTS network a DMMT has to establish a PDP context to the UMTS gateway, i.e., UMTS GGSN. To keep it simple, only the PDP context activation request and accept are shown in the Fig. 6 and other messages like RAB assignment and RB setup is suppressed, although we implemented them in simulations.

In case of WLAN to UMTS network roaming, the GMM module which also has the functionalities of SM will send a PDP context activation request message to the GGSN by inserting the UMTS_IP in the PDP address field. Actually, at this stage this UMTS_IP is basically provided by the CL. This is the same UMTS_IP address which was acquired, when the DMMT established its connectivity to the UMTS network first time. On receipt, the GGSN will search and find a matching entry in its RNT, which is mapped with the WLAN_IP. This will be a clear indication that this is the same DMMT who initiated its session in the UMTS network and then it moved to the WLAN network, now returning back to its home UMTS network. Therefore, it is desired that after performing the PDP context, the PDUs should be sent via Gn interface. Consequently, only the processing delay required by the GGSN for switching the interfaces will influence the handoff delay and afterwards, all the packets destined to the DMMT will be sent by using normal UMTS procedure. As a result, the total handover delay for the proposed mechanism can analytically be computed as:

$$D_{SSVHOP} = P_{GGSN}$$

As mentioned before, the P_{GGSN} shows the processing delay required by the GGSN to update its RNT. However, unlike the UMTS to WLAN handover case, this time GGSN will update its RNT by deleting the WLAN IP address entry in its table.

SIMULATION RESULTS AND DISCUSSION

In the simulation scenarios, DMMTs communicate with the internet FTP, HTTP, voice and E-mail servers. Table 1 represents applications and measurement parameters tested for the integrated UMTS-WLAN networks. These applications match different UMTS QoS classes. A conversational class represents real time traffic flows such as VoIP. For the real time services, three different codec types have been evaluated which includes G.711, also known as Pulse Code Modulation (PCM), which operates at the data rate of 64 kb/s, GSM FR (data rate of 13.2 kb/s) and G.723.1 (data rate of 5.3 kb/s). Of the above three codecs, the G.711 codec is the most widely supported and implemented codec in IP

Table 1: Description of the tested applications and measurement parameters

Application	QoS class	Measurement parameters	Size (bytes)	Protocol
PCM, GSM and G.723.1 encoded voice	Conversational	Hand off delay and pocket loss	80, 33, 20	UDP
E-mail	Background	Download response time	1-5 kilo	TCP
FTP	Background	Download response time	100-1000 kilo	TCP
HTTP	Interactive	Object response time	1-2 kilo	TCP

telephony. Generally, PCM is considered a base standard of codec. The G.723.1 and GSM are the most widely used codecs in GPRS and UMTS networks. The background class represents both FTP and E-mail services and interactive class corresponds to web browsing (HTTP).

In this study, two different simulation scenarios have been designed and evaluated. For the VHO delay and transient packet loss performance assessment, only real time services were used inside the integrated UMTS/WLAN network. Both upward and downward VHO cases were evaluated with all described codecs.

On the other hand, to analyze the data service performance in an integrated UMTS/WLAN network only non-real time services were used by increasing the packet sizes gradually. In this simulation scenario, the DMMT is located inside the overlaid WLAN coverage region of the integrated network. Since the DMMT is static in this case, therefore, all the PDUs were served by the WLAN access network. This simulation scenario illustrates the effectiveness of the SSVHOP and tight coupling mechanism on the network performance. More precisely, in terms of data service performance, this simulation scenario represents how efficiently a WLAN is operated when it is coupled with the UMTS network by using SSVHO and tight coupling mechanism. As described in Liu and Zhou (2005) it is desired that the PDUs should follow the optimal route to reach the destination. The optimal route is described as the route which requires the least number of network hops, moreover, alleviates the UMTS core network burden by bypassing the UMTS SGSN to reach to the destination. Figure 4 clearly illustrates that to send the PDUs from internet server to the DMMT; the SSVHOP achieves the optimal route. In contrast to the tight coupling mechanism, in which PDU traffic follows: IS→ Internet→ GGSN→ SGSN→ RNCE→ DMMT, in SSVHOP PDU will traverse IS→ Internet→ GGSN→ AP→ DMMT. This means not only SGSN is bypassed; moreover, an optimal route is also attainted by decreasing number of network hops.

Furthermore, since the tight coupling mechanism requires a GTP tunnel establishment between SGSN and RNC emulator, therefore, higher number of overheads would be required to send the PDUs from IS to DMMT compared to the "overhead free" SSVHOP mechanism. Because of the aforementioned reasons, SSVHOP should perform better than the tight coupling mechanism for the data traffic.

The mean handoff delay of 60 simulation runs is illustrated in Fig. 7. The average vertical handoff delay

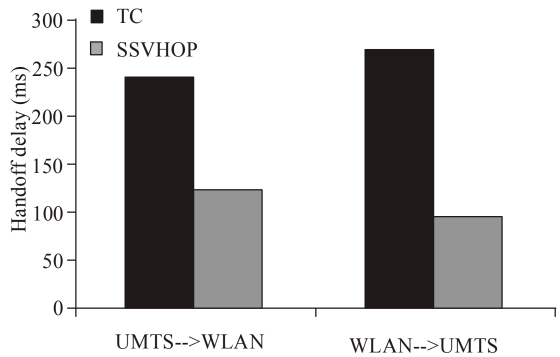

Fig. 7: Mean handover delays

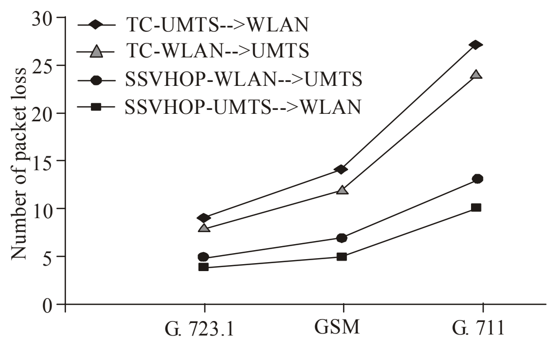

Fig. 8: Number of packet loss

for SSVHOP and tight coupling mechanism can be stated as follows. In case of tight coupling mechanism, the average vertical handoff delays for the UMTS to WLAN and WLAN to UMTS network switching are 240 and 270 ms, respectively. In contrast to the WLAN network switching, when the DMMT moves to UMTS network from WLAN network, relatively higher transmission cost because of the higher network hops, would be required for the first PDU to be received over the UMTS access network after performing the VHO. In consequence, it is quite obvious that upward VHO delay is higher than downward VHO delay. On the other hand, in case of SSVHOP mechanism, the average VHO delays in upward VHO required less delay for network switching. It can be observed that, by implementing the proposed SSVHOP mechanism, the average VHO delay in case of UMTS to WLAN and WLAN to UMTS network is reduced to 125 and 95 ms respectively. Since, we implemented a proactive RSS based mechanism for upward VHO case, therefore, even before reaching to the WLAN boundary a UMTS connection establishment mechanism was triggered. Consequently, only the processing cost required by the

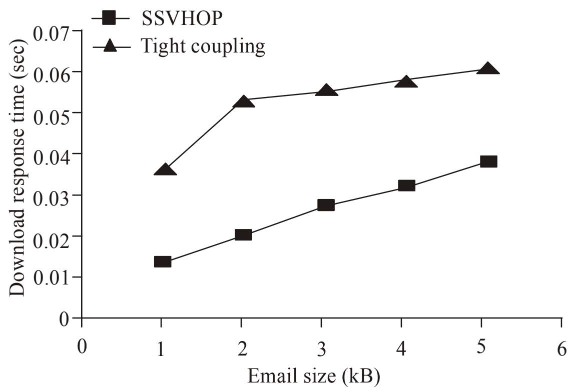

Fig. 9: Email: download response time

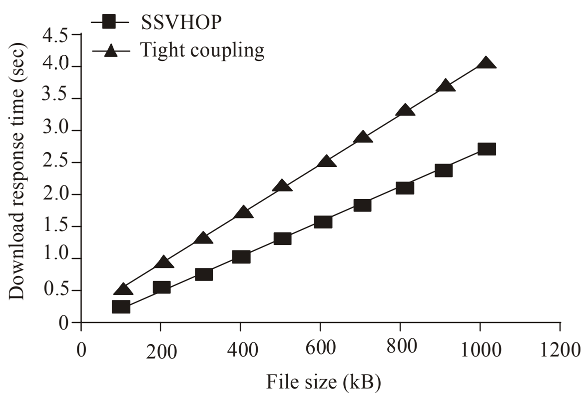

Fig. 10: FTP: download response time

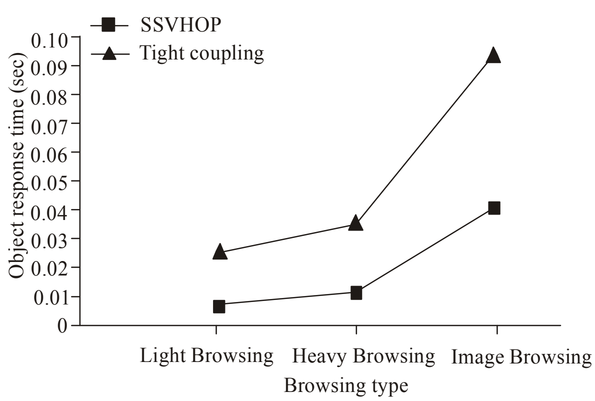

Fig. 11: HTTP object response times

GGSN will be required to perform the VHO. On the contrary, for the download VHO, in addition with the PGGSN, signaling cost will also incorporate in the VHO cost. Therefore, in SSVHOP mechanism, compared to the downward VHO, an upward VHO required less delay for network switching.

In general, we can see that the SSVHOP requires less VHO delay for both upward and downward VHO cases, compared to tight coupling mechanism because of the proactive RSS based protocol and less signaling and node processing cost requirement for the handoffs.

Figure 8 plots the number of packet loss with the corresponding codec mechanism used. Both UMTS to WLAN and WLAN to UMTS scenarios are illustrated. We can see that the packet losses increase with the faster packet arrival rate of data packets by different codecs. As stated previously, the tight coupling mechanism incurs high VHO delays; it also suffers with higher packet loss compared with the SSVHOP mechanism. These differences of packet loss by using the SSVHOP and tight coupling mechanism are mainly contributed by the difference of handoff delay of the corresponding integration mechanisms used.

In order to evaluate the data services performance in integrated UMTS/WLAN network, we consider a static DMMT located inside the WLAN access network and accessing the internet servers by using the SSVHOP and tight coupling mechanism. Figure 9 and 10 illustrate the average download response time metric investigation with the corresponding file sizes. The download response time represents the time elapsed between the requests send to the IS and receive the requested file from the IS. The connection setup signaling delay is also included in this time. For diversity purposes, email and FTP file sizes of 1-5 and 100-1000 kilo-bytes, respectively, have been used for the course of 3 h simulation run time. We can obverse the more rapid response by SSVHOP mechanism compared with the tight coupling mechanism. For example, as illustrated in the Fig. 9, for the case of 5 kilo-bytes email file, it takes about 0.038 sec for the user to download the entire file by using the SSVHOP. Whereas, the same file can be downloaded in 0.060 sec for the user accessing the IS by using the tight coupling mechanism.

It can be noted that, as shown in the 10, for the small FTP file sizes the value of the download response time of SSVHOP and tight coupling mechanism are relatively closer. However, as the file size increases, it takes longer time to download the file with the tight coupling architecture compared to the SSVHOP. For example, for the file size of 100 kilo-bytes, SSVHOP requires 0.27 sec to download the complete file. On the other hand, the same file can be downloaded in about 0.53 sec for the user accessing the internet server by the tightly coupled integrated network. Conversely, for the FTP file size of 1000 kilo-bytes download response time reaches to 2.67 and 4.03 sec for SSVHOP and tight coupling mechanism, respectively.

For web browsing, HTTP services have been simulated for the simulation run time of 3 h. As represented in Fig. 11, several variations of web browsing have been used with the different parameters. In this study, we used three different variations of browsing i.e., light, heavy and image browsing. Light and heavy browsing contains the object size of 500 and 1000 bytes that consist of page inter-arrival time of exponential distribution having a mean outcome of 720 and 60 sec, respectively. On the other hand, image browsing contains the object size of 1000 bytes that comprises of page inter-arrival time of exponential distribution having a mean outcome of 10 sec. In addition, the image browsing also uses medium and large size objects. The minimum and maximum of the medium size object ranges from 500 to 2000 bytes. On the other hand, minimum and maximum range of large size object is 2000 to 10,000 bytes.

It can be observed from Fig. 11, that the performance of the proposed SSVHOP mechanism is dominant over tight coupling architecture. More objects, thus, more web pages can be downloaded. In tight coupling architecture, downloading is quite slower than the proposed mechanism; therefore, the wireless client will have to wait longer to download the webpage. Hence, the internet surfing will be slower.

For data traffic scenario, as stated previously, these data service enhancements are achieved because of the optimal route selection and overhead free mechanism of the proposed protocol. Moreover, it is worth mentioning here that the tight coupling mechanism requires a RNC emulator to perform the integration of UMTS/WLAN networks. The RNC emulator performs dual task, i.e., at one time it works as the wireless access point and for the same communication session it operates like an UMTS RAN at its another interface. To attain this compatibility between UMTS and WLAN networks, the RNC emulator contains a conversion module, as shown in Fig. 2. Therefore, during a data session between DMMT and internet server RNC emulator performs a PDU format conversion procedure and either encapsulate or decapsulate the GTP headers. This format conversion requires additional processing time for every packet. In contrast to this, in the SSVHOP mechanism no such packet conversion is required for the data session as a simple IEEE 802.11b AP is required to connect with the GGSN. The GGSN appears as a simple router which only route the packet to the intended destination without performing any additional functionality. This simplicity and straightforwardness lead to the low latency and processing requirement for the data session compared to the tight coupling mechanism which deteriorates the data services.

CONCLUSION

In this study, we have discussed several network coupling mechanisms for the integration of UMTS and WLAN networks. The loose coupling mechanism provides ease of network implementation; however it does not provide seamless mobility features and introduces high handoff delays and packet losses during handoff which are not acceptable for the real time services. The seamless mobility can be achieved by the tight coupling mechanism. Nevertheless, significant modification in the network topology and protocol design makes the tight coupling mechanism less attractive for the network service providers because it eventually increases the network design complexities and total cost of deployment. This study has been concentrated on the mechanism that bridges the gap between network implementation ease/simplicity and seamless mobility. In this regard, we have introduced SSVHOP which fulfills the demands of seamless mobility and at the same time it also maintains the network simplicity by avoiding any significant modifications in the existing networks.

The simulation results show that the SSVHOP mechanism acquires seamless mobility by decreasing the handoff delay and packet losses during upward and downward vertical handoff cases. For comparison purposes, in addition with the SSVHOP, we have also designed and evaluated the tight coupling mechanism. Simulation results reveal that the SSVHOP decreases handoff delay by 47.9 and 64.8% during downward and upward handoff scenarios, respectively. This has been made possible due to the implementation of the proactive RSS based mechanism that triggers an early handoff and by decreasing the signaling and processing cost of the network. For packet loss analysis, we can see that the number of packet loss is proportional to the packet arrival rate of a particular voice stream. Therefore, maximum packets are lost in case of G.711. Conversely, minimum packet losses are observed when G.723.1 is used. Similar to the handoff delay, it is apparent that the SSVHOP mechanism is equally effective for the packet loss when different codecs are used.

When the DMMT is communicating with the internet servers via WLAN network, the SSVHOP provides an optimal routing mechanism by decreasing the number of network hops to/from internet servers. Unlike the tight coupling mechanism, no tunneling is required to establish between the network nodes for the data transportation in the SSVHOP. Thus, no tunneling overheads are required for the data session. In consequence of the optimal routing technique and overhead free mechanism, data service performance improvements have been achieved in terms of email and FTP download response time and faster web browsing.

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