Interworking between WLAN and 3G Cellular Networks: An IMS Based Architecture

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

Abstract

In this paper, a novel architecture for interworking of the Wireless Local Area Network (WLAN) and the Third Generation (3G) mobile cellular network is presented. This architecture is a hybrid model with additional controls compared with the existing architectures and the use of IP Multimedia Subsystem (IMS), as an arbitrator for coupling and real-time session management. Furthermore, a new networking entity called a mobility manager has been introduced within the IMS for seamless management of vertical handoffs. Efficient strategies for IP address distribution and bypassing high traffic loads form the cellular core network are other benefits of this architecture.

1. Introduction

Modern cellular networks are capable of providing high mobility, whereas WLANs are known for having relatively higher bandwidth. Ubiquitous data services and very high data rates across heterogeneous networks may be achieved by using WLANs as a complementary technology for cellular data networks [1]. Hence there is a strong need for efficient interworking mechanisms for WLANs and 3G cellular data networks.

With the aim for addressing this need, a variety of interworking architectures have been discussed in the current literature. By and large, these interworking architectures can be categorized as tight coupling, loose coupling, and peer-to-peer networking (also referred as no-coupling) [2], [3]. Since these architectures may only provide limited interworking functionality, there exists a need for alternative solutions which are capable of overcoming these challenges. The key significance of the architecture presented in these works is that the use of 3rd Generation Partnership Project's (3GPP's) IMS as a mediator for supporting real-time session negotiation and management. It also identifies an approach for managing vertical handoffs by embedding a new mobility managing entity within the IMS.

This work is supported by an ARC Linkage Project in collaboration with SingTel Optus Networks.

The remainder of this paper is organized as follows. The next two sections discusses on recent advancements in interworking and the IMS architecture respectively. Followed by this is the section on the presented architecture, which describes how the IMS has been used as a mediator for interworking. It finally concludes by providing a broad discussion on how various interworking scenarios may be reached form the above architecture.

2. Interworking of WLAN and Cellular Networks

As mentioned previously, current interworking architectures can be broadly categorized as tight coupling, loose coupling, and peer-to-peer networking. In tight coupling the WLAN is directly connected to the Universal Mobile Telecommunications System (UMTS) Core Network (CN). Thus the WLAN data traffic passes through the UMTS core network before reaching the external Packet Data Networks (PDNs). The key functional element in the system is the GPRS Interworking Function (GIF), which emulates an IEEE 802.11 Extended Service Set (ESS) to a Serving GPRS Support Node (SGSN) via the standard $I_{u\text{-}ps}$ interface [1]. A clear advantage of this approach is that the UMTS mobility management techniques can be directly applied. However, the biggest disadvantage of this is that a bottleneck situation may arise at the SGSN as a result of the increased data traffic flow routed via the WLAN.

Alternatively, a loosely coupled architecture transports signaling over an IEEE 802.11 WLAN to the UMTS CN, while data flows directly over the Internet Protocol (IP) based network. In this scenario, signaling provides authentication, authorization and accounting (AAA) and charging between the two interworked networks. However, there are other variants to this interworking architecture, which may require the user data traffic to be routed to the UMTS CN [4], [5]. A clear advantage of this method is that, since the data traffic is routed directly via an IP network (or the Internet) a potential traffic bottleneck can be easily avoided. However, in regards to a loose coupling architecture, hand-offs are less efficient and mobility can only be considered when the user is not in an active session [3].

The peer-to-peer networking mechanism is another popular approach. This can be seen as an extension of the loose coupling architecture that treats the two networks as peers [2]. Mobile IP (MIP) and AAA servers are used for providing a framework for mobility in this approach [6]. However, due to known deficiencies of the MIP protocol itself, this may not be the best solution for frequently roaming users [7], [8]. As a consequence of such deficiencies these approaches are only capable of providing limited interworking access.

3. IP Multimedia Subsystem (IMS)

The IMS was introduced by UMTS releases five and six within its core network [9]. It comprises of the required characteristics for control of multimedia sessions and plays an essential role in the provision of IP multimedia services in a UMTS network. It also provides for an entry point for third-party multimedia applications and services in a controlled and secure manner. In order to facilitate these services, the IMS is featured with a number of key mechanisms such as; session negotiation and management, Quality of Service (QoS), local mobility management, and provisioning for AAA.

Figure 1 provides a general overview of the IMS architecture outlining the essential networking elements used for providing real-time IP multimedia services [9]. Since the IMS architecture specifically relies on the packet-switching domain for transport and local mobility management, it operates independently to the circuit-switching domain. Thus circuit-switching elements such as mobile switching centers have been excluded from Figure 1.

The Call State Control Functions (CSCFs) and the Home Subscriber Server (HSS) are the key elements of this framework. They are essentially involved in processing signaling messages for controlling multimedia/call sessions. Apart from this, the CSCFs are also involved in the address translation, perform service switching and negotiation, and handling of the subscriber profile. Depending on various configurations and scenarios, the roles for the CSCFs are categorized as follows. The Proxy-CSCF (P-CSCF) is the first contact point of the IMS, which is located in the same network as the GGSN. This could either be in the home network or the visiting network. The P-CSCF forwards the Session Initiation Protocol (SIP) registration messages and session establishment messages to the Mobile Host's (MH) home network. The Interrogating-CSCF (I-CSCF) is the "main entrance" of the home network from a visited network. With the assistance of the Home Subscriber Server (HSS), the I-CSCF selects the appropriate Serving-CSCF (S-CSCF). The S-CSCF is the node that eventually performs the actual user registration and session control for the IMS network. The Home Location Register (HLR) has evolved into the Home Subscriber Server (HSS). Interfacing with the I-CSCF and the S-CSCF, the HSS can be regarded as a master database, which acts as a repository for subscription and location information.

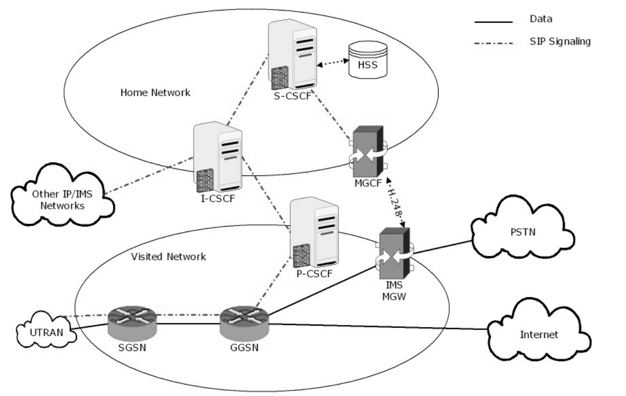

Figure 1. An Overview of the IMS Architecture.

It is essential for the IMS to interwork with the legacy Public Switched Telecommunication Network (PSTN) and other mobile networks. Therefore, the Media Gateway Control Function (MGCF) interconnects with circuit switched networks via the corresponding IMS Media Gateway (IMS-MGW). Also there is the Media Resource Function Controller (MRFC), which performs processing of media streams through the corresponding Media Resource Function Processor (MRFP).

The protocols which have been defined within the IMS architecture can be classified under thee broad categories. The first category (which is also the most important) comprises of the protocols used in the signaling and session control plane. The Session Initiation Protocol (SIP) is the core protocol chosen by the 3GPP for signaling and session management within the IMS [10]. Further, the extensible nature of SIP has been utilized by the 3GPP for incorporating additional features to suit the IMS [11]. The second and third categories consist of protocols used in the media plane and protocols used for authentication and authorization.

4. Interworking Architecture

Our recommended interworking model is illustrated by Figure 2. It intends to provide a MH the highest possible level of access to the UMTS services, where fully seamless access is considered to be the optimal accomplishment. The IMS has been used as an arbitrator for interworking between the WLAN and the UMTS

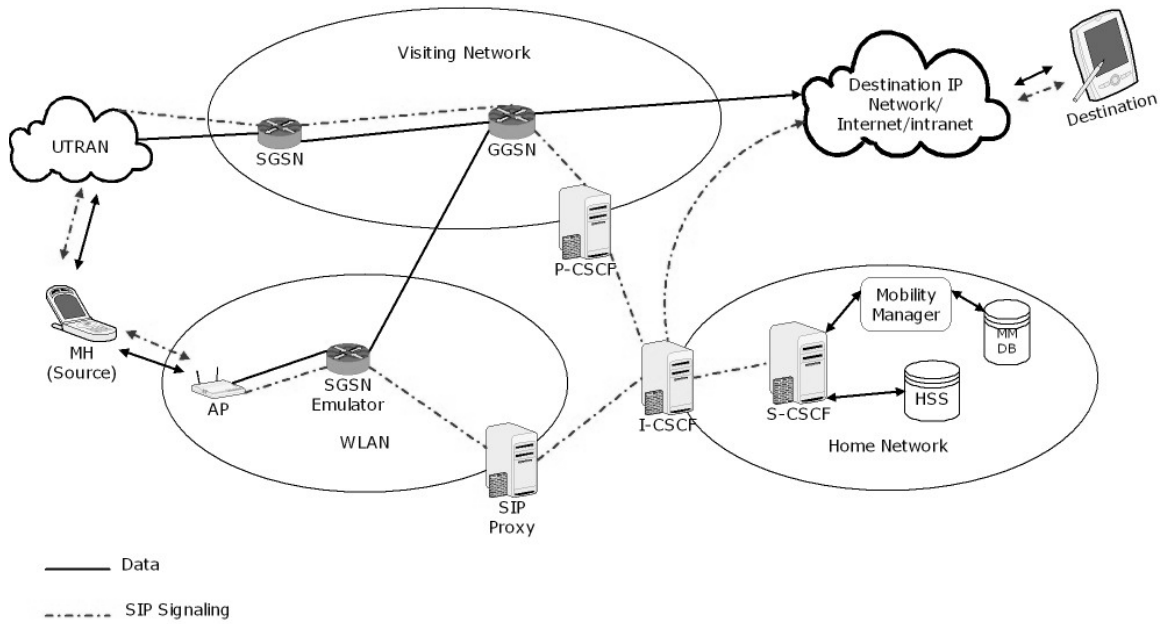

Figure 2. Architecture for Interworking between WLAN-3G Cellular Networks.

networks. Its ability for real-time session negotiation and management can be seen as a clear advantage of using the IMS. It further introduces an approach to initiate and monitor vertical handoffs by introducing a new entity called the mobility manager. The following sections will be presenting the details of this novel concept.

4.1 Data Routing and Signaling

The flow of data originates from the MH, through the SGSN and the GGSN (of the visitor network, in this case), and reaches the destination network. Since the 3GPP allows both Home-GGSN and Visitor-GGSN approaches for roaming, either approach may be used for user data routing [12]. This model uses the Visitor-GGSN approach to avoid the inter-PLMN backbone and to make data routing simpler for the network operator. In whichever approach, the data flow bypasses the IMS network altogether. Thus the IMS is said to follow the philosophy of using different paths for user data and signaling through the network.

The SIP signaling messages originate from the MH via the Universal Terrestrial Radio Access Network (UTRAN), through the SGSN and GGSN, out to the CSCFs and finally to the destination network. It is important to note that at the time the MH requires to establish a session, this request is sent to the S-CSCF via the P-CSCF and I-CSCF. Both the SGSN and GGSN act only as routers, and are not involved with SIP signaling. The data originating from the WLAN is routed via a SGSN emulator to the UMTS GGSN. It essentially emulates the WLAN as another SGSN belonging to the same UMTS network. Thus mobility may be managed within the UMTS network. Some of the functionalities of the BSS are bypassed in this approach and the load on the UMTS network, created by the high volumes of WLAN data traffic, may also be sufficiently reduced. Figure 3 illustrates the protocol stack of the SGSN emulator. This shows that significant functionality needs to be added to the SGSN emulator for supporting such a level of mobility.

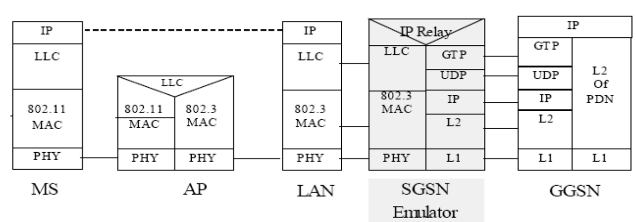

Figure 3. Protocol Stack for SGSN Emulator.

4.2 Session Establishment

The establishment of a SIP session within an UMTS IMS environment is involved with several functions. The key steps required for obtaining access to SIP services can be summarized as follows. The first step involves with the MH powering on and locking on to the UMTS network. Once the appropriate cell is selected the MH can be considered ready for the establishment of a data session.

Once the above mentioned system acquisition is done, the next step is to establish a data connection, or set up a data pipeline, for the SIP and other services. In order to perform the SIP registration, initially the MH is unaware of the IP address of the P-SCSF. Thus the data connection must be completed in two-steps by using the Attach and Packet Data Protocol (PDP) context activation message sequences. The activation of a PDP context assigns an IP address for the MH. The context activation creates an association for this IP address between the SGSN and the GGSN, which can be used for establishing the path required to carry SIP related signaling messages to the P-CSCF through the GGSN. With the activation of the PDP context the MH is able to identify the P-CSCF for the registration with the UMTS SIP network.

Prior to establishing a SIP session, the MH requires performing a service registration function to let the IMS know its location. The MH acts as a SIP client and sends a SIP registration message to its home system through the P-CSCF. The steps for a SIP service registration can be summarized as follows. Firstly, the Home Subscriber Server (HSS) for the MH is notified of its current location for the HSS to update the subscriber profile accordingly. Next the HSS checks if the MH is allowed to register in the network based on the subscriber profile and operator limitations, and grants authorisation. Once authorized, a suitable S-CSCF for the MH is assigned and its subscriber profile is sent to the designated S-CSCF.

After the activation of the PDP context and the service registration, the MH is ready to establish a (multimedia/voice call) session. The sequence of the SIP session origination procedure can be described as follows. The mobile origination procedure is initiated by a SIP INVITE message sent form the source MH. This initial message is forwarded from the P-CSCF to the S-CSCF via the I-CSCF, and finally to the destination with the Session Description Protocol (SDP) included. Next the two end-points go through the SDP negotiation stage. This is when the media characteristics (media flows, etc.) are exchanged. The resource reservation stage is reached next. The network determines and reserves the necessary resources for supporting this session. Once the resources are reserved a confirmation of session setup (i.e., a SIP OK) and an acknowledgement (i.e., a SIP ACK) is exchanged between the session terminating and initiating points. Once this is done, the (originating) MH can start the media/data flow and the session will be in progress.

4.3 Mobility Management

When the MH detects the presence of a WLAN in its vicinity, it initiates the vertical handoff procedures from the UMTS network to the WLAN. In a vertical handoff environment, when the MH moves from the UMTS network to the WLAN, the handoff is not necessarily triggered by signal decay of the current system. The metrics that assist in triggering a vertical handoff are essentially the network conditions (available bandwidth and delay, user preference, etc.), rather than the physical layer parameters (received signal strength, signal-to-interference ratio, etc.) [13]. Once such a decision has been made, the next key issue for a roaming system is the mobility management schema, which is required to maintain continuity of service after a vertical handoff.

One approach for managing (initiating and monitoring) vertical handoffs is by introducing a new network entity called the Mobility Manager (MM) within the IMS [14] . The management of handoffs is based on metrics such as network statistics, current load on access routers, MH's priority, user's profile, etc. These parameters are stored in a database, which is associated with the MM, and periodically updated. By considering the type of its operation, the best point of attachment for such an entity within the IMS architecture would undoubtedly be the S-SCSF.

Once handoff takes place, it will also manage the redirection of packets towards the future or new location of the MH. Packet loss can be further eliminated by managing the buffering of data packets addressed to a MH until it executes its handoff and fully reachable at the new attachment point. The criteria for buffering packets at an access router can be based on the type of communication flow, its sensitivity to delay, and tolerance for loss.

5. Interworking Scenarios

As a benchmark for identifying the capability of interworking, our architecture is assessed against the scenarios defined by the 3GPP TR 22.934 [15]. Under this framework, proposed by the 3GPP, six common interworking scenarios have been identified. The first scenario, which is the simplest, provides only a common bill and customer care to the subscriber but no real interworking between WLAN and UMTS PLMN. Scenario two provides the UMTS subscriber with a basic IP network connection through a WLAN and includes no other UMTS services.

The goal of scenario three is to extend the access to UMTS packet-switched (PS) services for subscribers in a WLAN environment. In addition, an IP service selection schema is also used for selecting the PS based service to which to connect. Such services may include IP multimedia services, location-based services, instant messaging services, presence-based services, and Multimedia Messaging Services (MMS). However, scenario three does not address service continuity across these access networks.

Scenario four addresses the above issue and helps maintain service continuity across UMTS and WLAN radio access technologies. Scenario five takes it another step further by introducing seamless service continuity between the UMTS and WLAN. That is, PS-based services should be utilized across the UMTS and WLAN radio access technologies in a seamless manner, without the user noticing any significant differences. Finally, scenario six describes access to UMTS Circuit-Switched (CS) services from the WLAN system including seamless mobility for these services. However, scenario six is not considered under this evaluation as it is beyond the scope of the current goals. The following sections discuss how different scenarios of interworking may be achieved form the presented architecture.

5.1 Scenario 1: Common Billing and Customer Care

The first scenario includes common billing and common customer care. As the WLAN routes the data traffic via the visiting network, an acceptable charging model based on the quantity of traffic exchanged can be incorporated into the UMTS billing system.

5.2 Scenario 2: UMTS based Access Control and Charging

The second scenario uses the UMTS access control procedures for WLAN users within the UMTS domain. It also includes features of scenario 1. Facilities exist for both WLAN and UMTS networks for accessing the HSS, as well as the charging and billing systems. However, interworking at this level does not require any negotiation of SIP sessions between the elements of the IMS. Since the sole purpose of the new architecture is to use the IMS based services, the next level of interworking must be considered.

5.3 Scenario 3: Access to UMTS IMS-based Services

This level extends the services of the IMS to a MH connecting via a WLAN. However, this scenario lacks the service continuity, which may require the MH to re-establish the session in the new access network. As previously described in Section 2, to facilitate SIP signaling between the IMS and the WLAN, the IETF SIP elements of the WLAN must be translated into the 3GPP SIP. Therefore, interworking between CSCFs and WLAN SIP proxy becomes a challenging task with top priority. The authentication and access control for IMS services takes place during SIP registration. This also facilitates mutual authentication between MH and the UMTS network. It is also important to manage billing and accounting procedures of the UMTS network for the interworking scenario.

5.4 Scenario 4: Service Continuity

Service continuity requires the levels of interworking as defined in the previous two scenarios (two and three). However, it does not guarantee seamless continuity of service, which means that some applications may require re-establishing of sessions. Therefore, mobility management (roaming and hand-off) need to be considered under this level. The services of the MM described under Section 4.3 can be applicable for achieving continuity of service. 3GPP's enhanced SIP services, used in the IMS, are capable of providing service continuity. However, the problems to be solved at this level mainly exist in the transport network. Thus mechanisms for supporting efficient ways for data routing in WLAN and UMTS interworked environments need to be identified. The suggested solution for efficient data routing is to have the WLAN emulate a SGSN, which connects to the UMTS network at the Gn interface. Thus data traffic from the WLAN is routed via the SGSN emulator to the UMTS network. The SGSN emulator approach may also be substantially reduced.

5.5 Scenario 5: Seamless Continuity of Service

Scenario 5 is very much similar to Scenario 4. However, it includes seamless service continuity with fully transparent services to the end-user. This is an issue which is not addressed so far by the UMTS Release 6, and currently being investigated by the 3GPP. Regardless of the numerous obstacles and complexities in achieving this goal, it is important to note how the suggested interworking model makes an important contribution towards reaching a step closer to the objective of seamlessness. As discussed in Section 4.3, the MM plays a vital role in achieving seamless continuity of service. The IMS architecture can also be used as a key mediator for reducing or eliminating potential issues such as resource allocation in interworking. Furthermore, this interworking model addresses the current issues in IP address allocation and distribution. Therefore, a MH does not require any change of IP addressing between the WLAN and UMTS network as long as the two networks are connected to the same GGSN.

6. Conclusions and Future Work

This paper presents an interworking model for WLAN and 3G cellular networks with the IMS acting as a signaling mediator. The most significant benefit of this approach is its ability for negotiating and managing real-time sessions. The evaluation of the model also points out how it may further address a number of unresolved issues in interworking. An effective framework for IP address distribution, provisioning for continuation or seamless continuation of service by introducing a new networking element for mobility management, and the use of a SGSN emulator mechanism for bypassing high traffic loads form the UMTS core network can be considered as some of these contributions. Future research directions will be essentially aimed towards improving the mobility manager for handling seamless data routing and QoS provisioning with specific emphasis on high data volumes originating from the WLAN.

7. References

[1] A. K. Salkintzis, C. Fors, and R. Pazhyannur, "WLAN-GPRS Integration for Next-Generation Mobile Data Networks," *IEEE Wireless Communications*, vol. 9, 2002, pp. 112-124.

[2] K. D. Wong, et al., "UMTS Signaling over 802.11 Wireless LAN," in *Proc. of the 58th IEEE VTC*, 2003, pp. 1798-1802.

[3] V. K. Varma, et al., "Mobility Management in Integrated UMTS/WLAN Networks," in *Proc. of the IEEE ICC*, 2003, pp. 1048-1053.

[4] A. K. Salkintzis, "Interworking Techniques and Architectures for WLAN/3G Integration toward 4G Mobile Data Networks," *IEEE Wireless Communications*, vol. 11, 2004, pp. 50-61.

[5] A. K. Salkintzis, "WLAN/3G Interworking Architectures for Next Generation Hybrid Data Networks," in *Proc. of the IEEE ICC*, pp. 3984-3988, 2004.

[6] K. Pahlavan, et al., "Handoff in Hybrid Mobile Data Networks," *IEEE Personal Communications*, vol. 7, 2000, pp. 34 - 47.

[7] S.L. Tsao and C.C. Lin, "VGSN: A Gateway Approach to Interconnect UMTS/WLAN Networks," in *Proc. of the 13th IEEE PIMRC*, 2002, pp. 275-279.

[8] Y. Min-hua, L. Yu, and Z. Hui-min, "The Mobile IP Handoff between Hybrid Networks," in *Proc. of the 13th IEEE PIMRC*, 2003, pp. 265-269.

[9] 3GPP, "IP Multimedia Subsystem (IMS)," 3GPP TS 23.228 Version 6.10.0 Release 6, 2005.

[10] J. Rosenberg, et al., "SIP: Session Initiation Protocol," RFC 3261, 2002.

[11] F. G. Marquez, M. G. Rodriguez, T. R. Valladares, T. de Miguel, and L. A. Galindo, "Interworking of IP Multimedia Core Networks between 3GPP and WLAN," *IEEE Wireless Communications*, vol. 12, 2005, pp. 58-65.

[12] A. Roos, M. Hartman, and S. Dutnall, "Critical Issues for Roaming in 3G," *IEEE Wireless Communications*, vol. 10, 2003, pp. 29-35.

[13] Z. Qian, G. Chuanxiong, G. Zihua, and Z. Wenwu, "Efficient Mobility Management for Vertical Handoff between WWAN and WLAN," *IEEE Communications*, vol. 41, 2003, pp. 102-108.

[14] P. Bertin, K. Guillouard, and J. C. Rault, "IP Based Network Controlled Handover Management in WLAN Access Networks," in *Proc. of the IEEE ICC*, 2004, pp. 3906-3910.

[15] 3GPP, "Feasibility Study on 3GPP System to Wireless Local Area Network (WLAN) Interworking," 3GPP TR 22.934 Version 6.2.0 Release 6, 2003.