A Unified Mobility and Session Management Platform for Next Generation Mobile Networks

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***Abstract*— This paper presents a novel approach towards realizing a unified mobility and session management platform for next generation mobile networks at the core network level. In particular, this framework enables a common platform for interworking between Universal Mobile Telecommunications System (UMTS), CDMA2000 technology, and Wireless Local Area Networks (WLANs). Within the proposed interworking architecture, the IP Multimedia Subsystem (IMS) is used as a universal coupling mediator for real-time session negotiation and management over a Mobile IP (MIP) based IP mobility management framework. Despite numerous architectural challenges on how IMS and MIP may contribute for session management and IP mobility, the proposed framework achieves this with minimal changes to the existing standards. The paper concludes by presenting simulation results obtained for validating this model using an OPNET based model.**

***Keywords*- 3GPP; 3GPP2; IMS; UMTS; CDMA2000; WLAN; SIP; Mobile IP; Mobility Management; Session Management**

I. Introduction

One of the primary motivations behind developing the third generation (3G) mobile communication system was to provide global access capability with a unified radio access network and a unified Core Network (CN). Despite these motivations, the current 3G cellular systems developed as extensions on the platforms of their second generation predecessors. Hence the motive for a unified communication system has not been achieved yet. Furthermore, global roaming and interoperability beyond one system to another still remains a challenge. Therefore, it is essential that in the development of the Next Generation Mobile Network (NGMN), there exist a unified platform for these systems for interworking with each other. This has given rise to much research activity aiming towards providing interoperability and global roaming between different cellular networking standards and technologies [1], [2]. Due to architectural and technical differences in these core networking technologies, many aspects need to be addressed prior to achieving fully seamless interworking. Therefore, this paper discusses the aspect of IP and session mobility within the packet switching service domain of heterogeneous mobile and wireless data networks.

On the other hand, when a 3G cellular network interworks with a WLAN, mobile users are able to experience ubiquitous data services and relatively high data rates across heterogeneous networks. Thus WLANs can also be considered as a complementary technology for 3G cellular data networks as well as a compulsory element of the future NGMNs [3]. Having identified the importance of such an interworking mechanism, we have previously proposed a solution for achieving the highest possible level of session continuation during a vertical handoff between WLAN and UMTS networks [4]. Therefore, this paper can also be seen as an extension to our previous works where a common platform is proposed for coupling a CDMA2000 network with our existing interworking framework.

The novelty of our architecture for WLAN-UMTS interworking was that it used the 3GPP's IMS as an arbitrator for real-time session negotiation and management [5]. Since 3GPP2 also adopts a similar concept as 3GPP by introducing an IMS in the CDMA2000 CN, the IMS can be deemed as a top candidate for a universal coupling mediator [6]. However, there are substantial differences between 3GPP and 3GPP2 CNs in regards to the level of contribution of the IMS in relation to mobility and session management. In particular, the 3GPP exclusively uses the IMS for IP mobility and session management at the application layer whereas 3GPP2 handles terminal mobility at network layer and the IMS for session management at the application layer. Therefore, this paper further analyzes the challenges of having the IMS as a universal coupling mediator and the interactions of the IMS with the 3GPP2's network layer based mobility management protocols.

The next section presents a brief background on mobility and session management in 3G mobile networks. Followed by this comes the section on the architectural considerations taken into account in the design process. Followed by is the proposed architecture, which describes how the IMS has been used as a universal coupling mediator for internetworking. The next section is on OPNET based simulation results prior to the final concluding remarks.

II. Mobility and Session Management in 3G Mobile Networks

This section provides an overview on the networking elements and protocols standardized for mobility and session management by 3GPP and 3GPP2.

A. 3GPP-IMS in UMTS

The UMTS Release 5 within its CN, introduced the IP Multimedia Subsystem [5]. It consists of the essential requirements for controlling of multimedia sessions and provisioning of IP multimedia services for a UMTS network. A general overview of the IMS architecture is provided in Fig. 1. This section provides an outline of the main networking

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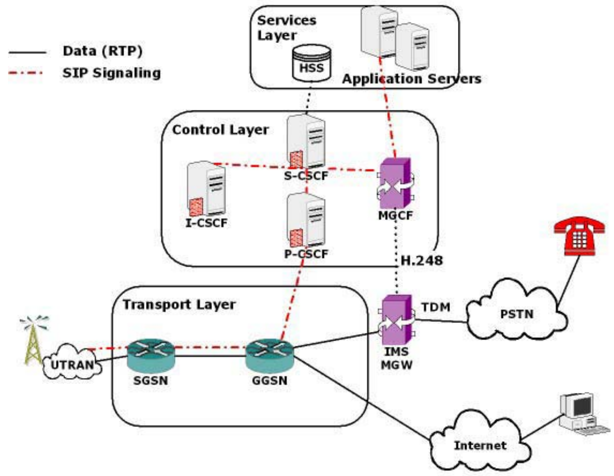

Figure 1. The 3GPP-IMS Architecture.

fundamentals of the IMS used for providing real-time IP multimedia session management [5].

The key elements of the IMS framework are the Call State Control Functions (CSCFs) and the Home Subscriber Server (HSS). A CSCF can be loosely defined as a Session Initiation Protocol (SIP) proxy server and the HSS as a master database for user profiles. The CSCFs can be identified as follows; Proxy-CSCF, Interrogating-CSCF, and Serving-CSCF. The P-CSCF is the first SIP proxy receiving a SIP request, which also acts as a SIP Back-to-Back User agent (B2BUA). The P-CSCF forwards session requests to the S-CSCF via the I-CSCF. The task of the I-CSCF is to select the appropriate S-CSCF by checking with the HSS. If the relevant S-CSCF is known, the I-CSCF may be bypassed. The S-CSCF is the actual SIP server that eventually performs the user registration and handles session control for the IMS network. The Media Gateway Control Function (MGCF) interconnects with circuit switched networks via the corresponding IMS Media Gateway (IMS-MGW).

SIP is the core protocol chosen by the 3GPP for signaling and session management within the IMS [7]. SIP is based on a request/response model where the SIP User Agent Client (UAC) invokes the requests to which the SIP User Agent Server (UAS) responds. Extensive information on SIP methods is available from [7]. Furthermore, the extensible nature of SIP has also been utilized by the 3GPP for incorporating additional features to suit the IMS [8]. Since the 3GPP-IMS uses a pure SIP based (or Application Layer based) mobility and session management approach, SIP is used to implement all four mobility aspects as defined by IMT-2000; namely, personal, terminal, session, and service mobility [9].

B. 3GPP2-IMS in CDMA2000

The 3GPP2's Multi Media Domain (MMD) is a collection of CN entities providing 3G capabilities based on IP protocols, elements, and principles. The MMD of the All-IP network comprises of multimedia session capabilities built on top of the general packet data support capabilities. The general packet data support portion of the MMD is known as the Packet Data Subsystem (PDS) and the entities that comprise the multimedia session capabilities of an All-IP network is collectively known as the IP Multimedia Subsystem [6]. This initial release of the 3GPP2-IMS is based on the IMS specified in Release 5 of the 3GPP specifications. As per the illustration in Fig. 2, the key elements of the 3GPP2-IMS architecture are much similar to the descriptions provided in the previous section. Despite the fact that 3GPP2-IMS specifications are fairly inline with their 3GPP-IMS counterparts, considerable differences exist [10]. Firstly, the issue of mobility is handled in two different ways. 3GPP2 uses Mobile IP (MIP) for IP mobility (i.e., terminal mobility) management and SIP for session mobility management. When a common interworking platform for NGMNs is considered, defining the interaction of 3GPP-IMS with MIP becomes a new challenge.

The next relevant point is the choice of IPv4 vs. IPv6. Although 3GPP mandates IMS over IPv6, 3GPP2 does not make such a specification. Therefore, either MIPv4 [11] over IPv4 or MIPv6 [12] over IPv6 can be used. As defined by 3GPP2, if MIPv4 is deployed, the Packet Data Switching Node (PDSN) of the home network may act as the MIP Home Agent (HA) or Foreign Agent (FA) as the Mobile Node (MN) moves. In the event when MIPv6 is being implemented, direct peer-to-peer communications can be established through its route optimization operation [12]. Since 3GPP2's standard for CDMA2000 does not fully support inter-PDSN mobility for IPv6, the proposed design will primarily be based on MIPv4 [13]. However, transition of this model to MIPv6 can be easily done by addressing user authentication, address allocation and enabling the MN to perform the MIPv6 update procedures [14]. Although it is of lesser importance, other differences between 3GPP and 3GPP2 IMS can be briefly stated as follows: 3GPP2's Home AAA and its database being equivalent to 3GPP's HSS, 3GPP2-IMS does not use PDP context activation for P-CSCF discovery, the P-CSCF and PDSN do not need to reside in the same network, and 3GPP2-IMS defines a new position server and a position determining entity.

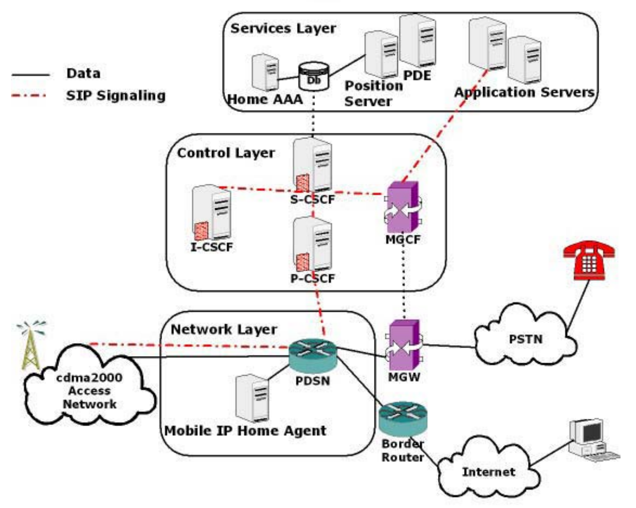

Figure 2. The 3GPP2-IMS Architecture.

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III. ARCHITECTURAL CONSIDERATIONS

Despite the fact that a joint MIP-SIP mobility management framework is introduced, the aim of this approach is not to design a hybrid version of the IMS by integrating MIP features (i.e., a S-CSCF with an integrated MIP-HA) as suggested in [15]. However, depending on the version of MIP used (i.e., MIPv4 or MIPv6) few variations for this signaling framework may exist. Say, if MIPv4 is used for handling IP mobility for 3GPP's (IPv6 based) in the IMS, the first concern should be Network Address Translation (NAT) compatibility [16]. Secondly, the IMS signaling may undergo triangular routing, which is acceptable according to 3GPP's specification [5].

If MIPv6 is used for handling IP mobility for 3GPP's (IPv6 based) IMS, a different set of issues may arise. Under MIPv6, the MN has two IP addresses: namely a static Home Address and a Care of Address (CoA). Hence, the question arises as to which address to be used by SIP for signaling. The first choice is having both the Home Address and CoA to be used by IMS-SIP. However, the current IMS standards do not support the use of multiple IP addresses. Secondly, if the CoA is utilized for IMS-SIP signaling, a pure SIP based mobility and session management framework can be constructed. The main drawback of this approach is that each time the MN gets a new CoA, re-registration of the CoA and re-establishment of a new (or ongoing) SIP session will be required [4]. The third approach is to use the Home Address for all IMS-SIP based signaling, which directly uses MIP for handling IP mobility.

The fourth approach, which is used in our design and similar in concept to the third method, works on an IPv4 platform. Main reasons for using MIPv4 is that it eliminates the complexity of managing two IP addresses (as in the above scenarios), enables IP mobility management (by transporting single/static IP address) in such a way that node mobility is transparent to the layers above. Since the 3GPP2's IMS standard specifies that IMS signaling could also be implemented on IPv4, by using this method, NAT related complications (IPv4 to IPv6 translation) could be avoided. Nevertheless, since the IMS is primarily a framework for SIP based session control, even though the original specification mentions otherwise, 3GPP's IMS could be successfully implemented over IPv4. Last but not least, another important motive for using an all IPv4 based platform is the fact that network operators are coming to a sad realization that despite of the initial hype, the migration towards IPv6 is slowly becoming more and more practically unrealistic.

IV. INTERWORKING ARCHITECTURE

Our proposed internetworking architecture is illustrated in Fig. 3. The UMTS CN is connected to the IP network through the GGSN, which also acts as its MIPv4 FA. Firstly the MN powering on and locking to the UMTS network takes place. Once the appropriate cell is selected the MN can be considered ready for the establishment of a data session. This paper assumes that this function is already performed by the MN, and will not be discussed in detail.

Once the system acquisition is done, the next step is to set up a data pipeline. The actual IP address allocation for the MN is initiated by sending the MIPv4 registration request to it's HA via the GGSN (MIP-FA). This mechanism is based on the specifications given under [17]. The MN acts as a SIP client and sends a SIP registration message to its home system through the P-CSCF. Once authorized, a suitable S-CSCF for the MN is assigned and its subscriber profile is sent to the designated S-CSCF.

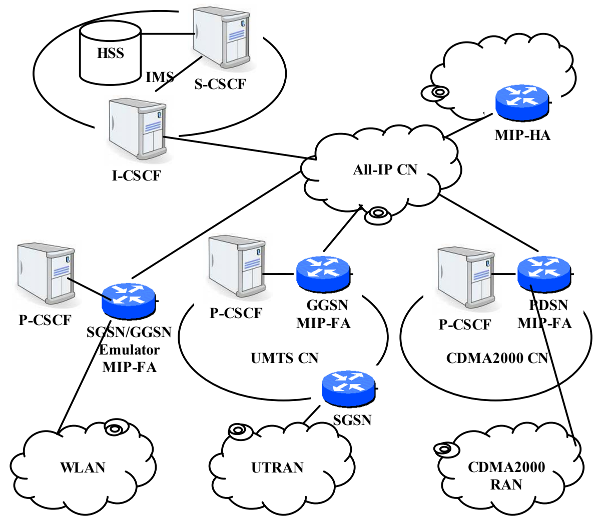

Figure 3. The Proposed Interworking Architecture.

After the activation of the PDP context and the service registration, the MN is ready to establish a media/data/call session. As illustrated in Fig. 4, 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 UMTS interface of the source MN. This initial message is forwarded from the P-CSCF to the S-CSCF of the originating network, via the CSCFs of the terminating network, and finally to the destination. This SIP INVITE carries a request to follow the precondition call flow model. This is important because some clients require certain preconditions (that is, QoS levels) to be met before establishing a session. Next, this model requires that the destination responds with a 183 Session Progress containing a SDP answer.

The acknowledgement of the reception of this provisional response by a PRACK request follows afterwards. When the PRACK request successfully reaches the destination a 200 OK response is generated by the destination with an SDP answer. Next an UPDATE request is sent by the source containing another SDP offer, in which the source indicates that the resources are reserved at his local segment. Once the destination receives the UPDATE request, it generates a 200 OK response. Once this is done, the MN can start the media/data flow and the session will be in progress (via the UMTS interface). When this MN roams between CDMA2000 and UMTS systems inter-system roaming takes place. The message flow for an inter-system roaming from UMTS to CDMA2000 can be described as follows. Firstly the standard CDMA2000 link layer access registration procedures are performed. Next the CDMA2000 interface performs the MIP registration procedures with the PDSN (MIP FA) as explained

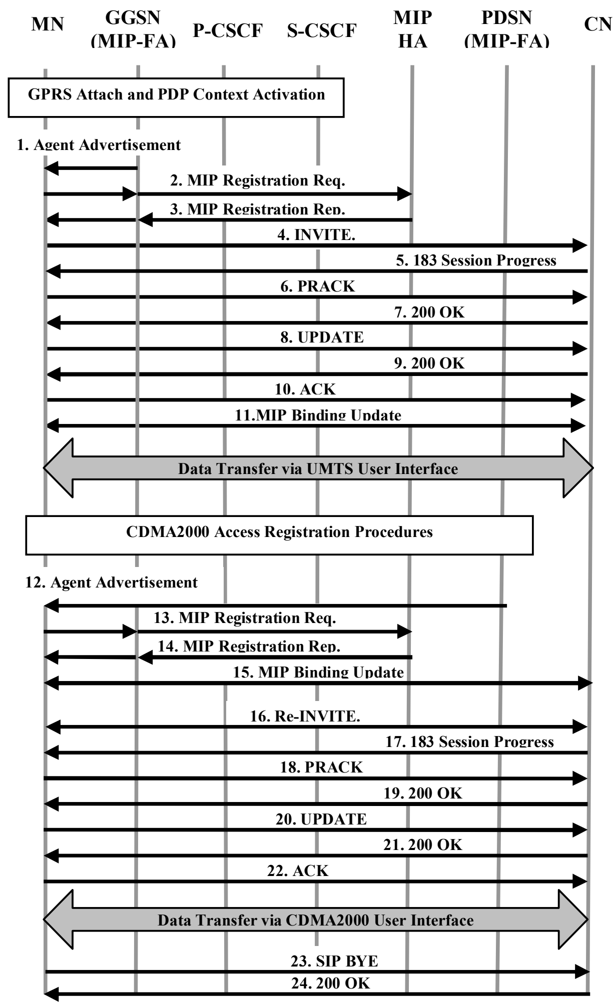

Figure 4. MIP-SIP Signaling.

previously. This is when the PDSN (MIP-FA) forwards this request to the MIP-HA and the HA assigns the home IP address to the new CDMA2000 interface. Lastly the exchanging of a MIP Binding Update message between the MN and the CN for avoiding triangular routing [11].

The next stage is the taking place of the IMS-SIP session handoff procedures. This requires sending a SIP Re-INVITE (with same Call-ID and other identifiers corresponding to the ongoing session) to the destination SIP UAC. Followed by this is a resource/preconditions reservation for the CDMA2000 interface. Once this is successfully done the new session flow can be initiated. It is important to note that until such time that the new data flow is initiated via the CDMA2000 interface, the data flow via the UMTS interface remains active. Thus the model follows the make-before-break handoff mechanism as proposed in our previous works [4]. Inter-system roaming form CDMA2000 to UMTS can also take place in a similar manner. Furthermore, since this design is an extension to our UMTS-WLAN interworking platform, WLAN-CDMA2000 roaming can also be accommodated within this architecture in a similar manner.

V. Network Modelling and Results

In order to investigate the validity of the above described architecture, a network simulation scenario is modeled using OPNET Modeler 11.5. Our newly developed SIP-IMS model is an enhanced version of the basic IMS-SIP signaling model, which is currently available under the contributed models library of the OPNET University Program [18]. These modifications can be summarized as follows: SIP Proxy Servers (UASs) modified as CSCFs, IMS-SIP based messaging and flow generation between CSCFs, introduce roaming facility between multiple domains, and facility for introducing process delay controls (i.e. for messages sent between CSCFs and the HSS queries). Followed by this, below the IMS architecture a MIP v4 framework is constructed.

The next task is creating an All-IP based heterogeneous network with MIP and SIP signaling as illustrated in Fig. 3. Since IMS and MIP protocols are implemented in the CN, their behavior can be considered to be independent to the underlying networks (i.e., to WLAN, UMTS, or CDMA2000). Taking the above facts and limitations of OPNET 11.5 into consideration, a simple All-IP heterogeneous test bed is created by interworking a UMTS network with a WLAN. Next, measurements are collected for investigating a joint MIP-SIP vertical hand-off (say, from UMTS to WLAN in this case). At this instance, the readings for vertical handoff are observed at the CN level as described in [4].

Fig. 5 illustrates the simulation results for vertical handoff delay obtained for the two mobility mechanisms. The average vertical handoff delay obtained by the OPNET model for a single VoIP session over a 2 Mbps wireless link bandwidth for the MIP-SIP model is 190 ms, and the same for a pure SIP based mechanism is 302 ms. The behavioural trends of the graphs indicate that the vertical handoff delay is largely reduced in the MIP-SIP scheme in contrast with a pure IMS-SIP based scheme. These reductions result from the use of rather short MIP messages for handling IP mobility instead of the IMS related SIP Refer method. Furthermore, the MIP-SIP method has a relatively less number of application layer/IMS based processing latencies, which also contributes to an overall low vertical handoff delay. The interesting point about our simulation results is that, to a certain extent, they are inline with results published for the case of horizontal handoff delays

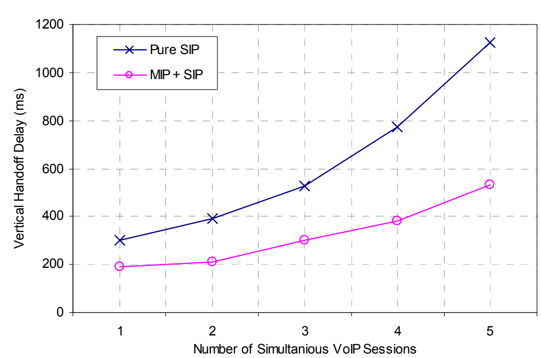

Figure 5. Mean Vertical Handoff Delay for MIP-SIP vs. Pure SIP

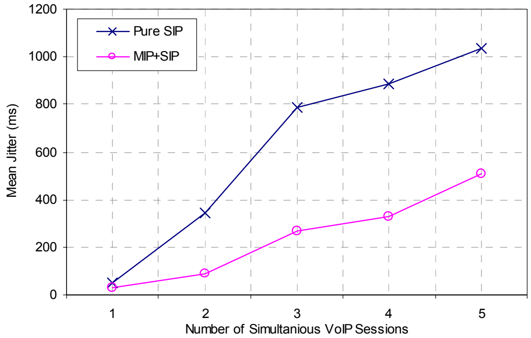

Figure 6. Mean Jitter for MIP-SIP vs. Pure SIP during Vertical Handoff.

[19],[20]. Furthermore, as the numbers of sessions increases the two graphs show a trend of diverging form each other. For example, the pure MIP-SIP method shows an (approximate) increase of 11% for two simultaneous handoffs and the joint Pure SIP approach shows an (approximate) increase of 50%. All these results suggest efficient ways of IMS deployment in interworking [4].

The next concern is to measure the jitter (i.e., the variation in the inter-arrival delay) for VoIP traffic during a vertical handoff. The main factors affecting the jitter during a vertical handoff for the considered VoIP data flow are the voice packet payload length (dependent on the codec used) and the downlink data flow rate. As the results in Fig. 6 indicate, the jitter is 28 ms and 47 ms for joint MIP-SIP and pure SIP based approaches for the case of a single VoIP session respectively. This is also a particularly encouraging observation. Since a jitter rate below 50 ms is expected to provide acceptable voice quality in real-time VoIP applications, the above readings indicate the likelihood of maintaining satisfactory (if not seamless) levels of VoIP communications during the vertical handoff process [21]. However, as the numbers of simultaneous handoffs increases the jitter rate tends to increase rapidly and way beyond the 50 ms limit. Furthermore, the trend shows that the pure SIP approach has higher jitter rates than the joint MIP-SIP approach.

VI. Conclusions

This paper presented a unified mobility and session management framework for next generation mobile data networks. This model enabled internetworking between UMTS, CDMA2000, and WLAN networks where the IMS acted as a unified session controller at the application layer and MIP handled IP mobility management at the network layer. The simulation results of the proposed architecture indicated that despite the additional overheads of MIP signaling delays, this new approach could be successfully used for interworking heterogeneous networks under one All-IP CN. The results further indicated that the proposed vertical handoff mechanism has the potential for transferring a session with acceptable levels of service continuation.

Acknowledgment

The simulations in this work were carried out using OPNET Modeler under the OPNET University Program.

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