Heterogeneous Wireless Networks: A Survey of Interworking Architectures

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ABSTRACT

A vast majority of current wireless cellular networks are deployed using the *homogeneous* deployment scenario. The homogeneous cellular system is essentially a network base stations and user terminals with standards power level profiles and similar technical characteristics. All base stations in the network are similar and carefully planned for compatibility. This deployment scenario is complex, rigid, and expensive. Hence the need for a more flexible, cost-effective and ubiquitous deployment model capable of broadband delivery. This need informed the advent of *heterogeneous* networks, which allow for the deployment of non-homogeneous base stations, with the attendant advantage of improved spectral efficiency per unit area. One of the most important features of next generation networks is the roaming possibility of end user equipments across different access networks. The Session Initiation Protocol (SIP) makes this experience achievable, it also describes other different mobility management solutions and compares the suitability of SIP for roaming across General Packet Radio Service (GPRS), Universal Mobile Telecommunication System (UMTS) and wireless Local Area Networks (WLAN). We present in this paper an overview of the various wireless networking implementations *vis-à-vis* interworking architectures. The paper also discusses the three generic interworking architectures for WLAN 802.11 and 3GPP networks among others.

Key words: *Converged networks, E-UTRAN, GPRS, HetNet, Session Initiation Protocol (SIP), UMTS, WLAN*

I. INTRODUCTION

Heterogeneous Networks (a.k.a. HetNets) are essentially made up of existing disparate Radio Access Network (RAN) technologies (e.g. WiMAX, Wi-Fi, E-UTRAN, etc.). They usually consist of multiple architectures, transmission solutions, and base stations of varying power capacity. The constituent networks are used for the purposes of improving user experience, reducing bottlenecks in RAN and core network (CN). HetNets are also helpful in introducing intelligent IP traffic routing and management, as well as efficient load balancing and resource allocation, by ways not limited to aggregating disparate network radio resources, as well as in offloading and loading selected or bulk packet-switched/circuit-switched (ps/cs) traffic between the HetNets. 3G-WLAN has been investigated beyond other inter-technology options. This is probably due to the attendant complementary offerings e.g. for WLAN: high data rates, short range, low mobility, while for UMTS: relatively low data rates, long range, high mobility [1]. These disparate radio interfaces are merged both at the UE and RAN; as a result, multi-radio frameworks (both client-based and host-based) enabling mobility and handover managements are necessary [2]. Moreover, none of the existing second and third generation technologies or services has been able to provide the ubiquity required in network coverage with accompanying Quality of Service (QoS) levels. Hence, it becomes of imperative importance that UEs make efficient use of all available network interfaces to maintain an '*Always Best Connected*' scenario to a corresponding node. Thus requiring multiple Radio Access Technologies (RATs) to coexist, internetwork and interoperate [3]. Interworking of wireless networks requires mobility management at the network layer and session management at the application layer. Protocols such as Mobile Internet Protocol (MIP), MOBIKE, SIP, etc. are all under investigation by various standardization bodies and independent research groups, particularly the *IEEE Standards Association* (IEEE SA).

The rest of the paper is structured as follows: Section II in its subsections describes in details various internetworking scenarios reported in the literature vis-à-vis the various wireless networking platforms currently available and those under development. EPC-based internetworking of WiMAX and UTRAN is discussed in part A. Interworking scenarios reported in the literature for WiMAX and 3G cellular networks are considered in part B. Part C of the same section considers internetworking of WLAN and WiMAX Networks, paying particular attention to the *MIH-MPA*, *Multi-mode*, and *Mobile SIP* approaches. Scenarios for internetworking CDMA 2000 and WLAN are discussed in part D. Part E considers the internetworking of WLAN with 3G networks, while the algorithm for internetworking WLAN with 3GPP networks is discussed in part F. The IMS-based

architecture for internetworking WLAN and 3G UMTS networks is presented in part G, while part H discusses the *IEEE SA* based approach to internetworking WiMAX and 3GPP networks. The paper is summarized in section III and concluded in section IV.

II. INTERWORKING WIRELESS NETWORKS

A. Interworking Mobile WiMAX and UTRAN

Song et al. present architecture for internetworking Mobile WiMAX and UTRAN in [4] through the EPC. Some of the essential nodes involved in the internetworking and mobility management are: Forward Attachment Function (FAF), Data Forwarding Function (DFF), and Automatic Network Discovery and Selection Function (ANDSF). The DFF and FAF are base station level logical entities located in the respective core networks of the RANs involved, with the former residing in the source network and the later in the target network. They are responsible for data forwarding, resource allocation and authentication. Link layer triggers or policy management peculiar to a subscriber can initiate vertical Handover (VHO) across the two networks. The functions (i.e. DFF, FAF and ANDSF) communicate to the UE via IP tunnels. The DFF and FAF assume specific functionalities of the source network (SN) and destination network (DN), i.e. for a VHO between mobile WiMAX and UTRAN (left to right), the DFF (WiMAX) would comprise of logical functionalities and protocols associated to the WiMAX base transceiver station (BTS), while the FAF emulates the UTRAN Radio Network Controller (RNC) with the appropriate protocols and functionalities. The discovery of the DFF and FAF is facilitated by the ANDSF, which eliminates the need for UEs to actively scan for RANs, thus reducing interference and increasing battery life on the UE. An active vertical handover session as described in [4] can be summarized in the following ten-step algorithm:

STEP 1: UE obtains target network information (FAF details)

STEP 2: UE obtains DFF addresses from ANDSF

STEP 3: UE establishes IP tunnels to the FAF for authentication

STEP 4: FAF initiates resource reservation and relocates UE to the target network

STEP 5: UE instructs DFF to initiate data forwarding

STEP 6: DFF establishes tunnel to the target FAF and perform handover on behalf of the WiMAX BTS

STEP 7: DFF forwards buffered packets to the FAF

STEP 8: FAF forwards the buffered packets to the UE (now located in the Target Network)

STEP 9: UE initiates PDP context

STEP 10: UE resumes data communication via the node B.

Steps 1 to 5 occur while the UE is still in the source network, thus significantly reducing the active VHO time.

B. Interworking WiMAX and 3G Cellular Networks: IMS–MIP Approach

A similar VHO scenario (WiMAX–3G cellular network: right to left) from an IP multimedia System (IMS) – Mobile IP (MIP) perspective is described in [5]. The IMS is responsible for session mobility, while MIP (v4 or v6) is used for mobility management across both networks. It is assumed that both networks have IMS functional modules and corresponding home agent (HA) and foreign agent (FA) residing in their CN and the UE is registered with the appropriate IMS entity and HA in its home network. The MIP platform manages IP addressing across the disparate networks (tight, loose, peer-2-peer coupling), while the IMS control layer modules ensure that session is kept alive during handoff via SIP signaling. When VHO occurs, binding updates are sent between the FA and HA, these updates help in redirecting user traffic from a corresponding node to the new target network module (FA), which the UE is presently connected to. SIP sessions within the IMS modules are re-initiated, with the UE initiating the SIP RE INVITE message. It is assumed that both the WiMAX and 3G Network interconnect to a central IP network.

C. Interworking WLAN and WiMAX Networks:

1) Media Independent Handover – Media Pre-Authentication (MIH-MPA) Approach

Taniuchi et al. in [6] describe the Interworking scenarios between WLAN and WiMAX networks, which employs the IEEE 802.21draft MIH service discussed in [7] and the MPA presented in [8]. The MIH Function (MIHF) is cross layer network design module/function from the IEEE 802.21 MIH draft that reports layer 2 events and triggers. It also provides a means for issuing commands to effect the established policy criterion. The MIHF is used with the MPA from Internet Engineering Task Force (IETF), such that the MIHF provides the information required for the UE, and MPA (MIH user) to initiate and perform inter-technology handovers. The MIH Service requires a client module integrated into the UE and a MIHF server residing on either or both of the CN involved. Dutta et al. [8] describe MPA as a mobility management entity capable of facilitating handover by establishing higher layer security associations and configurations with a target network before a link-layer handover is made. Handing over before making a layer-2 switch in tandem with MIH reduces packet loss and handover latencies significantly. MPA

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effects inter-technology handover, while MIH services assist in handover initiation. The UE queries the MIH information service (without active scanning) which can reside in either the source or target network, and then proceeds to authenticate and associate with the target network over the source network. A command service is issued by the MIHF to activate the required interface when VHO is about to occur.

2) Multi-Mode Approach

A multi-mode mobile node can also achieve interfacing WLAN and WiMAX technologies and a gateway function as described in [9]. The gateway function is typically implemented on an access service network (ASN), which handles session management, mobility management, authentication, QoS, and a common authentication, authorization, and accounting (AAA) platform. Interworking between both networks is further simplified, by deploying them using IETF protocols. This gateway approach can be adapted for various internetworking scenarios (UMTS and CDMA 2000, WLAN and UMTS etc.). It is the simplest approach to internetworking and interoperating dissimilar access networks with little or no modification to the corresponding radio access networks. This approach however, would require that subscriber information be managed by three different entities i.e. additional interfaces from the participating Home Locator Register (HLR)/Home Subscriber Server (HSS)/AAA to the gateway system [10].

3) Mobile SIP Approach

The Mobile-SIP approach is proposed in [11] to achieve WLAN–WiMAX vertical handover. As against the typical *re-Invite* method adopted in most of the SIP enabled handover scenarios, the authors propose a modified mid-call SIP method that employs the use of a SIP request when the mobile network changes access networks. Existing SIP *re-Invite* method requires the corresponding node to perform the handover by establishing a new multimedia session using the old connection identifiers and new IP address of the mobile node originating the session. The authors in [11] anticipate a problem with this method, since there is a possibility for the corresponding node to lose the address of the mobile node. To resolve this, the corresponding node has to contact the SIP server in the home network of the mobile node to obtain details of its originating session node. For this to be accomplished the UE has to send invitation retransmissions and information about its location to the SIP server located in the mobile node's home network before initiating a new session. Apparently, the existing SIP mid-call mobility doesn't support this function. Improved mid-call mobility as here described solves the above stated problems peculiar to typical mid-call mobility support by registering the mobile node's movement with the SIP server. The mobility method adopted (M-SIP) requires the SIP server

to perform the handover and change of access network. Also, the mobile node's movement is registered within the SIP server. A mobile node with dual network interfaces can initiate a VHO by sending a new SIP message (SIP INVITE_HANDOVER) to the SIP server, which in turn forwards the request to the corresponding node. The acknowledgement is sent to the mobile node via the same path. SIP inherently handles session and terminal mobility.

D. Interworking CDMA 2000 and WLAN Systems

An IEEE 802.21 centric test bed for internetworking CDMA 2000 and WLAN systems is described in [12]. It explains how the use of the MIHF combined with the MPA [8] could facilitate both Network-initiated and Host-initiated handovers. The Network initiated VHO includes a new entity: PoS, Serving and Target PoS located in the corresponding networks. The MPA alongside the authentication agent (AA), configuration agent (CA) and an access router (AR) located in the target network are responsible for security associations, session and mobility management by establishing authenticated and higher-level layer connection with the target network before the VHO occurs. The test bed setup described involves an evolution data only (EVDO) and a WLAN network, linked together via the Internet. The UE employs the MIHF described above, and a MPA client to perform the inter-technology handover, with a MPA server residing in the core network (Target or Source). VHO is performed from the EVDO to WLAN by the MPA engine. Other uses of the MIH to the MPA agents include identification of when to prepare for handover, access network discovery and selection, turn on and turn off radio interfaces. A signaling flow diagram for a network and host based initiated handover is also presented. The IETF protocols employed are Protocol for carrying Authentication for Network Access (PANA) for authentication [13], and IPSec [14], IKEv2 [15] and MOBIKE [16] for the proactive handover tunnel (PHT) mobility management. The tunneling agent is implemented on the Source Network (WLAN) as against the MPA framework of being implemented in the target network (TN). This is as a result of the inability to gain control over the CN elements of the MNO Providing the EVDO service.

E. Interworking WLAN and 3G Networks

In [17], internetworking of WLAN and 3G networks is implemented with the IP Multimedia system as the central mobility arbitrator, combined with a mobility manager (MM), which seamlessly manages the vertical handover. The functionalities and processes of the IMS session management are similar to those in [5]. The MM is responsible for managing buffered data traffic to the UE,

should they be sent from a corresponding node while VHO is in session.

F. Interworking WLAN and 3GPP Networks

The three generic internetworking architectures for WLAN 802.11 and 3GPP networks i.e. 1) tight, 2) loose and 3) peer-to-peer are presented in [17, 18].

1) *Tight coupling architecture*: the traffic from the WLAN Service set is routed through the CN of the cellular network. This is facilitated by a GPRS Interworking Function (GIF)/ Serving GPRS Support Node (SGSN) emulator. The GIF emulates the 802.11 basic/extended service set, thus seemingly appearing as another SGSN within the cellular network. With this approach, mobility and session management of the cellular network is directly applied. On the other hand, this would introduce bottlenecks at the SGSN as result of high data rate traffic from the WLAN [17].

2) *Loosely coupled architecture*: sends signalling exchange (providing AAA and charging functionalities) occurs between the WLAN and the 3G Network via the WLAN. User data is then transported over an IP network or routed to the UMTS CN.

3) *Peer-to-peer architectures*: in this case, the participating networks are treated as distinct networks or peers, while MIP is used to address mobility management across the networks involved.

G. Interworking WLAN and 3G UMTS Networks

An architecture built around the IMS, which internetworks WLAN with 3G UMTS network is presented in [19]. Here, the WLAN is tightly coupled with the UMTS network, such that the WLAN connects to a SGSN emulator, which masks the WLAN BSS as a routing area within the Gateway GPRS Support Node (GGSN). Thus allowing mobility management to be managed by the UMTS network. Furthermore, the UE doesn't have to change layer 3 address after the VHO, as its permanent home address as its connected to the same GGSN (routing entity) hosted by the UMTS network. As such, the vertical handover seems horizontal in some sense. Session handover (UMTS–WiMAX: overlapping UMTS coverage) is managed by IMS entities, the MN is required to activate its WLAN interface (after running the network discovery function) and send a re invite SIP message via its P CSCF and S CSCF (IMS entities) in its visited and home networks (WLAN Core Network) while the UMTS session is still active. After successful IMS registration, the re-invite SIP message is sent to the CN using the same caller ID and the respective identifiers tied to the ongoing (UMTS) session. Immediately the WLAN interface resumes data transfer, the UMTS session is aborted. Reverse session handover (WLAN–UMTS: non overlapping WLAN cell coverage) for a fast handover users, might result into a break before make handover scenario, due to the non overlapping cell coverage of the WLAN on the UMTS cell and the rapid signal drop of the WLAN. Session handover is similar to the UMTS-WLAN procedure, with the UMTS interface activated almost when the WLAN signal has dropped.

H. Interworking WiMAX and 3GPP Networks

[20] proposes a framework that is built around two IEEE drafts; IEEE 1900.4 [21] and IEEE 802.21[7] to perform a VHO from a 3GPP access network (AN) to a WiMAX access network. The fundamental concept of the IEEE 1900.4 is to define a decision based system that acts on a set of actions, which are required to optimize the radio resource coordination and QoS in a heterogeneous wireless network environment [22]. The following entities within the IEEE 1900.4 are employed in the VHO, VHD and VHC; VHC –t/n, Content Information Collector (Terminal/Network) (CIC–t/n), Terminal Handover Manager (THM) and Network Handover Manager (NHM) as proposed by the authors. These entities subscribe to the 802.21 as Media Independent Handover users. MIP, Stream Control Transmission Protocol (SCTP) and SIP handle mobility management within the framework. VHO preparation and initiation involves the CIC-t obtaining Mobile Terminal (MT) context information and access network discovery details, which are sent to the THM and stored in a Terminal Information Database (TIDB), concurrently network context information is retrieved and forwarded to the NHM and stored in a Network Information Database (NIDB). The THM and the NHM then exchange context information and the NHM "generates radio resource selection policies and constraints" and forwards them to the THM. In a situation where the received policies from the NHM trigger a VHO, the final VHD is concluded by the terminal (network policies and constraints have to be consistent). Thereafter, signaling exchange occurs within the 1900.4 entities (MIH Users), MIHF, (terminal and network) and RMs in the corresponding networks (source and target). Following signaling exchange, the UE obtains a foreign agent via foreign agent adverts, and registrations procedures. Then traffic flow is resumed via the new target network.

III. SUMMARY

With interworking of RATs in place, MNOs can offer the same services and features to subscribers irrespective of the access network used. The level of current investments in legacy second and third generation network elements guarantees that inter-technology mobility would offer

operators channels for maximizing their already existing access networks. It will likewise afford them the opportunity for matching network resources to application requirements. Inter-technology mobility is a key facilitator to the incremental rollout of 802.16m and LTE-A networks, as it would help operators with multiple access network technologies to reduce the return on investment time on new applications [23]. There is a popular school of thought that asserts that next generation wireless networks will be characterized by the seamless integration of multiple communications networks. This will be achieved in an environment with air interfaces, which intelligently and seamlessly connect people and things across different WANs, LANs, and PANs. We could not agree more.

IV.   CONCLUSION

We have presented in this paper various interworking scenarios (most deployed, some proposed) for achieving the seamless migration of UE across varying wireless networking technologies as described in the literature. This survey is reasonably exhaustive in contextual scope, and would serve as a veritable reference source for current and future researches in the field of NG Heterogeneous, multi-platform, multi-service, converged networks.

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