Mobility and QoS Management in Heterogeneous Wireless Networks

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Summary
The demand for accessing services while on the move, at any place and time, has lead to the current efforts towards integration of heterogeneous wireless networks, in particular UMTS, WiMAX and WLAN, as complementary systems. Integration can be performed at different levels: tight coupling and loose coupling. The paper presents the design and evaluation of a HMIPv6 based architecture for different wireless networks interworking. Our proposed architecture aims to solve the problems existing in present interworking solutions, such as congestion in the UMTS core network. On the other hand, it's a significant issue of how to guarantee the quality of service (QoS) in this heterogeneous environment. In This paper we propose to implement Mobile Resource Reservation Protocol (MRSVP) in the fourth generation mobile networks, to guarantee the QoS for real time applications.
Keywords:
heterogeneous wireless networks; coupling; HMIPv6; QoS; MRSVP; handover

1. Introduction

Wireless access technologies have characteristics that perfectly complement each other. Cellular systems provide wide coverage areas, full mobility and roaming, but traditionally offer low bandwidth connectivity and limited support for data traffic. On the other hand, Wireless Local Area Networks (WLANs) provide high data rate at low cost, but only within a limited area, whereas Worldwide Interoperability for Microwave Access (WiMAX) can supply mobile broadband for anyone, anywhere, whatever the technology and access mode.

In this context, the mobile terminal may be a wireless videophone, a laptop, or a personal digital assistant (PDA), and can be connected with a private or public network, from home to office. Combined with Universal Mobile Telecommunications System (UMTS), WiMAX offers high data rate services in addition to original voice services in hotspot areas. As a result, WiMAX and WLAN can be utilized as a powerful complement to UMTS network. In order to provide the mobile users with the requested multimedia services and corresponding quality of service (QoS) requirements, these radio access technologies will be integrated to form a heterogeneous wireless access network. Such a network will consist of a number of wireless networks, and will form the 4th generation (4G). The 4G wireless networks will offer several advantages for both users and network operators, so users will benefit from the different coverage and capacity characteristics of each network throughout the integrated networks.

Two generic architectures for integrating different access networks are: tightly coupled architecture and loosely coupled architecture [8]. In the tight coupling approach, the WIMAX/WLAN is embedded in the UMTS network In the loose coupling approach, the networks are interconnected independently using Mobile IP architecture. However If the mobiles, registered in the UMTS network, use a home agent (HA) that is deployed in their home network (UMTS) when roaming across WLAN and WIMAX networks, the UMTS network may get overloaded with WLAN/WIMAX traffic. To solve this problem, we propose an architecture based on Mobile IP and its Hierarchical Mobile IP extension [3]. Hierarchical Mobile IP provides regional registration management which tends to reduce the registration period, hence the packet loss suffered during handoffs. This is an important issue for avoiding congestion in the UMTS core network.
On the other hand, when the user is in a heterogeneous wireless environment, the first coming problem will be how to reduce the service delay or interruption that handoffs cause, especially, for real time services sensitive to both delay and loss. In order to provide QoS support for IP convergence services such as media streaming and VoIP applications, several QoS protocols have been standardized such as Resource Reservation Protocol (RSVP) [10], MultiProtocol Label Switching (MPLS) [11] and Diffserv [12].

DiffServ and MPLS are usually deployed in core-networks or backbone networks since they can provide aggregation function for data flows from different applications. In access networks, RSVP is widely utilized to provide a QoS guarantee for applications. Unfortunately, basic RSVP cannot be directly applied to mobility scenarios. Firstly, RSVP messages are not visible to the intermediate routers of an IP tunnel used in Mobile IP [13] because of IP-in-IP encapsulation [14]. Secondly, the previously allocated resources are no longer available after the MH moves to a new foreign link. In addition, RSVP does not cover the

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scenario of seamless handover among heterogeneous networks. Before handover, the mobile host (MH) does not know whether the resource in the target network is available or not. In an overlapped area which has multiple foreign links, it is also impossible for the MH to select the foreign link which can best satisfy its QoS requirement.

In this paper, we propose a MRSVP-based approach to set up advance reservations to a mobile host moving across heterogeneous networks.

The rest of the paper is organized as follows. Section 2 discusses the existing coupling solutions. Section 3 presents our proposed architecture. In Section 4, we show simulation results and evaluate the performance of the HMIPv6 based solution. Section 5 discusses the existing resource reservation solutions. Section 6 describes the MRSVP Protocol. Section 7 presents our proposed model. In Section 8, we show simulation results and evaluate the performance of our approach. Finally, we conclude the paper.

2. Existing coupling solutions

Heterogeneous wireless networks interworking can be distinguished into two main approaches: tight coupling and loose coupling [1] [2] [3] [8]. The distinction between tight and loose coupling is based on the tight or loose cooperation between the networks involved.

2.1 Tight coupling

With the tight coupling approach [2] [3] [4] [8], the WLAN and the WiMAX network are connected with the UMTS core network in the same manner as any other Radio Access Network (RAN) [8]. As a result, the data traffic from the WLAN or WiMAX users goes through the UMTS core network before reaching the Internet or other packet data networks (PDN). In this context, each network has to modify its protocols, interfaces and services in order to support the interworking requirements. In particular, this enables to support integrated authentication, accounting and network management.

An example of tight coupling integration is presented in [8] and illustrated in Fig. 1. In this architecture, a logical node called the virtual GPRS support node (VGSN) is introduced to interconnect the WLAN, WiMAX and UMTS networks. Its main functionality is to exchange subscriber and mobility information, and to route packets between the integrated networks. More particularly, the VGSN enables the UMTS, WLAN and WiMAX to handle their own subscribers independently, without the need of Mobile IP (MIP) functionalities.

The VGSN is deployed in the UMTS core network and is connected to the Serving GPRS Support Node (SGSN), the Gateway GPRS Support Node (GGSN), the WIMAX Gateway and the WLAN ga

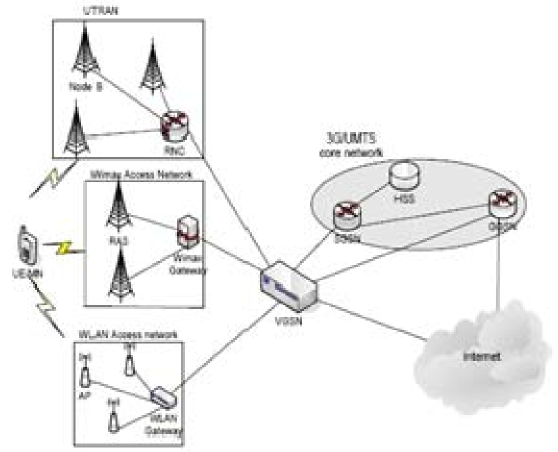


Figure 1. Tight coupling Integration at the GGSN Level

Tight coupling may be also done at the Radio Network Controller (RNC) level. This approach focuses on interworking at the UMTS Terrestrial Radio Access Network (UTRAN) level and, more precisely, on incorporating the RNC or lower UMTS entities' functionality into WLAN/WiMAX components [8]. This integration is accomplished with the Interworking Unit (IWU) which is responsible for protocol translation and signaling exchange between the RNC and the other access points (hotspots and WiMAX Base Stations). The critical point in this architecture is the RNC which transmits and receives traffic from both UTRAN and other wireless access technologies.

Such architecture is mainly tailored to operators deploying their own WLANs and WiMAX networks, as the UMTS infrastructure is mostly reused.
The main advantage of this approach is the efficient mobility management, based on existing UMTS functionality that ensures at least service continuity, including authentication, authorization, accounting, and billing. In particular, the mobile users are able to maintain their sessions, as they move from a network to another, whereas service continuation is subject to WLAN or WiMAX QoS capabilities. Furthermore, a large part of the UMTS infrastructure (e.g., core network resources, subscriber databases, billing systems) is reused, minimizing the cost of deployment.

Briefly, the tight coupling scheme requires a major modification to the access network architecture. The mobility management for tight coupling scheme is based on the existing mobility solutions of cellular networks, whereas mobility management for loose coupling schemes is based on Mobile IP.

The primary advantage of the loose coupling approach is that it does not require any architectural change and different access networks may be completely independent.

However, most current solutions require agreements between operators who own the different interworked access networks to be established. The details of loose coupling architecture based on mobile IP are presented in the following.

2.2 Mobile IP approach

IETF proposes a protocol called Mobile IP (MIP) to keep the IP consistence across heterogeneous networks by adding some transferring nodes [1] [5] [6], home agent (HA) and foreign agent (FA). HA stores the registration information of all terminals originated from the current network. When a mobile node (MN) roams into a foreign network, it will first obtain a Care of Address (CoA) from the FA [7]. The MN will further notify the HA in the home network of the CoA using a registration message. In The Mobile IP approach, the MN should register to the HA every time when it changes its IP address, so that, the packets destined for the mobile can be delivered to its current attached network. In the loose coupling strategy, UMTS, WIMAX and WLAN are interconnected independently [1]. In the UMTS network, the terminal (or user equipment, UE) uses standard UMTS session management (SM) and GPRS mobility management (GMM) to handle a packet data protocol (PDP) session and the roaming between radio access networks.

If a UE decides to handover from UMTS to WIMAX/WLAN, it simply disables its UMTS protocols and uses the IP stack. If the UE wants to use the same IP address that uses in the UMTS network or wants to be accessed via the original IP address, mobile IP should be involved. HA is deployed in the GGSN. Foreign agents are deployed in the WLAN access gateway (WAG) and in the access service network gateway (ASN GW) in the WLAN and WIMAX networks, respectively. Fig. 2 shows the detail procedures. The UMTS is the MN’s home network. Initially, the MN is sending or receiving data packets from a UMTS network.

This scheme allows the independent deployment and traffic engineering of UMTS, WIMAX and WLAN networks. Network operators and service providers can operate these networks separately through roaming agreements.

Generally speaking, the existing mobile IP and UMTS standards are quite enough and mature to support this approach. However, in the MIP strategy, the MN should register to the HA every time it changes its IP address. If the MN moves frequently across WLAN and WIMAX networks, it will send back the registration messages frequently to its HA. The handover latency, the packet loss and overload in the UMTS network are the major problems of Mobile IP approach.

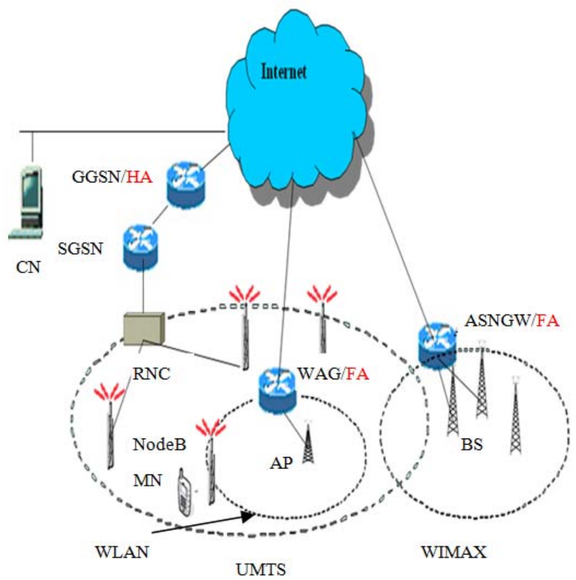


Figure 2. Mobile IP based Architecture

3. HMIPv6 based solution

3.1 HMIPv6

Hierarchical Mobile IPv6 (HMIPv6) is a hierarchical architecture for micro mobility based on Mobile IPv6 [9], with a two level architecture; the root being at a gateway foreign agent (GFA) and the second level supported by access routers. Each mobile node in HMIPv6 requires two care of addresses (CoAs): a regional CoA and an on-link CoA. When the mobile node moves to a foreign network, it sends two binding updates one to the home agent and/or the correspondent node (CN) and the other which is like a local binding update to a GFA, which is the root of the hierarchical architecture. When the mobile node moves to another subnet within the same domain, it then has to only send updates of its onlink CoA which is the local binding update to the GFA.

3.2 Architecture Description

In Mobile IP approach, a mobile node roaming across heterogeneous networks is required to register with its GGSN/HA each time it changes its care-of address. If the UE registered in the UMTS network, moves across the WIMAX and WLAN networks, the signaling delay for these registrations may be long, especially when the GGSN/HA is far away from the MN, and heavy signaling traffic will be generated in UMTS core network.

To reduce the registration delay and to avoid congestion in the UMTS core network, we propose a HMIPv6 based architecture whereby registrations are handled within the hierarchy and do not need to be communicated to the GGSN/HA.

Fig. 3 illustrates the operation of Hierarchical Mobile IP. It shows the difference between global and regional registration. It can be seen that the first have to traverse the whole of the network to the HA while the others have to reach a local entity, termed in the figure as Gateway Foreign Agent (GFA). The GFA is deployed in the WIMAX/WLAN network; it is placed at top level of FAs (WAG and ASN GW).

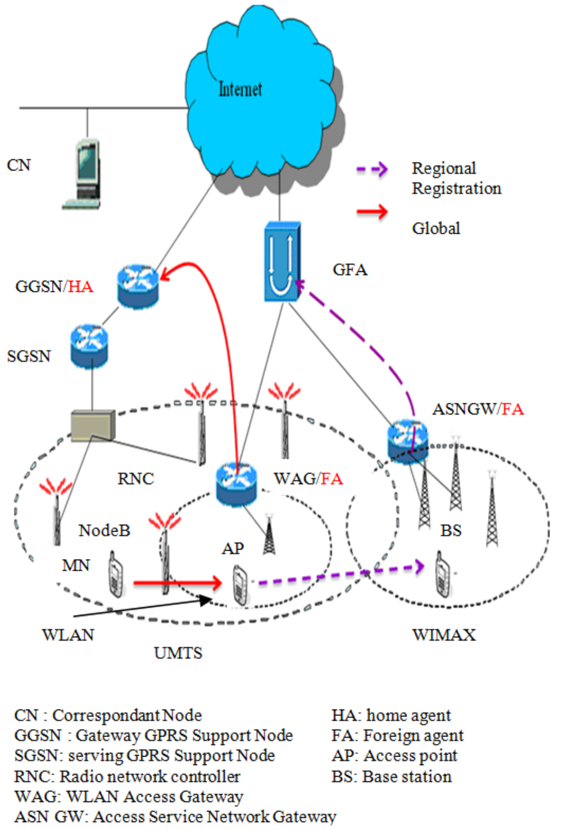


Figure 3. HMIPv6 based Architecture

When the mobile node moves from UMTS, as the home network, to WLAN as the visited network, it makes a global registration. If the MN continues to move from the WLAN to the WIMAX, it makes a regional registration within the GFA.

This approach aims to provide fast and efficient handovers between WIMAX and WLAN networks for the mobile nodes registered in the UMTS network.

4. Simulations Results

Simulations are conducted to evaluate the performance of our proposed model. The simulation environment has a UMTS network, a WIMAX and a WLAN. The UMTS network has two radio network subsystems. The WIMAX network has two Base stations and the WLAN network has ten access points. We assume that all users are registered in the UMTS network and move across UMTS, WLAN and WIMAX networks. We assume that at t = 0, 50% users are in UMTS, 25% users are in WLAN and 25% are in WIMAX. At t = 20 s, a number of mobile nodes move from WLAN to WIMAX.

We compare three different approaches, i.e. tight coupling, mobile IP approach and HMIPv6 approach. Fig. 4 shows the handover latency.

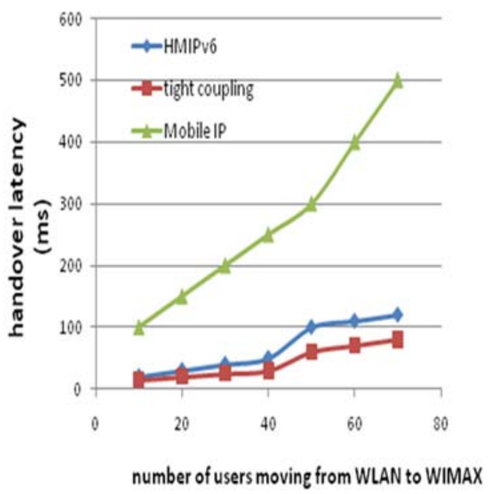


Figure 4. Handover latency for different interworking strategies

Results obtained show that Mobile IP approach has the poorest performance since the signaling packets have to go to the UMTS core network (GGSN/HA).

In HMIPv6 approach, the regional registration within the GFA helps to enhance the QoS during handoff by reducing handover latency. In fact, the mobile node doesn't need to register to the GGSN/HA. The latency might not be acceptable for real time applications. Fig. 5 shows packet loss during handover. We learn that tight coupling and Mobile IP approaches have high packet loss rates compared to HMIPv6 approach. In fact, in tight coupling and Mobile IP scenarios, the data packets destined to the WLAN and the WIMAX users go through the UMTS. Therefore packet loss is due to the overload the UMTS core network. The result shows that in the HMIPv6 based architecture, the quality of service doesn't degradate as user goes far from its home network (UMTS) and moves across the WLAN and WIMAX networks.

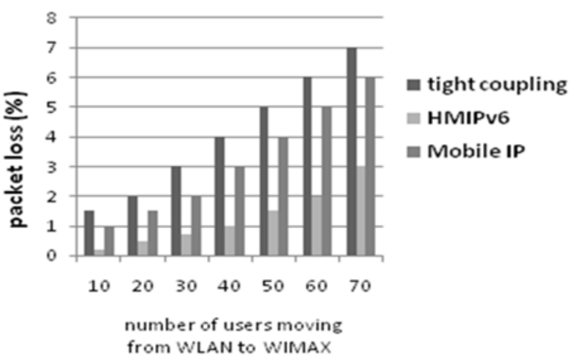


Figure 5. Packet loss for different interworking strategies

5. QoS approaches proposed in literature

The literature offers several proposed solutions for providing mobility support in QoS guarantee.

Terzis [15] proposed a simple QoS signaling protocol that combines RSVP Tunnel with the mobile environment to resolve the RSVP message invisibility problem. The underlying principle is to establish tunnel RSVP sessions between the home Agent (HA) and the foreign agent (FA). In addition to encapsulating PATH messages from the sender and sending them to mobile host's care-of address (CoA), HA also sends to FA an extra pair of tunnel PATH messages without encapsulating IP headers. Using this tunnel RSVP session, the method can actually resolve the RSVP signaling invisibility problem.

In [16], the authors propose RSVP extensions for real-time services to guarantee the QoS with RSVP in heterogeneous wireless networks. They set an intersystem, "QoS Agent," between the gateways of WLANs and cellular networks to manage the mobility of mobile users, and use the schemes of resource pre-reservation and precise pre-reservation decision mechanism to reduce the delay time of re-routing while handoff occurs and guarantee the QoS of real-time services efficiently. Simulation results show that this approach can reduce 52% waste of the whole network resources as the number of the WLANs is set to forty.

Reference [17] presents a new resource reservation protocol for seamless handover. HO-RSVP integrates with Mobile IPv4 to maintain a continuous QoS guarantee between two mobile nodes. In the protocol, the resource reservation remains unaffected in the unchanged segments of the signal path in case of mobility It is only necessary to make a new reservation in the changed segments. The protocol can also prevent the MH from moving to a performance-degraded access network through resource pre-reservation before handover. When the receiver is mobile, resource reservation can be refreshed in the data path for the sender after handover. When the sender is mobile, a procedure is initiated to tear down the old reservation after handover.

6. Overview of MRSVP

Mobile ReSource ReserVation Protocol (MRSVP) was proposed by Talukdar [18,19] to achieve the desired mobility independent service guarantees in Integrated Services Packet Networks with real-time multimedia applications. The MRSVP protocol makes advance resource reservations at multiple locations where an MH may possibly visit during the service time. The mobile host (MH) can thus achieve the required service quality when it moves to a new location where resources are reserved in advance. The MRSVP protocol is described as follows. Just as Mobile-IP protocol requires mobility agents to aid in routing, MRSVP requires *proxy agents* to make resource reservations for the MHs. A proxy agent is said to be a *local proxy agent* if it is collocated within the location where an MH currently visits or a *remote proxy agent* if it is within the MH's neighboring subnetwork. The local and remote proxy agents are recorded in a Mobility Specification (MSPEC). The MSPEC indicates the set of locations where an MH may possibly visit in the near future. When a recipient MH moves to a new location, it needs to search all of the proxy agents in its neighborhood and then update MSPEC using a *Proxy Discovery Protocol* [19]. The updated MSPEC is sent as a *Receiver_MSPEC* message to the sender that initializes the flow to the recipient MH. By examining the *Receiver_MSPEC* message, the sender can obtain the locations where the recipient MH may possibly visit. In addition, the recipient MH sends a *Receiver_SPEC* message to all remote proxy agents recorded in MSPEC (to join multicast group). These remote proxy agents can thus retrieve the QoS-guaranteed parameters for the recipient MH's services. Through the exchange of a pair of PATH and RESV messages between the sender and recipient, an *active resource reservation* can be built from the local proxy agent of the sender to the local proxy agent of the recipient. Several *passive resource reservation* paths are then built from the remote proxy agents of the sender to the remote proxy agents of the recipient. An active reservation is the path on which packets are actually transmitted, whereas passive reservation paths are only reserved in advance without any actual packet flows. When the MH moves to a new location, MRSVP changes the passive reservation of the new visited location into an active state and the original active reservation is altered into a passive state at the same time. In this way, the needed resources for the MH in the new region can be retrieved rapidly because the resources were preserved in the original passive reservation path. That is, a seamless handoff for QoS guarantees can be retained using the MRSVP protocol.

7. Our proposed approach

7.1 Reservation models and schemes

Our idea is to implement MRSVP in the heterogeneous wireless networks to maintain a continuous QoS guarantee for mobile users moving across different wireless networks. We assume that the user has a dual mode device.

In our model, the heterogeneous environment is composed of UMTS and WiMAX networks. We assume that the UMTS and WiMAX networks are open coupled and Mobile IP is exploited to interconnect them [20]. We assume that the MH is registered in the WiMAX network and moves to UMTS; In this case, the WiMAX gateway (ASNGW) is the HA and the Gateway GPRS Support Node (GGSN) is the FA, The mobile host has two IP addresses (home address in WiMAX and care-of address in UMTS).

Real time applications are very sensitive to packet loss and delays and the WiMAX network offers higher bandwidth than the UMTS network. So, a mobile node moving from WIMAX to UMTS has to reserve resources in advance to garantee no degradation of real time service.

In our proposed architecture; we assume that the sender is a fixed host and the receiver is a mobile host. The WiMAX network is the home network of the mobile receiver and the UMTS network is the visited network. So, the visited NodeB in the UMTS network is a remote proxy agent of the mobile receiver.

We describe the details of the reservation routes in the following section.

In MRSVP, there are two types of Path messages as well as two types of Resv messages [19]. These are:

1. Active Path message: carries a SENDER_TSPEC for active reservation.
2. Passive Path message: carries a SENDER_TSPEC for passive reservation.
3. Active Resv message: carries a FLOWSPEC for active reservation.
4. Passive Resv message: carries a FLOWSPEC of only passive reservation.

In our reservation model, the sender is a fixed host, so it sends only passive PATH messages. The mobile receiver doesn't need to reserve resources in the home network (WIMAX network), because there is sufficient bandwidth. For this reason, the mobile receiver doesn't generate an active RESV in the WIMAX network.

The UMTS network offers less bandwidth and the new location into which the mobile host moves may be overcrowded and the available bandwidth in the new location may not be sufficient. So, the remote proxy agent in the UMTS network sends a Passive Resv in response to the passive path. Passive reservations are established. Passive reservations are converted to active reservations after handover.

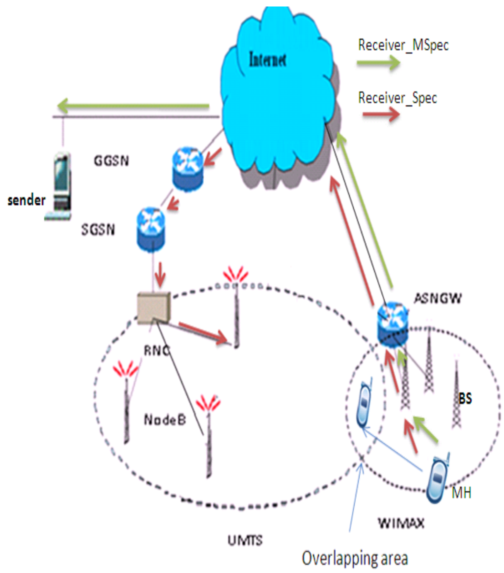
In addition to the messages present in RSVP, some additional messages are required in MRSVP [19]. Our model supports only two messages:

- Receiver_Spec: this message is used by a mobile receiver to send the FLOWSPEC and the flow identification (i.e. the SESSION object) to its remote proxy agent.
- Receiver_Mspec: This message is used by a mobile receiver to send its MSPEC to the sender who sets up the routes of passive reservations. It contains the addresses of proxy agents of the locations in the MSPEC of the mobile receiver.

7.2 The Proposed Scenario

We assume that a recipient MH is receiving a real-time traffic in the WiMAX network. When it moves to the cell boundary, it needs to search all of the proxy agents in its neighborhood and then update MSPEC using a *Proxy Discovery Protocol* [19].

As shown in Fig. 6, the updated MSPEC is sent as a *Receiver_MSPEC* message to the sender that initializes the flow to the recipient MH. By examining the *Receiver_MSPEC* message, the sender can obtain the locations where the recipient MH may possibly visit.



BS : Base Station MH: Mobile Host
GGSN : Gateway GPRS Support Node
SGSN: serving GPRS Support Node
RNC: Radio network controller
ASN GW: Access Service Network Gateway

Figure 6. Mobility Specification update

As illustrated in Fig. 7, if the Receiver_Mspec contains an IP address of a nodeB, the sender detects that the mobile IP is moving to the UMTS network and sends a Passive PATH to the nodeB in the visited network. The nodeB, replies with a Passive RESV and passive reservations are set up.

When the mobile host performs a handoff, the passive reservation from the sender to its new location has to be converted to an active reservation, as shown in Fig. 8. We use the handoff detection mechanism of the IETF Mobile-IP [13] to detect handoff by a mobile host. The Mobile-IP modules in both mobile host and the mobility agents (both home agent and foreign agent) are augmented to notify the handoff event to the MRSVP module.

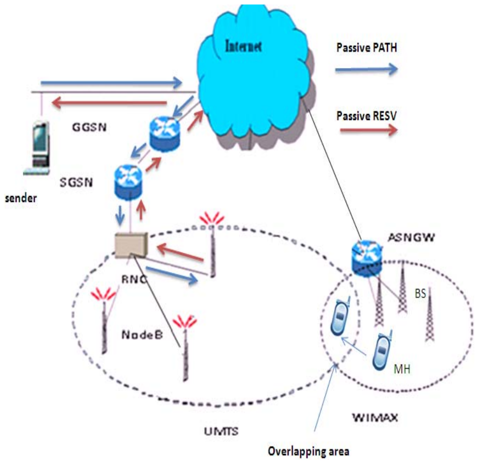


Figure 7. Passive reservation establishment

When a mobility agent detects that the mobile host has moved in and successfully registered in its subnet, it informs the proxy agent in that node so that the proxy agent can take the necessary steps for the flow conversion.

8. Simulations Results

In the network configuration; there are two access networks, WiMAX and UMTS. The MH is comprised of the laptop, UMTS card (for receiving data in UMTS field) and WiMAX card (for receiving data in WiMAX field). The MH can handover freely between the two kinds of access network. Mobile IPv4 is used to ensure a consistent service for the MH in the two networks.

To evaluate the performance of our proposed approach, we adopt VoIP application to run in our simulation platform and use MRSVP procedures to provide the QoS guarantee. In the VoIP application, audio codec is g.711 which has an average bit-rate at 64kb/s. We assume that the sender is a constant bit rate (CBR) source attached to user datagram protocol (UDP) agent.

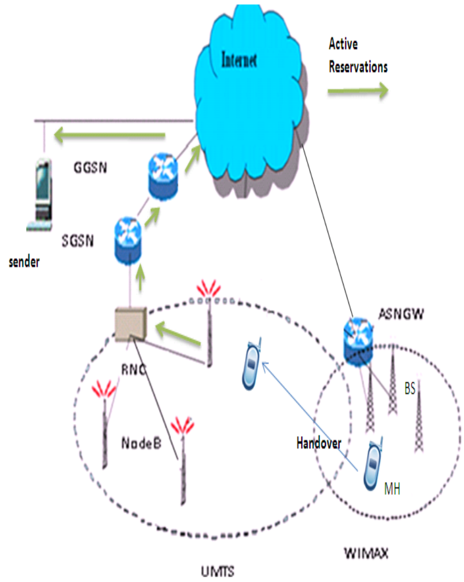


Figure 8. Conversion of reservation from passive to active state

For the VoIP application, the sampling rate for audio device is 20ms/per packet. During the interval of 10s, about 500 packets will be transmitted.

In the first scenario, we assume that the MH doesn't make pre-reservation in the UMTS field. It performs handover after 50 seconds. Fig. 9 shows that the packet delay increases in the UMTS field.

The second scenario adopts our approach, we assume that at t = 0, the MH is located in the WiMAX network and starts to receive traffic , after 30 seconds, the MH moves to the WiMAX cell boundary. So, the Mobile Host makes a pre-reservation in the UMTS network. We propose that the UMTS network is overcrowded (all nodes are sending). At t = 50s, the MH performs a vertical handover to the UMTS. The passive reservation is transformed to an active state.

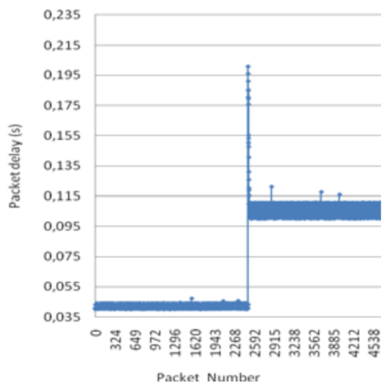


Figure 9. Packet delay for VoIP without resource pre-reservation in the UMTS network

Fig. 10 shows the performance of VoIP application adopting our approach. In this figure we highlighted the three different stages that the MT experiences. Initially, the MT is located inside a WiMAX domain, experiencing packet delays in the order of 0,04 seconds. When the MT goes outside of WiMAX radio range, it performs a handover to the UMTS network. During the subsequent UMTS access stage, the packet delay along this route is about 0,04 seconds. So, the QoS is maintained after handover.

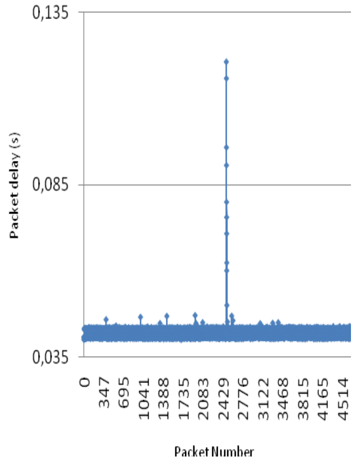


Figure 10. Packet delay for VoIP in our approach

In the two cases the packet delay rises to a peak after 50 seconds because of handover latency.

9. Conclusion

This paper proposed a HMIPv6 Based architecture for UMTS-WIMAX-WLAN Interworking. At first we have presented and compared the existing coupling models. Then we have described our solution.

With the presented approach, the UMTS users can have a seamless roaming between networks without registration to GGSN/HA. Simulation results show that our approach reduces handover latency and packet loss significantly comparing with tight coupling and mobile IP approaches.

In order to guarantee the QoS in the heterogeneous environment, we also proposed to implement MRSVP protocol in the heterogeneous networks. We have chosen this protocol because of its performance in the homogeneous environment. Our goal is to make resource pre-reservation before handover from WiMAX to the UMTS network that offers less bandwidh.

By simulation and packet delay analysis, we proved that our approach maintains the same QoS guarantee in the visited network (UMTS) as in the home network (WiMAX). Without resources pre-reservation, we learn that the packet delay increases after handover.

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