Seamless multicast handover in an NC-HMIPv6 environment

LAMBERT KADJO TANON, SOULEYMANE OUMTANAGA, KONE TIEMOMAN
Institut National Polytechnique Félix Houphouët Boigny
Laboratoire de Recherche en Informatique et Télécommunication
08 BP 475 Abidjan 08
COTE D'IVOIRE
nonatipv6@yahoo.fr, oumtana@nic.ci, http:// www.nic.ci

Abstract: - The multicast facilitates group communications in IP networks and largely improves the usage efficiency of the bandwidth. However if this transmission technology has reached a sufficient maturity in fixed networks, it results in many problems in an IP environment where the receiver is mobile. The problem is partially attributable to the protocols managing the host mobility.
Indeed, in the mobile Internet, the host mobility affects unicast addresses which are considered in the multicast routing protocols as stable. So the change of these unicast addresses lead to long handover latency and packets losses due to interruptions provoked by the mobility.
So, the best adaptation of the multicast in the mobile Internet depends strongly on the type of mobility protocol in use. The current propositions for applications of multicast services are made in the mobility environments offering mobility management insufficiently optimized according to the following essential performance criteria: improvement of the handover latency, the scalability and the packet loss rate. Our proposal, based on the NC-HMIPv6 protocol, offers a better mobile multicast management through leaning the possibilities offered by this protocol. By widening the features of various entities in the NC-HMIPv6 environment, an effective management of the multicast handover is proposed.

Key-words:- Mobile IPv6, HMIPv6, NC-HMIPv6, NC-HMIPv6-M, Multicast, ASM, MLD, PIM-DM, PIM-SM, PIM-SSM.

1 Introduction

The multicast service under Internet was born during the last decades [1]. It allows a device (called sender or source) to send IP packets (voices, data and video) to a group of devices in an IP network, by using a single copy of each packet. So, the packets duplications are avoided and the sender network benefits from a better use of the available bandwidth. The way of managing the group communications facilitates the deployment of several group services in the fixed Internet, such as the video-conferencing, collaborative work, television over Internet, web radio, network games, VoIP, and other multimedia applications. However, in the IP mobile Internet environment, the management of such services turns out to be problematic. The recent works [2], [3] and [4] aimed to apply the multicast to protocols being in charge of the mobile Internet management proves that.

Indeed, to allow a terminal connected to Internet to benefit from mobility functions, the Mobile IP protocol [5] was implemented. It offers the host mobility in order to guarantee the continuity of services for this terminal. However, this protocol suffers from handover latency leading to many problems such as packet losses, interruptions, etc. With the purpose of perfecting this IP mobility protocol, several arrangements were made while implementing in IPv6 protocol. Mobile IPv6 [6] (mobility support under the IPv6 protocol) is an improvement of Mobile IPv4. It is thus based on the principal assets of its predecessor and the facilities offered by IPv6. As Mobile IPv4, it has to meet the challenge of offering mobility like that observed in the telecommunications networks as GSM (Global System for Mobile communications) networks.
Mobile IPv6 is based on the performances of wireless technologies which can offer, by simple configuration, a perfect mobility through several access points attached to the same access router. It makes it possible to reduce mobility problem to the problem of networks change. This change of network called handover (intra-domain handover while moving in the same domain or inter-domain handover in different domains) constitutes the biggest challenge for Mobile IP, particular for Mobile IPv6. These various types of handover and a certain number of criteria such as scalability, handover latency, packets losses, adaptation to existing standards, facility of implementation, lead to numerous mobility protocols. These IP mobility

protocols, some of which are viewed as the improvements of the others, have the common base: Mobile IPv6. The latter thus inherit the problems such as:

- considerable latency in the process of handover,
- the triangular routing (thus non-optimized) for certain communications, for example when an initialization for a communication with a mobile server occurs,
- the management of the quality of service weighed by the control messages,
- the security of mobiles, visited and Home Networks, the correspondent nodes, etc. become complicated.

They create different mobility environments according to the type of protocol used, among Mobile IPv6, FMIPv6 [7], HMIPv6 [8], Cellular IPv6 [9], NC-HMIPv6 [10], which are characterized by their improvement level of the criteria mentioned above (latency, scalability, packets losses, etc). Thus all new services to be implemented must adapt to the existing mobile topology. It must consequently neither lead to an additional latency nor make the existing architecture too complicated.

However, IP multicasting functions, according to its particular routing mode, constitute a particular service, which is unfortunately not taken into consideration by Mobile IPv6 and its derivative protocols. Its adaptation to IP mobile environment thus constitutes a challenge. That justifies the particular treatment which is the object of recent literatures ([8][11]).

To improve this IP mobile communication technology and offer to the mobile users, a transparency during the subscriptions and unsubscriptions to the groups, several propositions were made since then. In these propositions, the multicast routing is subjected to that of the traditional unicast routing. So, multicast services did not save the problems related to handovers such as the latency period and the packets losses which are the object of our study. Our purpose is to propose a clear architecture, allowing to improve multicast handovers. In section 2, we describe some native problems that occur in the implementation of this type of communication in IP mobiles networks. Section 3 described the solutions suggested in the literature. We propose in section 4, an architecture of multicast communications in an IPv6 mobility environment governed by the NC-HMIPv6 (Network-Controlled Hierarchical Mobile Internet Protocol Version 6) protocol [10] dealing with the case of a mobile receiver.

2 IETF Multicast Data Transmission Mechanisms In Basic IPv6 Mobility Environment

In IPv6 fixed network, in order to manage multicast group, two types of routing protocols are used:

- protocol used by receivers to join a group: MLD. There are two versions: MLDv1 [12] and MLDv2 [13]
- protocol used to construct a multicast tree. The protocol widely used is PIM (Protocol Independent Multicast) offering two main communication models: ASM (Any-Source Multicast) and SSM (Source-Specific Multicast). They allow forwarding the multicast data packets from the subscribers' access router to the sender's access router according to the known information about this sender. Two models are offered for the sender: DM (Dense Mode) for a broadcast method and SM (Sparse Mode) for a selective distribution.

Tree structure has been partially proved to be an efficient distribution architecture, taking into account of the best routing path (for example, using the algorithm SPT (Shortest Path Tree)) and offering an acceptable management of the quality of service and the scalability[14][15].

All these protocols were implemented to allow a better management of the group traffics in the Internet without taking into account of the mobility of senders or receivers.

2.1 Native mechanisms for the multicast transmissions management in Mobile IPv6 environment

The mechanisms of multicast group management offered by Mobile IPv6 do not differ, in priori, from those of unicast traffics. So, for the mobile Internet, and since the mobile node exists in the administrative network, known as Home Network, multicast streams are delivered by its multicast access router. It benefits from this routing optimization offered by the multicast routing protocols. When moving into another network, called visited network, a new address is granted, and two scenarios appear concerning its behavior towards previous multicast streams:

- continue receiving the multicast stream from the previous access router located in the Home Network: Bidirectional Tunneling;
- Make a new subscription within the visited network: Remote Subscription.

2.1.1 Bidirectional Tunnelling

This data transmission mechanism is used by Mobile IPv6 to allow a mobile terminal to receive its data streams from its Home Network, in a secure way. The same method is used to forward multicast streams intended for a mobile sender or a mobile receiver which is currently outside of its Home Network [16]. That is not efficient for the multicast routing optimization according to SPT (Shortest Path First) algorithm. For example, if we consider the case that a mobile receiver is in the same network as its sender. This receiver has to establish a secured connection by packets encapsulation (tunnel) with his Home Agent (equipment managing its mobility).

So, the use of the unicast tunnel for multicast transmissions has to face the scalability. As a result, it becomes inefficient in terms of bandwidth and CPU time management. On the other hand, there are cases where the establishment of a tunnel is necessary:

- no multicast access router in the visited network;
- Stream forbidden by the security policy of the visited network
- the branch of multicast tree, less optimal in the visited network.

However, the mobile multicast is subordinated to the mobile unicast. This technology is always ineffective, especially for a prolonged use. It can only be a palliative solution. By making the hypothesis of the inexistence of security policy excluding the multicast streams and also the existence of access multicast routers in visited networks, the way of managing the group traffic is not optimal. For example, if there is a multicast access router in the visited network and it has already delivered the same data streams to its receivers, then a new subscription of the mobile in its new network is efficient.

2.1.2 Remote Subscription

The IPv6 route optimization mechanism enables direct path communication between the mobile node and its correspondent node, for example, a direct bidirectional communication between the mobile node and the sender without traversal of its Home Agent.

In the multicast case, the state of the visited network should be taken into account. If the visited network possesses a multicast access router, we have these various cases:

- the same type of multicast flows are delivered by certain local receivers: in this case, the mobile receives a flow directly without loss of traffics due to a new adhesion in the visited network.
- no report is made for this flow: in this case, the mobile receiver joins its current group through current multicast access router in the visited network and it be followed by an adhesion near the source [3]. This yields an multicast handover latency more than 1.5 seconds, much more than the maximum frame latency needed for the real-time applications (50 ms) [17].
- the current stream of a mobile node is forbidden by the security policy of the visited network or there is no multicast access router in the visited network. The delay for the mobile node to reach a new network, where the requested flow is available, is part of the multicast handover latency. By adding the delay of membership, the total latency is excessively large for the real-time traffics, if the flow is only delivered by Remote subscription mechanism.

Besides, for these scenarios and within the framework of an exclusive application of the IPv6 routing optimization, if the mobile node is the sender of the multicast, the multicast tree must be completely reconstructed, rooted at the new access router of the sender. That is the consequence of searching for the multicast tree for the flow. It thus results in an increase of the binding and MLD control messages in the Internet (for example, the interactive games where sender and receiver are confused).

2.2 Evaluation of the handover latency

Mobile IPv6 identifies durations to make a successful handover. This handover is made as well at Link Layer level (attachment to an Access Point) as to the Network Layer level (configuration of temporary addresses by IPv6 Stateless Address Autoconfiguration).

Also, for the specific case of multicast, the delay for the construction of multicast tree could not be negligible in terms of latency. It depends on the distance from the access router to the first access router on its shortest path leading to the sender. And, it is necessary to take into account of the delay for the adhesion of the receivers (MLD messages duration). Here, we define parameters allowing to cover both types of handover (multicast handover and mobility handover):

2.2.1 MHLD (Mobility Handover Link layer Delay)

It is the delay set by a Mobile to make a Link Layer handover. It covers following durations:

- The delay set by the mobile node to detect Access Point parameters.
- The delay set for parameters validation: actual attachment to the new Access Point

2.2.2 MHND (Mobility Handover Network layer Delay)

It is the necessary duration for the mobile node to make Network Layer handover. It includes:

- the necessary delay to implement the auto configuration without its link address;
- the necessary delay to receive the router advertisements from a new access router, which contains configuration parameters;
- the necessary delay to implement the auto configuration without temporary addresses: Global Care-Of-Address (GCoA) used as principal address and Local Care-Of-Address: (LCoA) [14].

2.2.3 MUSD (Mobility Manage Update Signalling Delay)

It is the necessary duration to update databases about its mobility. It is constituted by the following steps:

- validation of its GCoA if it is an inter-domain handover;
- delay set for the update of database or routing table. For the micro-mobility protocols, it is necessary to record the association GCoA – LcoA, if it is an inter-domain handover. In the case of an intra-domain handover, this step will include a partial update of the association GCoA - LcoA through substituting the previous LCoA by the new one.

Note that, for an intra-domain handover, the first step is not needed in the micro-mobility protocols. Thus, the MUSD is minimal.

2.2.4 MIPSD (Mobile IP Signaling Delay)

This parameter expresses the necessary maximal duration to make a MIPv6 binding update near its home agent and correspondent nodes.

Considering the necessity of validation of the GCoA, we can get the equation:

$$MUSD < MIPSD \tag{1}$$

2.2.5 MoHD (Mobility Handover Delay)

This parameter expresses the total duration of an IPv6 mobility handover. For an intra-domain handover, it is identified by the following equation:

$$MoHD = MHLD + MHND + MUSD + MIPSD \tag{2}$$

This duration MoHD varies according to the mobility protocol. The micro-mobility protocols minimize considerably the quantity MHLD+MHND+MUSD. Their main difference is in the management of this delay. The document [10] gives a comparison of this delay for different protocols which manage host mobility.

However the delay MoHD is practically identical for all the protocols for inter-domain handover. It is due to the fact that binding updates become necessary for the Home Agent [14].

2.2.6 MLSD (Multicast MLD Local Signaling Delay)

It is the delay set by MLD signaling messages sent to the multicast access router. It is constituted of:

- the duration of the timer (for MLDv1)
- the delay of sending multicast listener report
- duration set by the multicast flow from the access router to reach the mobile node. This delay is a function of the load of the Access Point and the access router.

2.2.7 MRSD (Multicast MLD Remote Signaling Delay)

It is the duration for the mobile node to send an explicit remote MLD listener report to its home agent. It is constituted of:

- the delay of implementing a tunnel for the sending of the report.
- the duration set by a stream from the home agent to the mobile node. This delay is a function of the Access Point load, home agent load and the networks topology and load.

2.2.8 MPSD (Multicast PIM Signaling Delay)

It is the duration set by the access router to construct its multicast branches. It is constituted of the following parts:

- duration set by JOIN messages, which are sent to the sender or to the Rendez-vous Point (RP) or even to another node in the Internet.
- duration set to deliver the flow to the access router.

2.2.9 MuHD (Multicast Handover Delay)

This parameter expresses the total duration attributable exclusively in the multicast handover. It is identified by:

- In the case of remote subscription

$$MuHD = MLSD + MPSD \tag{3}$$

- In the case of the bidirectional tunnelling

$$MuHD = MRSD \quad (4)$$

MuHD represents the necessary delay for IPv6 tunnel implementation for the group data transmissions between the home agent and the mobile node. It is the delay from the packet reception of the first multicast flow to the GCoA validation.

The delay MuHD is minimal in the case of remote subscription, if a multicast group membership is made beforehand by a node in the visited network. In this case, the multicast access router still possesses the line corresponding to that multicast group in its multicast routing table. If not, it is necessary to take into account the type of the protocol used (ASM, SSM, DM) and the multicast distribution tree geometry (SPT, RPT). In the case of bidirectional tunnelling, the address of the home agent is necessary for the establishment of the tunnel.

2.2.10 MaxHD (Maximum Handover Delay)

MaxHD is the maximum duration in the worst case for a mobile multicast handover is identified by

$$MaxHD = MoHD + MuHD \quad (5)$$

(For example, during a bidirectional tunnelling).
Let us note *L_HD (Latency due to Handovers Delays)*, the multicast service ceasing duration while the multicast receiver moving. This latency is in the worst case equalled

$$L\_HD = MaxHD \quad (6)$$

This total latency can be reduced by:
- multicast handover anticipation mechanism,
- mobility handover anticipation;
- bi-casting of multicast flow,

In the analysis of the relation (6), it is clear that the multicast in an IP mobile environment is effective if the proposed mobility mechanism is optimized. This means the reduction of MoHD quantity in (5).

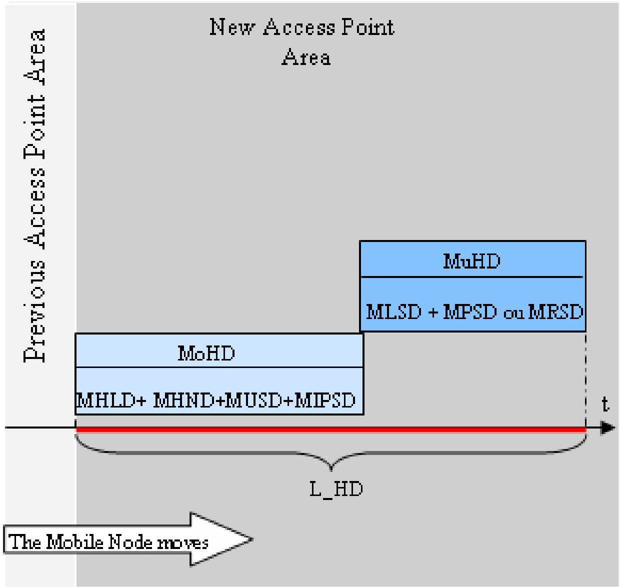

Fig.1 Mobile multicast handover, in the worst case

3 Related Works

The first proposals about mobile multicast appeared by the end of the 90s [21]. Since then, several others were made [18 20] [22- 27] [11] . Mobile IPv6 does not deal with the multicast group management in an explicit way. And since it is used as a basic support in the conception of the various mobility management protocols, there will be a lack in the explicit treatment of this type of traffic by all the mobility protocols. It is thus necessary to remedy it. Therefore, the works had started by taking into consideration the domains or the networks' changes [18] [24] [29], especially the fast changes.
Since the latencies and the packets losses were always the challenge with the unicast routing, supplementary data losses are not expected with the IPv6 mobile multicast. This is achieved by:
- the predictive multicast handover in both Data-Link Layer and Network Layer;
- the efficient use of the two mechanisms mentioned in section 2 for data anticipation [28].

All these points set some challenges to all the proposals which have to integrate the multicast into the mobile Internet IP.

These challenges concern the proposals of the macro-mobility protocols (mobility between domains) the same as they do with the micro-mobility protocols (mobility within the same domain).

3.1 Solutions in micro-mobility environments

The micro-mobility is an approach allowing to manage the mobile node movements within the same domain. These movements remain transparent for any equipment outside the considered domain. It allows reducing the number of the control messages (there is no control messages spent towards the outside of the domain). Getting near to the mobility agents also allows reducing the latency due to handovers and packets losses which ensue from it. This approach thus allows a better management of the fast movements [14].

Among the micro-mobility protocols, only HMIPv6 is maintained in terms of explicit integration of the multicast routing [4]. The methods of multicast stream management in mobile environment which are: bidirectional tunnelling and remote subscription, were combined together in order to offer to the receivers and the sender, better stream transmission. The HMIPv6 infrastructures were thus improved to take into account the multicast traffic management:

- the MAP (Mobility Anchor Point), mobility agent located within a domain HMIPv6, must integrate functions of multicast group services management. It receives subscription Reports, and it remains attached to the distribution tree till the unsubscription of all the receivers.
- the mobile receiver, by using tunnelling mechanism, sends subscription Report to its MAP through HMIPv6 signalling message [8]. For intra-MAP-domain, mobile node sends its Report directly to its local MAP. All multicast traffic is directed through this MAP using the Regional Care-of Address RCoA as multicast subscriber or source address.
- the mobile sender, outside its MAP domain, initiates multicast-based communication by sending packets through its MAP using RCoA (Regional Care-Of-Address) as its source address. Its HoA address is included in an Home Address Destination Option to allow the identification of the multicast stream and the reconstruction of the distribution tree.

The document [4] thus describes in an explicit way, this mobile multicast architecture which is called M-HMIPv6. This study [21] thus proposes a joint and effective management of the mobile multicast and the mobility generally, the extension of the Option messages header, the use of a tunnel between the new and the previous MAP when mobile node moves from a previous MAP to a new one.

Beside these works that concern the micro-mobility protocols, the other reflections enabled protocols getting a better management of inter-domains movements.

3.2 Solutions in the environments of macro-mobility

The macro-mobility is the mobility taking into account micro-mobility managers' changing. It manages the movements of the mobile node from a domain covered by a micro-mobility manager to another one.

Standardized by Mobile IPv6 [6], the IPv6 mobility knew significant progress with proposals improving the macro-mobility mechanisms such as FMIPv6 (Fast Handover Mobile IPv6). These two protocols (FMIPv6 and MIPv6) cover the macro-mobile environment, and are adapted to the management of multicast group communication.

Studies such as [2] , [29] and [30] concerned the Fast MIPv6 environment [7]. They propose the extension of the features of the access routers: the New Access Router (NAR) and the Previous Access Router (PAR) of networks visited by the mobile receiver. Unicast tunnels delivering the multicast stream of the mobile node is established between the mobile node and its PAR, allowing the mobile node to maintain itself to the multicast tree, while NAR is not connected yet. So, to manage collectively the mobile multicast and the mobile unicast, the signalling messages are extended for multicast group information. All these extensions allow, in such an environment, to reduce the latency of the multicast handover. As the propositions concerning FMIPv6, extensions of Mobile IPv6 infrastructures features are proposed [18] [19] [20] [23] [24] [26]. The Home Agent manages the receivers' multicast state. It also implements proxy MLD features.

3.3 Critics of existing solutions

The solutions proposed by the various studies supply the multicast routing solutions adapted to the considered mobility protocol. The main difference between these solutions is thus situated at the level of the mobility support used.

The modifications that operate at certain network infrastructures level allow adapting the multicast routing architecture to the mobile unicast existing architecture. The mechanisms of anticipation adopted for the handover duration management differentiate a proposition from the other one ([18], [30], [31]).

These propositions thus allow abandoning the native solution, which was offered by Mobile IPv6. However, the problem which put these various propositions is the Data-Link Layer and Network Layer handover durations. Indeed, the multicasting was conceived to improve the bandwidth usage in IP fixed Internet benefiting from a little changeable or stable distribution tree of distribution. Multicast protocols supply a better management of this tree using unicast addressing (SSM and SM) that is supposed to be fixed. Now for all the propositions of mobile multicast routing, these addresses are reconfigured in the visited network. That increases the mobility handover duration and thus the multicast handover. According to analyses made in [32], the duration MHLD is included in the total duration. Therefore, the total latency for these protocols is identified by:

L_HD = MLHD+MHND+α,

With α>0 , duration appropriated for each protocol (HMIP, MIP, FMIP) in use.

That makes these propositions less effective than a proposition offering a total handover duration independent from *MHLD+MHND*.

Our solution is based on a micro-mobility protocol offering a better management of duration *MHLD+MHND*. It offers a better total latency to the multicast handover and also an effective management of the quality of service.

4 NC-HMIPv6-M: Multicast-based In NC-HMIPv6 Environment

4.1 A brief overview of protocols used

This section is dedicated to the choice of the mobility protocol governing our IP mobile multicast environment. Also, it is useful to select among the protocols of multicast routing, those who offer a better adaptation to allow reaching the following objectives:

- reducing the data losses by anticipation
- optimizing the generation of signalling messages intrinsically bound to the multicast routing
- protecting the IPv6 mobility handover.

These objectives will offer a smooth mobile multicast handover.

4.1.1 The NC-HMIPv6 native environment

The IP mobile environments are governed by mobility protocols defining their functioning. By basing on the main criteria which are:

- the latency during handovers (necessary delay for a successful change of network by a mobile node)
- the scalability aspects
- the adaptation of the existing standards (how much the existing standards need to be adapted to support updated protocol)
- the IP packets losses (the losses of data due to the mobile node movement)
- the anticipation and bi-casting management (the possibility of forwarding packets to mobile node without disturbing the order of these flow packets),

a strong comparison can be done in order to select what protocol offers the best mobility management.

Also, it is clear that, for fast movements management between networks within the same domain, macro-mobility protocols seem less adapted than micro-mobility ones [10, 36].

At the level of the micro-mobility protocols, according to the studies [10, 34, 35, 33], those based on a hierarchy of the mobility agents are faster in terms of handovers [34] [35]. However the use of central equipment (a mobility agent) constitutes a real problem concerning the scalability aspects. To mitigate this problem, it is possible to configure several mobility agents for the same domain [14]. By taking into account this possibility and basing on the various improvements, the NC-HMIPv6 protocol, (extension of HMIPv6) offers a better management of the mobility [10]. The works [10] prove it and justify our choice of this protocol for our mobile multicast architecture.

The NC-HMIPv6 Network-Controlled Hierarchical Mobile Internet Protocol version 6) protocol, as mentioned above, is an evolution of HMIPv6 (Hierarchical Mobile Internet Protocol version 6) [10]. It predicts the unicast handover parameters. For that purpose, it introduces new entities such as:

- Moblity Manager (MM) corresponding to the MAP in the HMIPv6 environment.
- DataBase (BD) containing the information of the access routers managed by the MM and Access Points connected to these access routers.

As in the HMIPv6 environment, the mobile node possesses three various types of address:

- Home Address (HoA), its permanent address,
- Virtual Care-of-Address (VCoA), it is obtained by stateless auto configuration of the network prefix of the MM and its identifier of interface. This address plays the role of primary temporary address.
- Local Care-of-Address (LCoA), it is a local temporary address, obtained by Stateless Address Autoconfiguration of its identifier of interface and the network prefix of its current access router.

Contrarily to the HMIPv6 protocol where the handover execution decision is initiated by mobile node itself, here the mobile node collects the quality measurements of radio links that it might establish with neighbouring access points (belong to its list of neighbouring access points) of its current access point and sends these measurements to the mobility manager. According to several criteria (for example, the access point load, the quality of the reception signal), the MM sends (after consulting the DB) a response to the handover request to the mobile node. This response contains information about:

- the access point which presents the best profile,
- the address of attached access router (if the access point is attached to a new access router),
- and the prefix length of this address.

So, the mobile node builds its new local address before its movement.

If the degradation of the signal quality (fixed threshold value) of the current access point does not facilitate the communication with its mobility manager, the mobile node applies the HMIPv6 handover. This HMIPv6 mobility handover allows the mobile node to initiate a Data-Link Layer handover by attaching to a new Access Point according to the information in its access points list. Both combined handover mechanisms allow reducing the latency due to the handover. This handover conditions are stemming from multicast transmissions.

4.1.2 The multicast protocols used for our architecture

4.1.2.1 Node subscription

There are two types of multicast group management protocols:

- the subscribers' management protocols
- the multicast tree construction protocols.

In this section, a protocol of each type is proposed, by basing on a better adaptation to NC-HMIPv6 the architecture described in 4.1.1.

The subscribers' management protocol in the IPv6 fixed Internet is the MLD (Multicast Listener Discovery) protocol. There are two versions: MLDv1, MLDv2. MLD allows communication between a multicast access router and hosts on attached-link. In MLD version 1, MLD Query messages sent by multicast access router or Querier router (when there is more than one multicast access router on the link [14]), allows hosts to make their subscription. According to the MLD Query, the receiver host selects the multicast group which it wishes to subscribe. The receiver has the possibility of sending explicitly to the multicast access router, an MLD Report for the desired group. To minimize the number of such Report message on the local link, receiver sets a delay timer for each multicast group.

However this delay timer is applied even if no demand is made by other link-host for the wished group. This delay can be harmful for the mobile receivers during a multicast handover. MLDv2 brings corrections to this delay. In MLDv2, receivers can directly send their Report messages without setting a timer. So, to better manage the mobile multicast handover, it is recommended to implement MLDv2. All mobile nodes must implement MLDv2 to avoid routers switching between MLDv1 and MLDv2.

4.1.2.2 Multicast tree construction

Concerning the multicast tree construction protocols, there are two basic models:

- source rooted trees model: DVMRP (Distance Vector Multicast Routing Protocol) [36], PIM-DM (Protocol Independent Multicast-Dense Mode) [37], PIM-SM (PIM-Sparse Mode) [15], PIM-SSM (PIM-Source-Specific Multicast) [38]
- the single shared delivery tree model: PIM-SM, CBT (Core Based Tree) [39].

Multicast tree construction protocols, such as PIM-DM and DVMRP, are relatively easy to manage in terms of mobile multicast routing (flood-and-prune mechanism). However they do not offer a good use of network bandwidth and Internet core routers' capacity. For these protocols, all the routers are supposed to interconnect subscribers to the group until they send explicitly the Prune message. What results in serious network outages including multicast loops.

The protocol PIM-SSM which allows every receiver, to communicate with the sender via a communication channel characterized by the couple (sender address, SSM group address), is a variant of PIM-SM. According to the study of [3], PIM-SSM is more secured, and it provides less multicast control messages than PIM-SM. PIM-SM and CBT suffer from traffic concentration and bottlenecks occurring near core routers (for CBT) or Rendezvous Points (for PIM-SM). For these protocols (PIM-SM and CBT), subscriptions can be made without caring about the presence of a sender ready to deliver the multicast stream. For our architecture, the multicast distribution tree construction is assured by the PIM-SSM protocol. It is better adapted to the management of the subscribers by combining with MLDv2.

4.2 NC-HMIPv6-M environment description

The NC-HMIPv6-M (Multicast-based NC-HMIPv6) architecture is an extension of NC-HMIPv6 for the management of multicast group traffics. The present study allows estimating the mobility of the receiver, knowing the source address.

The architecture below shows the various entities of the NC-HMIPv6-M environment.

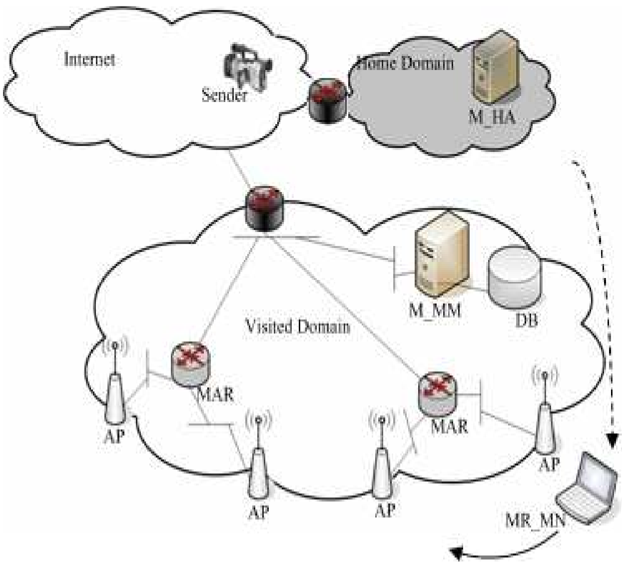

Fig2 : *NC-HMIPv6-M environment*

The management of the mobility will be based on the two mechanisms proposed by IETF and described in section 2 (use of the mode bidirectional tunnelling mechanism and Remote subscription one [16]).

The functional entities of the NC-HMIPv6 environment will be improved to support multicast mobility:

- the Mobile Node is a Multicast Receiver (MR_MN).
- the Home Agent (HA) will be endowed with functions of Multicast access router (M_HA) and also with proxy MLD functions.
- The Mobility Manager (M_MM) delivers multicast streams to mobile receivers in its covered area. It's thus endowed with Multicast functions.
- The DataBase (DB) enriched by data allowing to manage the group traffic.
- The Access Routers are Multicast Routers (MAR).

The multicast streams management protocols used, as specified in section 4.1, are:

- MLDv2 [14] [13] for mobile receivers management. New record types are integrated in multicast Report message in order to explicitly take into account the receiver's mobility. The new MLD records are: MLD_Standby, Multicast_Listener_Hold, Flow_Forwarding. MLD_Standby Report maintains the Multicast Access Router (MAR) in multicast tree as long as it possesses *Mobile Receiver HoA - (S, G)* correspondence in its multicast routing tables, created to tunnel multicast streams. Multicast_Listener_Hold Reports, introduce by Xia in [32] allows to erase *Mobile Receiver HoA - (S, G)* correspondence, Flow_Forwarding Report allows tunnelling multicast stream to two-scopes specified address.
- PIM-SSM for construction of multicast tree.

Our proposed architecture allows minimizing the quantity *MuHD* express in (5). The anticipation mechanism provided by NC-HMIPv6 also allows during the mobile handover, anticipating the multicast handover. The following figure illustrates this case.

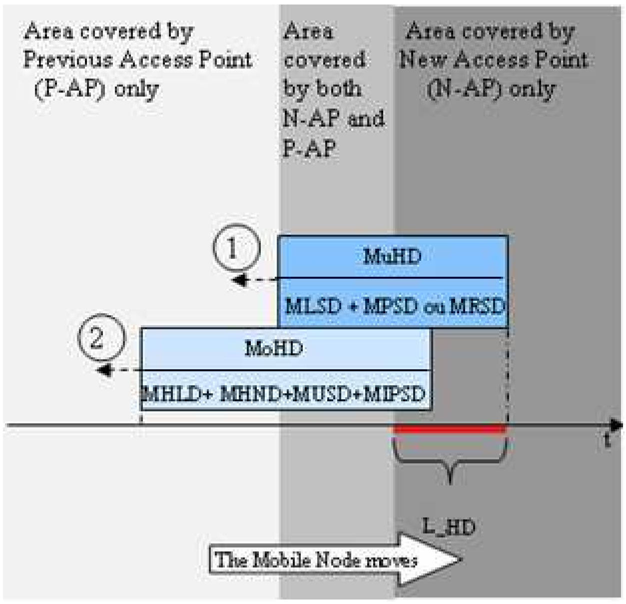

Fig3 : *Multicast handover Mobile by anticipation*

The figure Fig3 illustrates a case of the mobile handover prediction (arrow (2)) and also a multicast handover one (arrow (1)). In these conditions, we obtain a minimization of the latency L_HD, compared to latency seen in Fig1.

The functionalities of entities are explained bellow:

4.2.1 Multicast mobility Management at M_MM level

The Multicast Mobility Manager (M_MM) records in the Database, (S, G) – MAR correspondences, where S is the multicast sender and G the group [14]. M_MM is considered as local Rendezvous

Point that switches multicast flows to its attached-routers within its area. It will be attached to the multicast tree until there is no more multicast access router in its M_MM-domain (domain covered by Access Point managed by an M_MM) susceptible to receive this multicast stream. In that case, the multicast correspondence inherent to this stream and to the concerned MAR will be deleted from the DB. A redundancy of Multicast Mobility Managers turns out necessary to avoid the clogging and better manages the scalability. The mechanism of M_MM selection is the same as what is use by MLD Queriers or the M_MM can benefit from an anycast addressing as mentioned in [14]. The algorithm depends on network operators or domain administrators.

4.2.2 Multicast mobility Management at the DB level

The database is the entity storing information on the access points of the NC-HMIPv6 domain. It contains also the useful parameters for the mobility handover management. Here, the DB will be enriched with the information on the multicast group of the M_MM-domain.

4.2.3.Multicast mobility Management at the level of the M_HA

The Home Agent manages multicast states of all its mobile receivers away from Home Network. Thus, HA caches an entry with respect to the multicast group of which these receivers belong to. This entry allows remaining in the multicast tree concerning the group. HA deletes this entry after received Multicast_Listener_Hold Report.

4.2.4.Multicast mobility Management at the level of MAR

The Multicast Access Router (MAR) manages fast movement of MR_MN within its network. As MLD Querier, MAR sends an MLD Query to all its attached receivers and receivers their Report messages. Also, after receiving the Flow_Forwarding Report, it tunnels the multicast stream to the MR_MN in its new location.

The Rendezvous Point of all the MAR of the M_MM-domain is the M_MM. These approaches allow a better managing all multicast sub-trees rooted at the each M_MM for all M_MM domains. This function attributed to the M_MM reduced the delay of Join messages sent by the MAR.

4.3. Mobile Multicast handover management: receiver mobility in a NC-HMIPv6-M domain

The multicast handover mechanism is described according to the visited domain status towards the multicast group of the mobile receiver membership. The specific cases of networks within the receiver's multicast stream are forbidden by the security policy of the visited network and those Access routers don't support multicast streams are excluded. In these cases, M_HA uses continuously tunnelling mechanism to deliver the multicast data flows to the MR_MN. The various cases described below are based on this hypothesis.

In this architecture, a single M_MM is considered. We shall also suppose that the multicast stream is delivered to the mobile receiver within its Home Network by its M_HA before moving away. Some parameters are defined below to relieve the expressions:

- T_ra: reception moment of the MAR's RA (Router Advertisement) in the visited network. This moment characterizes an attachment to an Access Point and a validation of the local link address (use of DAD algorithm);
- T_mld: reception moment of the MLD Report of the MR_MN by the MAR;
- T_fr (First-packet Reception): reception moment of the first packet of the solicited multicast stream by the MR_MN;
- T_sm: reception moment of Subscription Message or Join Message by the M_MM;
- T_sm': reception moment of the first packet of the multicast stream by the M_MM after sending its Subscription Message or Join Message to the source;
- T_fd: reception moment of the First Duplicated packet of the solicited stream by the MR_MN;
- T_mld': reception moment of the first packet of the multicast stream by the MAR after sending its Join message to M_MM;
- T_frd: reception moment of First-Remote Delivered-packet) by Remote Subscription mechanism;
- T_dsm: reception moment of packet-duplication Signalling Message by the M_HA;
- T_da: reception moment of the packet-duplication deletion's Acknowledgement.

The various moments enumerated above allow estimating the latency during the mobile multicast receiver's handover. Thanks to the following various scenarios, we describe the functioning of our architecture based on the mechanism illustrated in Fig3.

4.3.1. The Multicast Access Router (MAR) belongs to the multicast tree

This case appears when there is at least a member of the multicast group within the visited network or more generally, if the delay timer of the MAR has not expired yet. The multicast handover takes place together with the NC-HMIPv6 handover according to the scheme described in Fig 4:

- *Step 0: this step describes the status of mobile receiver just before its data-Link Layer handover***.**

The NC-HMIPv6 signalling messages diffused by the M_MM (step 0a) are forwarded by the MAR of the M_MM-domain. What allows the MAR to inform the receivers using Router Advertisement message (RA) (step 0b). Mobile receiver uses all received information to connect to the Access Point by following an HMIPv6 data Link Layer handover procedure.

- *step 1: starting of the mobile multicast handover procedure*

Thanks to its local link address, the MR_MN sends an explicit MLDv2 Report, without activate beforehand its timer (delay timer equals 0), to the MAR (step 1a). Thanks to the data contained in RA messages, the mobile receiver configures its VCoA and LCoA addresses and confirms its LCoA address with the MAR. Thus MAR begins to deliver the multicast stream to it (step 1b). A NC-HMIPv6 binding updates sent to the M_MM (step 1c) and the M_HA also allows updating the various Binding cache and databases. The M_HA also receives a remote MLD Report in order to update its MLD Binding Cache (step 1d) and to redirect multicast streams within the new location of the MR_MN.

- *step2: duplicated packet detection*

The reception of two identical copies (local stream (step 2a) and tunnelling one from the Home Agent (step 2b)) will allow the MR_MN to suspend the tunnelled stream by sending an MLD_Standby Report to the M_HA (step 2c).

- *step 3: treatment of the duplication by the M_HA*

This MLD_standby Report allows the Home Agent to keep in its MLD table, the line corresponding to the multicast stream and to send a Binding acknowledgement to the MR_MN (step 3). The deletion of this line will be made explicitly by the MR_MN by sending Multicast_Listener_Hold Report to the M_HA [23].

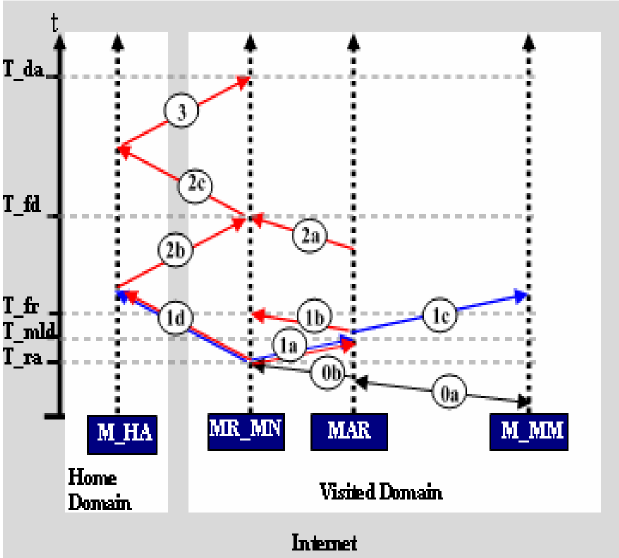

Fig4. *multicast handover: case of a network visited with MAR is attached to the multicast tree*

The latency (L_HD) due to the multicast handover is appreciably equal to

$$\begin{cases} L\_HD = MLHD + MuHD \\ MuHD = MLSD = T\_fr - T\_ra \end{cases} \quad (7)$$

while $MPSD=0$ and
$MRSD = T\_fd - T\_ra > T\_fr - T\_ra$

This *L_HD* delay is appreciably null if we do not take into account security measures bound to the multicast stream (encoding if possible of the stream, group security).

4.3.2. Multicast stream delivered to some Access Router within the visited domain

Here (cf. Fig5), the MAR of the visited network does not belong to the multicast tree concerning the receiver current stream. However, the membership of another MAR within the same M_MM domain allows maintaining the M_MM on the multicast tree.

The step 0 (0a, 0b) is identical to the same step of the previous case. This step corresponds to data Link Layer handover.

- *step 1: Execution of the mobile multicast handover procedure*

The MAR sends its Join message (step 1b) to the local Rendezvous Point (M_MM), after having received the MR_MN Report (step 1a). The M_MM registers a (S, G) - MAR correspondence in the database BD [10] of the M_MM domain. So as in the case 4.3.2.1, the M_HA will receive a Binding update and an MLD Report (step 1c).

- *step 2: reception of the multicast stream by the MR_MN*
After its attachment to the multicast tree, MAR can deliver the stream to the MR_MN (step 2b) after receiving it from the M_MM (step 2a).

- *step 3: duplicated packet detection*
After receiving the MLD Report, the M_HA sets up a tunnel to convey the stream to the mobile (step 3a). What can create a doubloon if the mobile already receives this stream locally (3b). The doubloon can be provoked by the local delivered stream. This case can occur when the authentication and authorization mechanisms of the multicast group are complex.

- *step 4: treatment of the duplication by the M_HA.*
After detecting the packet duplication, a MLD_standby Report is sent to the M_HA by the MR_MN (step 4a). The M_HA will update its MLD table and send a Binding acknowledgement to the MR_MN (step 4b).

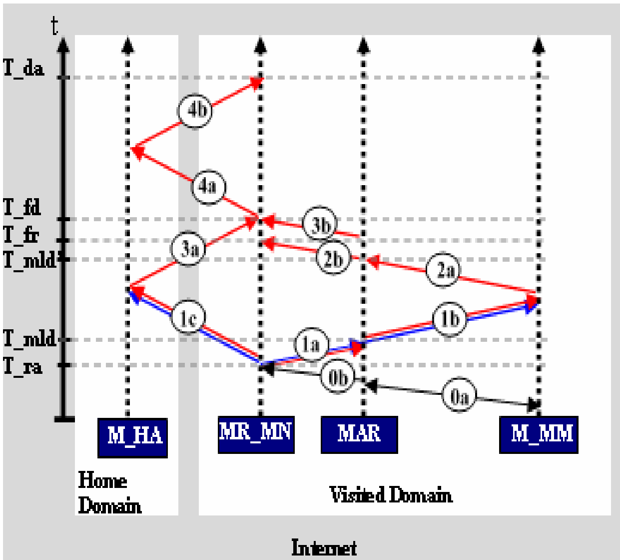

Fig5. *Multicast handover: case of a visited network with the MAR not member but M_MM is attached to the multicast tree*

The difference *T_fd-T_mld'* is the duration between the reception of the first multicast stream moment in the visited domain NC-HMIPv6 and the reception of the same stream moment. we have

MuHD = (T_mld'-T_ra)+ (T_fr-T_mld') (8)

Thus implying

MuHD =T_fr-T_ra

The duration MRSD amounts to *T_frd-T_ra*. And because of T_frd > T_fr (all the traffic passes through the M_MM), we obtain:

MRSD > MLSD+MPSD

What proves the relation (8).
The mobile multicast latency is thus

L_HD=MuHD= T_fr-T_ra

This latency was thus improved, thanks to the remote subscription. However, it remains higher than the one observed in the previous scenario case described with the relation (7).

4.3.3. No access router of the visited domain belongs to the multicast tree
This present case entails a total reconstruction of the branch of the multicast distribution tree as soon as the MR_MN goes within the new NC-HMIPv6 domain (cf. Fig6). The steps 0 and 1 are identical to the same steps of the paragraph 4.3.2. Contrary to the scenario 4.3.2, here, the M_MM is not connected with the multicast tree. An MLD Report of the MR_MN will entail successive PIM-SSM messages to the Multicast Access Router of the sender (by applying the algorithm SPT, afterward). It is possible that this branch recently created, shares a sub-tree in the heart of the network. What would allow reducing the latency. So in this scenario, considering this construction of this specific branch, the subscription made with the M_HA will allow delivering the multicast stream.

The membership to the group will allow the Mobility Manager to put in DB the (S, G) - MAR correspondence, in case of success and to deliver the stream to the mobile node via its current MAR (steps 2b, 2c and 3c). The database will be also updated in case of redundancy of M_MM with (S,G)-M_MM correspondence.

In the step 3, the MR_MN receiving the stream by coming from the M_HA (step 3a) detects after a lapse of time (estimated to *T_fd - T_fr*), a packet duplication (steps 3b and 3c) caused by the same stream coming from the MAR (step 3c). It thus begins the procedure seen in step 4. That procedure resolves the duplication case seen in the previous scenarios.

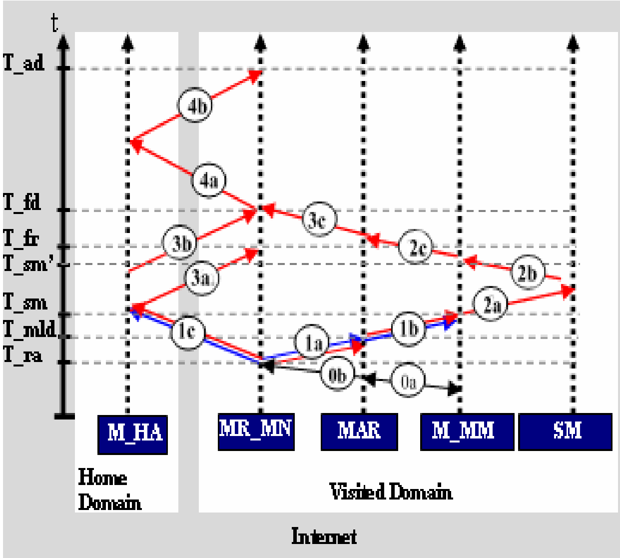

Fig6. *Multicast handover: case of a visited domain having no M_MM attached to the multicast tree*

The duration *T_sm'-T_sm* varies according to the status of the network core concerning the requested stream and some security policy from which benefits the group. And the total latency approaches (6)

In the case of a redundancy of M_MM, a common Database, containing information of the groups with which the various M_MM are connected, is created for the domain. If one of M_MM of the visited domain is connected to the multicast distribution tree, a tunnel will be created between both managers (the applicant M_MM and that already diffusing the stream) (step 2a of Fig7).

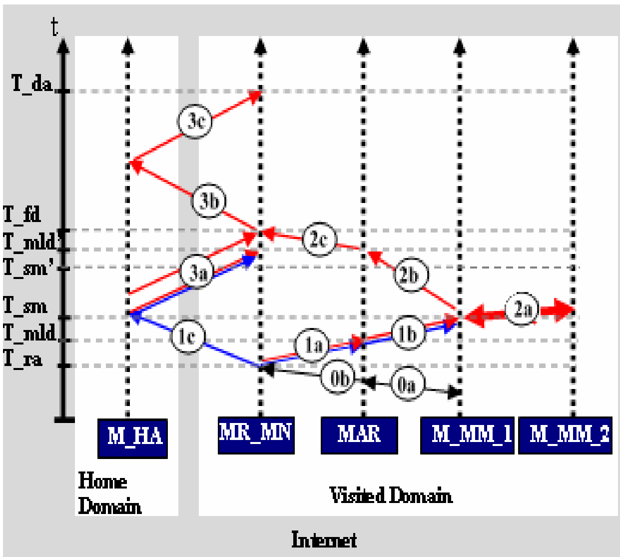

Fig7. *Multicast handover: tunnelling between managers*

This tunnel is built by basing on the information contained in the common Database of the domain. This allows reducing considerably the latency time *T_mld'-T_mld* of the previous case.

4.3.4. intra-domain mobile multicast handovers

This scenario deals with the case of a mobile receiver moving from one MAR to another one within the same M_MM domain. The change of MAR will thus provoke a mobile multicast handover. The figure Fig.8 illustrates this case.

The MR_MN, according to the criteria of NC-HMIPv6 handover initiation procedure described in the paragraph 4.1.1, sends its Binding update signalling to the M_MM (step 1). After receiving the *Binding Acknowledgement* from the M_MM (step 2), the MR_MN configures its new local temporary address [10]. After address configuration, the MR_MN sends a Flow_Forwarding Report to its current MAR. This MLD Report contains data related to its new destination (new LCoA belonging to the future visited network, the new MAR's address, information on its multicast group of membership) (step 3). From then on, the MR_MN attaches to its new Access Point (step 4) according to the NC-HMIPv6 procedure (section 4.1.1). After this procedure and successful DAD one, the MR_MN confirms this new LCoA (step 5) and sends a NC-HMIPv6 Binding Update to M_MM (step 7). Simultaneously, it sends an MLDv2 Report to its new Multicast Access Router (nMAR). If this last one is connected with the multicast distribution tree, the MR_MN receives directly the stream (step 6). This stream is also delivered to the MR_MN by its previous multicast access router (pMAR) (step 8). This modification operated in the NC-HMIPv6 architecture allows alleviating certain problems such as the complexity of subscription due to the security policy of the multicast group, the no attachment of nMAR to the multicast tree. However, from detection of the first duplicated packet, an MLDv2 EXCLUDE Report concerning this stream is sent to the pMAR.

In the case of non-membership of the nMAR to the group, this last one will create its branch of the multicast tree rooted on M_MM.

The latency period amounts in

$$L\_HD = MaxHD\text{-}MHLD = \min\{T\_frd - T\_ra\ ,\ T\_fr - T\_ra + (1-\mu)MPSD\}.$$

as

$$\mu = \begin{cases} 1 \text{ if nMAR is attached to multicast tree} \\ 0 \qquad\qquad\qquad \text{if not} \end{cases}$$

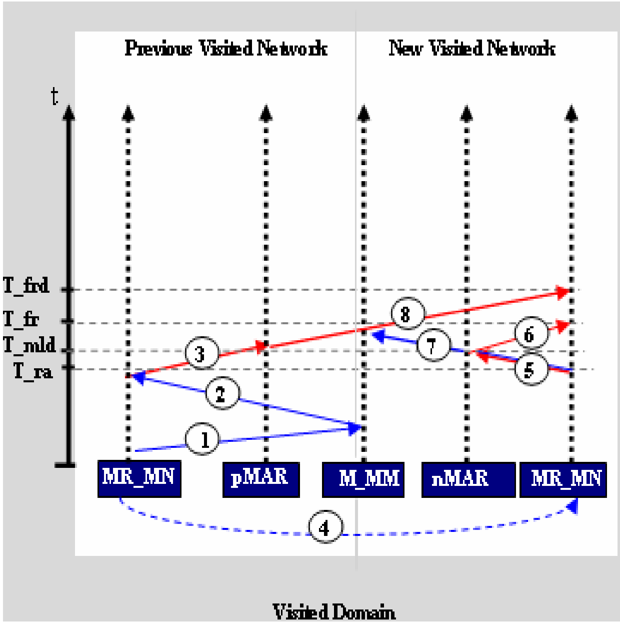

Fig.8 *Mobile multicast handover within the same domain*

In the case of the degradation of the radio link as mentioned in section 4.1.1, the Mobile executes a mobile multicast handover according to one of the described cases higher (4.3.1 or 4.3.2).

4.3.5. Handovers multicast intra-domain: new subscription

In every membership of mobile receiver to a new multicast group in the visited network, a MLD_standby message is tunnelled toward the M_HA. If the M_HA is not a member in the multicast group (attached to the multicast tree), it sends its Join message to the source for this requested stream. The difference with the current MLDv2 Report, it is that the M_HA has no to deliver the stream to the MR_MN after its attachment. MR_MN must send an explicit MLDv2 Report to obtain the stream.
The Home Agent registers the (S, G) - HoA-VCoA correspondence in its remote MLD table. Such line can be deleted by Multicast_Listener_Hold [23].
This approach will allow the M_HA delivering more quickly the multicast stream to MR_MN. It so avoids the creation of the branch after receiving Remote MLD Report.

4.5. Innovations and limitations

Our proposition bases on the following outstanding points:
- The environment of mobility used is NC-HMIPv6: this environment is optimized in terms of mobility with regard to the environments in which the previous researches were made.
- The Mobility Manager represents a local Rendezvous: this allows reducing the latency by creating new branches rooted on the Mobility Manager.
- The extension of the features of the database of the Mobility Manager to integrate data referring to the multicast handover
- The extension of the features of the Home Agent by adding proxy MLD functions. This approach allows a better management of receivers' mobility.
- The introduction of new types of MLD Reports in order to adapt MLD to the mobility. Which will allow extending the MLD Report messages scope

All these points allow a better managing of the multicast handover and a less packets losses.
Also, this worked constitutes an extended version of [40]. Some points such as:
- efficient analysis of existing mobility proposals
- efficient analysis of protocols as proposal support
- More complete figures covered the whole studied environment
- Algebraic relations for mobile multicast handover are improved.

However, as all existing proposals, the multicast source mobility constitutes a real problem [41]. To avoid total reconstruction of multicast tree, the mobile source tunnels its stream to its Home Network. This is based on a triangular routing, not optimized for mobility routing [42]. The use of optimization routing strongly affects multicast tree. It provokes the root change (by changing the source address). For some multicast protocols such as PIM-SSM which use source address to create multicast data transmission channel, this implies total tree reconstruction. To avoid this total tree reconstruction, our proposal bases exclusively on the tunnelling mode.

5. Conclusion

The multicast service was not considered in an explicit way because of the conception over the various protocols of the IPv6 mobility. So, it results in a mismatching in its application with the mobile Internet. The main problem does not deny the latency happens during the handovers. This latence causes interruptions in the group service (for example, the source mobility causes a partial or total re-instruction of the diffusion tree) and packets' loss (the case of a mobile receiver causes a re-instruction of just a branch in the diffusion tree). The multicast

services which have strict time conditions, such as VoIP, or those with high sensibility towards data losses become capable to adapt with the mobile Internet.
To solve the mobile multicast problem, many mechanisms are proposed. They are based on the different mobile architectures available.
So, the mobile protocols, such as mobile IPv6, Fast handover Mobile IPv6 and HMIPv6, benefit from an extension for the traffic group management.
However, the multicast handover (being subordinated from the mobile handover), a protocol that offers a better latency regarding the handover, forms a strong base for the multicast integration. This makes the propositions based on the HMIPv6 and FMIPv6 protocols offer a latency management caused by the mobile multicast handover better than those use the mobile IPv6. Because, regarding the handover term, HMIPv6 and FMIPv6 are considered as the developed form of the Mobile IPv6.
Our proposal integrates the multicast into the NC-HMIPv6 environment. Different scenarios, a clear description of the NC-HMIPv6-M environment, were mentioned. These scenarios allow the description of the different handover types noticed for a mobile receiver beyond an efficient analysis of the available multicast architectures. To define the time parameters through the mobile multicast handover duration, result from two handovers (mobile handover and multicast handover), we supplied an algebraic value for each scenario defined.
Also, to allow a perfect mobility in the multicast routing, new registering types were suggested for the MLDv2: Flow_Forwarding, MLD_Standby and Multicast_Listener_Hold.
However, a comparative study that covers the simulation and implementation of the different solutions (M-FMIPv6, M-HMIPv6) and our proposal NC-HMIPv6-M is needed in order to quantify the gain realized with NC-HMIPv6-M.

6. References

[1] Aguilar, L. *Datagram Routing for Internet Multicasting*, In ACM SIGCOMM '84 Communications Architectures and Protocols, pp. 58-63, ACM Press, June, 1984.

[2] Leoleis G., Prezerakos G., Venieris I., *Seamless multicast mobility support using fast MIPv6 extensions*, Computer Comm. 29, pp. 3745-3765, 2006.

[3] Schmidt T.C., Waehlisch M., *Multicast Mobility in MIPv6: Problem Statement and Brief Survey*, draft-irtf-mobopts-mmcastv6-ps-03.txt, February 2008

[4] Schmidt T.C. and Waehlisch M., *Seamless Multicast Handover in a Hierarchical Mobile IPv6 Environment (M-HMIPv6)*, draft-schmidt-waehlisch-mhmipv6-04.txt, December 2005.

[5] Perkins C., *IP Mobility Support for IPv4*, RFC 3344, August 2002

[6] Johnson D. B., Perkins C. and Arkko J., *Mobility Support in IPv6*, RFC 3775, June 2004.

[7] Koodli R., *Fast Handovers for Mobile IPv6*, RFC 4068, July 2004.

[8] Soliman H., et al., *Hierarchical Mobile IPv6 mobility management*, RFC 4140, August 2005.

[9] A. G. Valko, "*Cellular IP: a new approach to Internet host mobility*,". ACM SIGCOMM Computer Communication, Vol. 29, No. 1, pp. 45-54,. January 1999.

[10] Guillouard K. et al., Network-controlled mobility within radio access networks based on WLAN technologies, Annals of telecommunications, 58(3), March 2003 http://www-rp.lip6.fr/dnac/3.2-khouaja-article.pdf, 2002.

[11] Vida R., Costa L., Fdida S., *M-HBH - Efficient Mobility Management in Multicast*, Proc. of NGC '02, pp. 105-112, ACM Press 2002.

[12] S. Deering, W. Fenner, B. Haberman
Multicast Listener Discovery (MLD) for IPv6
Request for Comments: 2710
October 1999

[13] Vida R. and Costa L., *Multicast Listener Discovery Version 2 (MLDv2) for IPv6*, RFC3810, June 2004.

[14] Cizault G., *IPv6 : Théorie et pratique*, 4ème Edition, 2006

[15] Fenner B. et al., *Protocol Independent Multicast - Sparse Mode (PIM-SM): Protocol Specification*, RFC 4601, August 2006.

[16] Handley M., et al., Bi-*directional Protocol Independent Multicast (BIDIR-PIM)*, draft-ietf-pim-bidir-09.txt, February 2007.

[17] Noel T., Montavont N., Bertin P., *Mobilité IPv6 et WLAN : Expérimentation et évaluation à l'échelle d'un campus*, LSIIT. Université Louis Pasteur, Strasbourg

[18] Christ O., Schmidt T.C., Waehlisch, M., *A Light-Weight Implementation Scheme of the Tree Morphing Protocol for Mobile Multicast Sources*, Proc. of 33rd Euromicro Conf., IEEE/CS, Sept. 2007

[19] Garyfalos A., Almeroth K., *A Flexible Overlay Architecture for Mobile IPv6 Multicast*, IEEE Journ. on Selected Areas in Comm., 23 (11), pp. 2194-2205, November 2005.

[20] Garyfalos A., Almeroth K. and Sanzgiri K., *Deployment Complexity Versus Performance Efficiency in Mobile Multicast*, http://imj.ucsb.edu/papers/BROADWIM-04.pdf.gz

[21] G. Xylomenos and G.C. Plyzos, *IP Multicast for Mobile Hosts*, IEEE Communications Magazine, pp. 54-58, January 1997.

[22] Jannetau C., Tian Y., Csaba S. et al. *Comparison of Three Approaches Towards Mobile Multicast*, www.comnets.rwth-aachen.de/~o_drive/publications/ist-summit-2003-IPMobile Multicast-paperv2.0.pdf.

[23] Jelger C., *Multipoint et Mobilité: Optimisations pour IPv6*, LSIIT-UMR 7005 – CNRS/ULP, Université Louis Pasteur.

[24] Jelger C., Noel T., *Multicast for Mobile Hosts in IP Networks: Progress and Challenges*, IEEE Wireless Comm., pp 58-64, Oct. 2002.

[25] Jelger C. and Noel T. *Supporting Mobile SSM sources for IPv6 (MSSMSv6)*, Internet Draft (work in progress, expired), January 2002.

[26] Kellil M., Romdhani, et al. , *Multicast Receiver and Sender Access Control and its Applicability to Mobile IP Environments: A Survey*, IEEE Comm. Surveys & Tutorials 7(2), pp. 46-70, 2005.

[27] Zhang, H. et al., *Mobile IPv6 Multicast with Dynamic Multicast Agent*, draft-zhang-mipshop-multicast-dma-03.txt, (work in progress), January 2007.

[28] Jianfeng Guan, Huachun Zhou, Wei Qu and Yongliang Hao, *MP-FMIPv6: MLD Proxy Based Fast Multicast Protocol for Mobile IPv6*, Computer Science, 2007

[29] Xia F. and Sarikaya B., *FMIPv6 extensions for Multicast Handover*, draft-xia-mipshop-fmip-multicast-00.txt, September 2006.

[30] Georges A. LEOLEIS, Iakovos S. VENIERIS, *Fast MIPv6 extensions supporting seamless multicast handovers*, Wireless Personal Communications, 2007

[31] Ki-I1 Kim, Jeoung-Lak Ha, Eun-Hee Hyun, Sang-Ha Kim, *New Approach for Mobile Multicast Based on SSM*, Proceedings of the 9th IEEE International Conference on Networks, 2001

[32] Thomas C. Schmidt, Matthias Wählisch, *Performance Analysis of Multicast Mobility in a Hierarchical Mobile IP Proxy Environment* Proceedings of the TERENA Networking Conference 2004

[33] Pierre Reinbold and Olivier Bonaventure, *A comparison of ip mobility protocols*. Technical Report Infonet-2001-13, Facultes Universitaires Notre-Dame de la Paix, Namur, Belgium, October 2001. http://www.infonet.fundp.ac.be/doc/tr/Infonet-TR-2001-13.html accessed August 2002

[34] Luke Niesink, *A comparison of mobile IP handoff mechanisms*, Twente Conference on IT (Février 2007) http://referaat.cs.utwente.nl/new/paper.php?paperID=113

[35] Andrew T. Campbell, Javier Gomez, Sanghyon Kim, Chieh-Yih Wan, *Comparison of IP micro-mobility protocols*, IEEE Wireless Communications, February 2002, pp. 72-82. http://citeseer.ist.psu.edu/campbell02comparison.html

[36] D. Waitzman, C. Partridge, S. Deering, *Distance Vector Multicast Routing Protocol* November 1988, RFC 1075

[37] A. Adams, J. Nicholas, W. Siadak, *Protocol Independent Multicast - Dense Mode* (PIM-DM), RFC 3973, January 2005

[38] S. Bhattacharyya, *An Overview of Source-Specific Multicast (SSM), RFC* 3569 , July 2003

[39] A. Ballardie, *Core Based Trees (CBT) Multicast Routing Architecture, RFC* 2201 September 1997

[40] Kadjo T. L., Oumtanaga S., Tiemoman K., Tety P., *Proposal for multicast transmissions in NC-HMIPv6 environment,* 2nd WSEAS Int. Conf on COMPUTER ENGINEERING and Applications (CEA'08) Acapulco, Mexico, January 25-27, 2008

[41] Romdhani I., Kellil et. al., *IP Mobile Multicast: Challenges and Solutions*, IEEE Comm. Surveys, 6(1), 2004.

[42] F. Xia, B. Sarikaya, *Hybrid Subscription for Multicast Reciever Mobility in MIPv6* (in progress) November 6, 2007