Micro-Mobility Solution Based on Intra-domain multicast and Congestion Avoiding for Two-Nodes Mobile IP Network

Yacine Benallouche and Dominique Barth
PRiSM-UMR 8144
Université de Versailles Saint-Quentin
45, Avenue des Etats-Unis
78035 Versailles Cedex, France
Email: {bey, dominique.barth}@prism.uvsq.fr

***Abstract*—In this paper, we deal with micro-mobility in TWINBOARD network, which is a two nodes mobile network architecture based on an all IP infrastructure. The two nodes are the Base Station (BS) and the Access Gateway (AG). To manage micro-mobility, we propose a new approach providing efficient and smooth handover, while being able to coexist and inter-operate with existing technologies. Specifically, we propose an intra-domain multicast-based handover approach combined with an Alert mechanism. Alert approach is a distributed mechanism that provides routers with information regarding the congestion state of other routers without any modifications on existing routing protocol. Our solution achieves an efficient intra-domain handover and avoids flooding in the network. The simulations used to evaluate our scheme and compare it to other multicast scheme - DVMRP (Distance Vector Multicast Routing Protocol) show that our solution presents a good performance and outperforms DVMRP scheme. Our main contribution consists on an efficient new approach to manage IP micro-mobility using intra-domain multicast with alert mechanism.**

***Keywords* - Micro-mobility, intra-domain handover, multicast algorithm, alert algorithm**.

I. INTRODUCTION

Current mobile networks are composed of several network elements interconnected by specific network infrastructures, leading to important development, deployment and maintenance costs. For example, in the data-path of 3G networks defined by 3GPP there are at least four types of interconnected nodes: node B, RNC, SGSN and GGSN. The architecture under definition at the WiMAX Forum presents a step forward towards simplification in defining an IP based infrastructure connecting 3 nodes [23]: Base Station (BS), Access Gateway (AG), and Anchor Point/Home Agent (HA).

Considering the topics and the objectives of the Next Generation Mobile Networks (NGMN) initiative launched by major European and North American mobile network operators [20], the European CELTIC project TWINBOARD [1] investigates the performances and the cost of a two nodes IP architecture for a mobile network (see Figure 1). In this project, we consider a mobile network composed of BSs connected to one or some enhanced AGs through a dedicated network that we call **Access Aggregation Network (A2N)**. The major objective of the TWINBOARD project is to propose a novel **A2N architecture** considering a specific features of IP networks especially in terms of load distribution, reliability, and flexibility. Here all mobility related functions and associated features are ensured by BS-AG tandem.

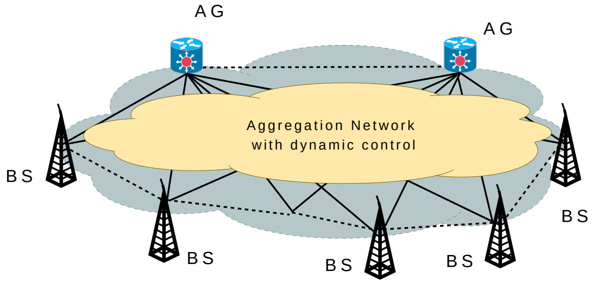

Fig. 1. TWINBOARD network Architecture

The target architecture defined by TWINBOARD recommendations is an optimized Packet Switched (PS) network architecture, which will provide a smooth migration of existing 2G and 3G networks towards an IP network with improved cost competitiveness and broadband performance. The A2N network is an IP based network and loosely meshed with tree-like traffic

---

[1] TWINBOARD European CELTIC PROJECT, see http://www.celtic-initiative.org/Projects/TWINBOARD/default.asp.

pattern -mostly GW from/to BS- that is changing due to mobility. Due to these peculiarities, load sharing and resilience mechanisms known from the Internet are expected to yield suboptimal results.

Related works: Several studies on micro-mobility [7], [16] show that Mobile IP (MIP) [11], the proposed standard, has several drawbacks from its network overhead and its end-to-end delays due to the triangle routing problem. Many micro-mobility approaches attempt to improve MIP [13], [14] in current IP mobile networks. However, such approaches suffer from complexity and handover performance [6]. To the best of our knowledge, the proposed utilization of multicast combined with alert message diffusion in Two-Nodes Mobile IP network has never been studied to manage intra-domain handover.

The rest of the paper is organized as follows. In Section II, we give an overview of multicast protocols. In Section III, we describe our proposed algorithms and we prove the NP-completeness of the related problem. Section IV presents our TWINBOARD simulator and its environment (used topologies, multicast group and traffic model). Section V gives evaluation and simulation results. In Section VI, we present conclusions and outline perspective future works.

In our case, we propose two distributed algorithms mainly implemented on GW and BS nodes to guaranty QoS dealing with the real time constraints of mobility. The paradox we deal with is to guarantee moving mobile connections by insuring enough flexible resource use on an IP routing without considering too expensive mechanisms on each router of the aggregation network. Considering these attempts, the solution we propose focuses in particular on optimization of the route tables and on traffic load balancing techniques between BS and GW, without using resource allocation mechanisms in the IP interconnection network.

The architecture we propose is based on two collaborative algorithmic mechanisms. Firstly, to avoid congestion in the network and to insure flexibility in the use of the bandwidth of the network, we adapt the routing alert algorithm proposed in [19] for inter-domain network by introducing a hierarchy concept in the IP network based on the particularity of the considered traffic (from BS to GW and from GW to BS). Secondly, we propose a distributed process to control multicast functionalities in each IP router to obtain a constraint delay multicast tree compatible with the embedded IP routing. Here multicast is used to anticipate handover when it is considered as probable. Then traffic to the target mobile user is multicasted to the BS to, which it is connected and to the geographical neighboring BS. The aim of the proposed process using only IP basic mechanisms, is to limit congestion overhead due to the multicast.

These algorithmic solution takes benefits of forwarding and routing of datagrams and presents several natural advantages:

- Cheap installation and exploitation on adapted and inexpensive existing IP infrastructure.
- Good load distribution (Alert mechanism).
- Ability to coexist and to inter-operate with existing technologies.

II. MULTICAST OVERVIEW

We categorize algorithms for the multicast tree construction in two categories [17]:

1) Source-Based Algorithms (SBA).
2) Core-Based Algorithms (CBA).

In SBA algorithm the tree's root is the source node and the leaves are the multicast group's components. SBA is currently used as the tree construction algorithm for Distance Vector Multicast Routing Protocol (DVMRP) [18], Protocol Independent Multicast Dense Mode (PIM-DM) [3], and Multicast Open Shortest Path First (MOSPF) [10].

The CBA or the core-based algorithm selects a core node as a multicast tree's root. Afterwards, a tree rooted at the core node is constructed to reach all the multicast group's members. In this case, the core node is different from the source and it is very important to select the best one as much as possible. Therefore the source send messages to the core node, which distribute those messages to the destinations. Among the protocols that use the CBA we can cite Protocol Independent Multicast Sparse Mode (PIM-SM) [4] and the Core-Based Tree (CBT) protocol [2]. The core-based algorithms are highly suitable for sparse groups and for large networks. Indeed they provide excellent bandwidth conservation for receivers. With the multicast technology, multimedia applications, such as videoconferences, require an efficient management of the QoS. An essential factor of these real-time strategy is to optimize the DVBMT problem [12].

The multicast delay variation is the difference of the maximum end-to-end delay and the minimum end-to-end delay among the paths from the source node to all the destination nodes. Minimizing this parameter allows all the destination nodes to receive the same data simultaneously as much as possible. One issue to the DVBMT problem is to minimize multicast delay variation under multicast end-to-end delay constraint. In [12], authors propose a heuristic solution called Delay Variation Multicast Algorithm (DVMA), where they construct at first the tree by considering only the end-to-end delay constraints. Afterwards, they enhance the tree by considering the the multicast delay variation constraint. Nevertheless, DVMA presents a high time complexity, which is does not fit in modern applications.

Another heuristic solution with lower time complexity than DVMA is called Delay and Delay Variation Constraint Algorithm (DDVCA). DDVCA is based on the Core-Based Tree (CBT), where the core node is selected as the node with minimum delay variation with all other multicast group's nodes. However, the DDVCA exhibits high network charge around the core node. Indeed, all the multicast packets transit through the core node, this last one resends these packets to the leaves.

Our multicast algorithm overcomes these limitations and it is used in wireless networks to manage the handovers by constructing an optimized tree from one from an Access Gateway (AG) to some Base Stations (BS) on, which mobility can be predicted. Unlike DDVCA where the tree construction is based only on one core node, our distributed solution extends this construction on several core nodes. This allows us to minimize the bandwidth consumption as we spread the charge on different core nodes.

III. MULTICAST&ALERT-BASED MICRO-MOBILITY

In this section we present our solution to manage micro-mobility with congestion avoiding. We propose two algorithms: Multicast algorithm and alert algorithm.

A. Problem Context

Handover performance and router congestion are a significant factors in evaluating performance of IP mobile network. With the Internet growth it becomes crucial to design efficient, scalable and robust handover protocols. We propose a new architecture for providing efficient and smooth handover with congestion avoiding. Our approach consists of two distributed algorithms:

- Multicast Algorithm used to construct an optimized multicast tree from an Access Gateway (AG) to some Base Stations (BS) on, which mobility can be predicted [1].
- Alert Algorithm used to avoid IP router congestion [19].

Note that the multicast will occur only within the period during, which the BS communicates the candidates cells to the moving Mobile Node. Once this information is acquired by the Mobile Node and one cell is selected, then the unicast routing runs again and the multicast is interrupted. The handover trigger is based on a simple power signal comparison between the current BS and the candidate one. In our case, Handover Trigger event are invoked when the received signal level in the current cell becomes lower than the pre-defined thresholds. A *handover_trigger* notification message is sent by the current cell to the AG in order to launch the multicast to the candidate cells.

We consider a single domain as shown in Figure 2. The Border Router (BR) connects the network to the internet and one Access Router (AR) serves a number of BSs. When a mobile node moves from one BS to another without changing its AR, we talk about an intra-AR handover case that is not considered in this paper because it is specific to AR implementation.

Each BS on, which mobility can be predicted is assigned a multicast address and it sends a notification to its attached AG . We do not focus on mobility prediction, so we assume that we know the Base Stations set on, which mobility can be predicted [8], [15]. Considering this set to be the multicast group M_i, it appears suitable to match them to the local group given by the neighboring set NS_i of each Base Station BS_i in the planar graph $PG = (V_p, E_p)$, where V_p is the set of Base Stations and E_p is a set of directed links. Therefore, for a given BS_i a multicast group $M_i \subset V_p$ is constructed by m Base Stations belonging the set NS_i and distributed geographically on the TWINBOARD access network.

Actually, the multicast is triggered at the AG level considered as the intelligent entity responsible of processing the handovers and other functions in TWINBOARD network. In the simulated handovers scenario (Figure 2), one mobile node attached to the Base Station BS_i is in communication with another mobile node attached to the Base Station BS_j that may roam outside of its serving cell. Before handover trigerring, unicast packets are sent by BS_i to its attached AG along the IP routers network by using an unicast routing protocol combined with the Alert mechanism. Once the handover is detected, and according to the address of BS_j obtained from the unicast packet, the AG selects the multicast group members m_j from the NS_j set. Thus, it constructs the multicast packets to be forwarded to each multicast group member using the proposed Multicast Algorithm combined with the Alert Algorithm.

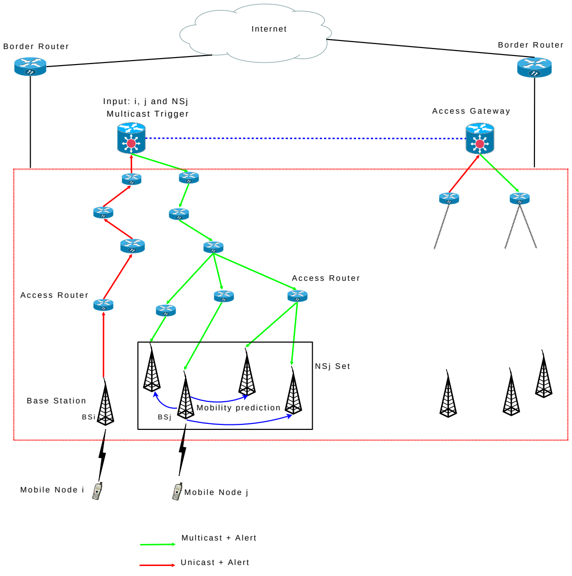

Fig. 2. TWINBOARD Architectural view

B. *Multicast Algorithm*

When a mobile user moves from one point of access to another within a domain, a handover event takes place between the two points of access. Handover involves to redirect the incoming traffic flow to the new access point. In proactive handover the link between the mobile user and the new access point is established prior to its disconnection with the old access point. Hence a smooth handover, i.e., handover with low packet loss, can take place by exploiting the fact that the new access router is known a priori and that multicasting allows proactive path setup to the new access router. The packets are multicasted to the mobile nodes within the domain where handover can be predicted. Mobility prediction need not necessarily be a part of the micro-mobility algorithm as it can be better achieved with additional information from lower layers.

Problem definition:
We define the related multicast problem from a graph theory point of view (see Figure 3 for an example). Then, we show that it is NP-complete and not approximable problem. We consider a symmetric digraph $G = (V, E)$ within a coherent routing function R, a vertex $s \in V$ (called transmitter) and a vertex subset D (called destination set).

Definition 1: We define a **Broadcast scheme** *from s to D as a subtree of G rooted in s, with depth equal to* $\max_{v \in D} |R(s, v)|$, *with leaves in set D and where the edge set can be decomposed in a set of paths such that*:

1) *The initial extremity of each path is s or an intermediate vertex with outgoing degree > 1 in the subtree.*
2) *The final extremity of each path is a leaf.*
3) *Each path $< i, f >$ corresponds to the route $R(i, f)$.*

The number of edges in the subtree defines the *size* of the broadcast scheme.

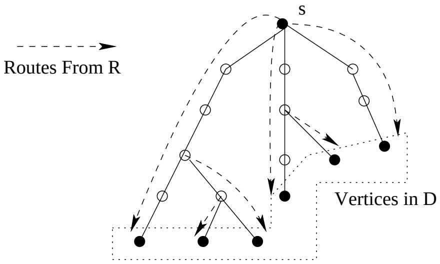

Fig. 3. An example of multicast scheme

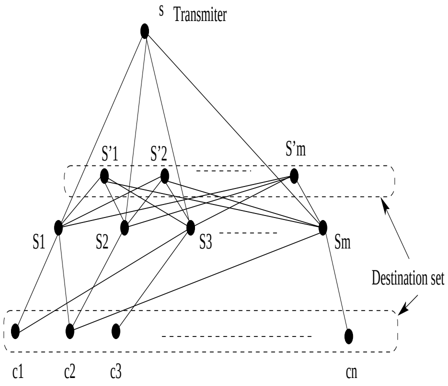

Fig. 4. Polynomial reduction

The problem of finding a multicast tree minimizing the number of edges under an IP routing constraint can be defined as follows:

Problem: Destination_Mobility (DeMo)
Given: A symmetric digraph $G = (V, E)$, a coherent routing R, a transmitter $s \in V$, a destination set D and an integer k.
Question: Does there exist a Broadcast scheme with size at most k ?

Complexity:

Theorem 1: For some $c > 0$, Problem **DeMo** is NP-complete and not approximable within $c \log(n)$,where n is the number of vertices of the graph.
To prove this theorem, we propose a polynomial reduction from the **SET-COVER** problem.

Proof: Problem DeMo is clearly in NP. Indeed, it is easy to check in polynomial time for a given structured trees if one of them is (or not) a broadcast scheme with at most k edges. Counting the number of edges requires at most $\mid E \mid$ elementary operations. The trees generation can be done in polynomial time within the number of the structured trees by choosing recursively the initial extremity for each element of D.
To prove that Problem DeMo is NP-complete, we propose a polynomial reduction from the **SET-COVER** problem defined as follows:

Problem: Set Cover (**SET-COVER)**
Given: A set $C = \{c_1, \dots, c_n\}$ of n elements, a set $S = \{S_1, \dots, S_m\}$ of m subsets of C such as: $\bigcup_{i=1}^{m} S_i = C$ and an integer k'.
Question: Does there exist a subset S' of S (called cover of the set C: $\bigcup_{i|S_i \in S'} S_i = C$) such that $|S'| \leq k'$?

The problem **SET-COVER** has been shown to be NP-complete in [5].
Consider any instance I=(C, S, k') of the Problem **SET-COVER**. We transform this instance to the instance I'=(G, R, D, s, k) of the Problem **DeMo**.

1) G is defined as follows:
   - We define the sets of vertices:

     $\zeta = \{c_1, \dots, c_n\}$, $\varphi = \{S_1, \dots, S_m\}$, the vertex s and the set $\varphi' = \{S'_1, \dots, S'_m\}$.
   - We connect by a symmetric edge the vertex s to each vertex of the set φ.
   - We connect the vertex c_j to the vertex S_i by an edge if and only if $c_j \in S_i$.
   - So, the vertices set of the graph G is composed by: $V = s \cup \zeta \cup \varphi \cup \varphi'$.
   - We consider a complete bipartite graph between φ and φ'.
2) The set of destinations is : $D = \zeta \cup \varphi'$, and the transmitter is the vertex s.
3) The routing R is defined as follows :
   - For $i \in \{1, \dots, k'\}$, the route $R(s, S'_i)$ is the shortest path crossing first the arc to $S_i \in \varphi$, then the arc from S_i to S'_i;
   - For each couple (i, j) the route $R(S_i, S'_j)$ is the arc that connect them in the complete bipartite graph;
   - For $j \in \{1, \dots, n\}$, if and only if $c_j \in S_i$ the arc from S_i to c_j is the route $R(S_i, c_j)$;
   - For each other couples of vertices in the graph G, we consider a shortest path routing.
4) We choose $k = k' + m + n$.

It's clear that the number of vertices in the graph G is polynomial considering $|C|$. Thus, we obtain a polynomial reduction $\mathbf{SET-COVER} \rightarrow \mathbf{DeMo}$. This construction is shown in the Figure 4.

Consider now that the answer to Problem **SET-COVER** for I is positive. So, it exists a set $C \subset S$ of k' elements, which cover the set C. We define a Broadcast scheme where the tree is induced by the union of the edges of the following routes:

1) The routes of length 1 from s to each vertex S_j such that $S_j \in C$.
2) For each i such that $S_i \notin C$, a route made of length 1 from a vertex $S_j \in C$ to S'_i.
3) For each $c_i \in \zeta$, a route made of length 1 from a vertex $S_j \in C$ to c_i such that $c_i \in S_j$.

First, it is clear that this set of routes induces a subtree of G rooted in s with $k' + m + n$ edges, depth 2 and leave set D. Secondly, by considering routes from s to vertices S'_j such that $S_j \in C$, and all other edges as routes, we can conclude that this tree defines a broadcast scheme.

Conversely, consider now that the answer to Problem **DeMo** for I' is positive. So, it exists in the graph G a Broadcast scheme of at most k edges with s as transmitter and where each destination (final extremity) is in D. Since φ is a vertex set disconnecting s from D and since the maximal delay is $m+n+1$, then the tree can only consists in some path from s to a subset S_φ of φ and then one arc from a vertex in S_φ to each vertex in D. Thus, $|S_\varphi| = k'$ and since S_φ is also a subset of S, the answer is positive for instance I to Problem **SET-COVER**.

We conclude that Problem **DeMo** is NP-complete. Now, let us demonstrate that Problem **DeMo** is not approximable within $c \log(n)$, for some $c > 0$ with n the number of vertices. We consider Problem **DeMo** as an minimization problem. We have seen that any tree in a broadcast scheme for any instance I' described above consists in some path from s to a subset S_φ of φ and then one arc from a vertex in S_φ to each vertex in D. Thus, the number of arcs in such a tree is equal to $a + m + n$ and that this number is equal to $opt + m + n$ where opt is the minimum size of a solution for instance I to Problem **SET-COVER** considered as a minimization problem.

Consider that for some constant c, Problem **DeMo** is c-approximable, i.e., there exists a polynomial algorithm providing a solution size $a \times (m+n+1) + n$ for I', and a solution of size a for I, such that

$\frac{a+m+n}{opt+m+n} \leq c$. Thus, $\frac{a}{opt} \leq c\left(1+\frac{1}{opt}\right) \leq 2c$, i.e., Problem **SET-COVER** is $2c$-approximable, which is a contradiction with the fact that for some $c > 0$, this problem is not approximable within $c\log(m+n)$ [9]. We conclude the proof of the Theorem 1. ■

Distributed algorithm to solve Problem DeMo: We give now more details about our proposed algorithm to achieve an efficient intra-domain handover. A multicast datagrams are composed of two portions: a fixed length header and a data field. The header contains a main destination address considered by the routing function, and a set of secondary destination addresses. An IP router receiving such a multicast packet has to decide if it creates and sends new multicast packets through all the outgoing links or remains on the main destination route. For each empty part on a link, no packet is sent. Note that the complexity of this distributed algorithm is low and that no large memory size is required in routers. Moreover, this algorithm just consists in piloting the usual IP multicast functions in these routers.

The header of a multicast packet P consists in:

- A set of destination $Dest(P)$ and a main destination $Maindest(P) \in Dest(P)$.
- A delay $Delay(P)$ being the maximal number of remaining steps for each destination in $Dest(P)$ to receive the packet.

For each couple of nodes u and v in the graph, let us denote by $succ_R(u,v)$ the successor of u on the route $R(u,v)$. Consider now a node u receiving a multicast packet P at a given step. Any distributed algorithm to solve Problem **DeMo** consists for u to send a multicast packet P_w to each $w \in \Gamma_G^+(u)$ at the next step. Such a distributed algorithm has to respect the following rules. For each node $w = succ_R(u,v)$, let us first define:

$$Sent(w,P) = \{v \in Dest(P) s.t. |R(u,v)| = Delay(P)\}.$$

Then,

1) $Sent(w,P) \subset Dest(P_w)$,
2) $Delay(P_w) = Delay(P) - 1$,
3) if $w = succ_R(u, Maindest(P))$ $then$ $Maindest(P_w) = Maindest(P)$,
4) the set of subsets $\{Dest(P_w) |\ w \in \Gamma_G^+(u)$ and $Dest(P_w) \neq \emptyset\}$ is a partition of $Dest(P)$.

If for any w, $Dest(P_w)$=$\emptyset$ then no packet is sent by u to w. Considering u' as the neighbor of u having sent P_u to u, we define for any $v \in Dest(P_w)$: $Last(v)$=$|R(u',v)|$.

We Consider w_0=$succ_R(u, Maindest(P))$. Then for any $w \in \Gamma_G^+(u)$ and respecting the previous rules, the distributed multicast algorithm consists in the following instructions:

Algorithm 1 Node U receiving a multicast packet P

```
Require: Packet $P$; $w = succ_R(u,v)$.
Ensure:
 1: if $w \neq w_0$ then
 2:     $Dest(P_w) = Sent(w,P)$
 3:     for all $v \in Dest(P) - \bigcup_{w\in\Gamma_G^+(u)} Sent(w,P)$ do
 4:         if $|R(u,v)| \geq Last(v)$ then
 5:             Put $v$ in $Dest(P_{succ_R(u,v)})$
 6:         end if
 7:     end for
 8:     for all $w \in \Gamma_G^+(u)$ and any $v \in Dest(P_w)$ do
 9:         Set $Last(v)$=$|R(u,v)|$
10:     end for
11: end if
12: $Maindest(P_w)$= the least number vertex in $Dest(P_w)$.
13: $Dest(P_{w_0})$=$Dest(P)$-$\bigcup_{w\in\Gamma_G^+(v)-\{w_0\}} Dest(P_w)$
```

The step number 1 guarantees the respect of the previous rules. The step 2 is the optimization step of the algorithm consisting in identifying on the current branch of the tree, if for any destination $v \in Dest(P) - \bigcup_{w\in\Gamma_G^+(u)} Sent(w,P)$, the current vertex u is or not the much closer vertex from v.

To initiate the process, we consider that the transmitter s has received a packet P with a node in D such that the distance from s to this node is maximum (this distance initializes $Delay(P)$). This node will be the main destination and all the other nodes in D compose the secondary destinations. For any $v \in Dest(P)$, we also set $Last(v)$=$|R(s,v)|$.

C. Alert Algorithm

This algorithm is based on works proposed in [19] for inter-domain network. We adapt this routing alert algorithm for intra-domain network by introducing a *hierarchy concept* in the TWINBOARD network similar to the one used in inter-domain network. Alert algorithm uses the existing intra-domain routing protocol functionalities. It acts directly on routing tables by disabling, activating or replacing routes. Our goal is to provide routers with information regarding the congestion state of other routers without any change in the routing protocol. We say that a router is:

- Perturbed or in *red state*: if the total amount of traffic transitting through it, emitted by it, and sending to it exceeds its capacity.
- Stable or in *green state* : if its capacity exceeds its traffic loads.

Each router informs its neighbors when it becomes perturbed in order to allow them to change their routing and it also keeps them informed when it returns to an operational state. Each router is provided with:

- RT_i containing the next hop for the intra-domain routing protocol.
- Routing table LT_i containing a lists of the next hops towards every destination. This table is altered by classical intra-domain routing mechanism only.
- Priority table PT_i storing a list of potential congestioned-free routes. It is same as the RT_i table if there are no perturbed routers.
- State Table st_i containing states of its neighbors. This table is updated by alerts sent by neighboring routers when their states change. The default values in this table are *green*.

The alert message is composed of: an identifier of the router (ID), a new state, and a delay d. Once in the router scheduler, the received message will be processed after d delay (unit of time) and will replace any older message that arrived from the same emitting router. The delay is set according to an exponential distribution in order to avoid synchronization in the network. The mean of the distribution is small for *red* alert and big for *green* alert. By this way, we limit the emergence of oscillations that can occur by exchanges of *green* and *red* messages.

Algorithm 2 details the behavior of a router i treating a packet p received from the node j. First, the router i selects destinations for, which the router j (in *red* state) is the next hop. The router i then chooses uniformly the alternative next hops among routers in *green* state and stored in the set $LT_i[dest]$. If no node can be chosen, the node i selects the routing path stored in RT_i table in spite of its state.

IV. SIMULATOR DESCRIPTION

In this section we simulate the behavior of the TWINBOARD network in case of intra-domain handovers by combining the two algorithms: Multicast and Alert Algorithms. The two proposed algorithms are compatibles with the embedded IP routing. The purpose of our simulation is to show how the proposed scheme can be adopted and compatible with the existing IP routing protocols.

Algorithm 2 Node i treating a message p

```
Require: message $p = (j, state, delay)$; tables $RT_i$,
    $PT_i$, $LT_i$, $st_i$
Ensure:
  delete $p$ from the scheduler
  $st_i[j] \Leftarrow state$
  if $state$ = $red$ then
    for all $dest \in V$ do
      if $PT_i[dest] = j$ then
        let $S = \{x \in LT_i[dest] / st_i[x] = green\}$
        if $S = \emptyset$ then
          $PT_i[dest] \Leftarrow RT_i[dest]$
        else
          $PT_i[dest] \Leftarrow$ choose_uniformly_in(S)
        end if
      end if
    end for
  else
    for all $dest \in V$ do
      if $st_i[PT_i[dest]] = red$ then
        if $j \in LT_i[dest]$ then
          $PT_i[dest] \Leftarrow j$
        end if
      if $RT_i[dest] = j$ then
        $PT_i[dest] \Leftarrow j$
    end for
  end if
```

A. Simulation environment

In order to prove our concepts and the advantages of our algorithms, we have developed a simulator using OMNeT++ [21], which is a free, open-source discrete event simulation tool, similar to other tools like PARSEC, NS, or commercial products like OPNET. Otherwise, OMNeT++ contains definitions of many popular protocols (UDP, TCP, IPv4, IPv6) as well as models of basic network nodes (routers, hubs, access points, gateway, base station etc.) that help us on modelling intra-domain mobility without worrying about the underlying mechanisms.

B. Topology and traffic Assumptions

The simulated network has been modelled according the TWINBOARD architecture as shown in Figure 2. The main elements are Base Station (BS) and the Access Gateway (AG) interconnected by a network of basic IP routers. We used topologies with 80 nodes where the number of Gateway, Base Stations and their degree of connectivity are considered as parameters of simulation:

- The degree of the gateway is chosen greater than 1.
- The degree of the BS is equal to 1 (Access Points).

- The topology of the IP routers network is generated by the BRITE generator [22].

The traffic is generated by the set of BS (sources) then it flows through the IP routers to reach the gateway to be finally multicasted to the Base Stations members of the multicast group. $TV_i(j)$ represents the traffic amount to be delivered from the source BS_i to the destination BS_j member of the multicast group. The traffic amount $TV_i(j) = \frac{\alpha}{|V_p|^2}\mathcal{N}(10, 8)$ generated by the BS_i is a random quantities given by a normal distribution with the mean equal to 10 and the standard deviation equal to 8.

The parameter α is the *flow's desired traffic parameter* used to vary the level of the traffic in the network. To simulate the intra-domain handovers event, we vary periodically the traffic matrix as follows:

- We choose randomly and with certain probability P_{ij} two traffic matrix elements $TV_i(j)$ and $TV_j(i)$.
- We reduce the value of the traffic matrix element $TV_i(j)$ of a certain quantity q.
- We increase the value of the traffic matrix element $TV_j(i)$ of a certain quantity q.

Indeed, we simulate the user handovers by a tolerate traffic matrix fluctuations. Although networks are engineered to tolerate some variation in the traffic matrix, large changes can lead to congested links and break the assumptions used in most designs. To simulate realistic scenarios, the cellular network (set of BSs) is represented by a random planar graph with degree equal to 6.

C. *Simulator Modules*

Our simulator deals with the IPv6 Mobility Extention. We can easily build different network scenarios by providing a few simple parameters from, which the simulator constructs the network automatically.

According to OMNeT++, the structure of our simulator is modular. We defined the modules and implemented their functions in C++. The main modules are:

- **Gateway:** The intelligent component implements the mobile extention management (Multicast and Alert Algorithms).
- **Base Station:** These elements represents all physical radio access points belonging to the same network.
- **Router:** This component stands for the whole wired network between Base Station, servers and Gateways. It is responsible for routing packets and simulates network delays as well.

V. PERFORMANCE ANALYSIS

With the limited charge capacity of routers and network overhead the optimization of multicast and the Alert mechanism are very important. We simulated three scenarios by varying the level of the traffic flowing through the network. This controlled-load function is invoked by specifying the parameter α (described above):

- The first scenario depicts an unloaded network obtained with the value α=0.06. This value engenders a minor traffic fluctuations.
- The second scenario is given by an average network load (α=0.13). This value increases the network load of 200% compared to the one in unloaded network.
- The third scenario corresponds to a heavily loaded network (α=0.5) enough to saturate 20% of routers in the network.

Note that these three values of α are obtained by experiences.

For each scenario, we investigate the following statistics to evaluate the performance of our approach and compare it to the DVMRP (Distance Vector Multicast Routing Protocol) combined with the Alert algorithm :

- *Number of perturbed routers*: A router is *perturbed* if its traffic loads exceeds its capacity.
- *Number of perturbed routes*: A *perturbed route* is a route containing at least one perturbed node.
- *Volume of a perturbed traffic*: Is the sum of traffic passing on perturbed routes. Traffic from i to j is perturbed if the route from i to j is perturbed.

We chose DVMRP protocol because it is an $Interior\ Gateway\ Protocol$ (IGP); suitable for use within an Autonomous System (AS), but not between different ASs. DVMRP provides an efficient mechanism for connectionless message multicast to a group of hosts.

To verify the functioning of our approach we performed three series of simulation runs on the same network topologies (50 routers) for three values of α. All the graphs follow a common format. Each one shows simulation statistics obtained by the proposed and DVMRP algorithms (combined with Alert algorithm) for the three scenarios mentionned above. In what follows, we denote by **standard approach** the combination of the two algorithms: DVMRP and Alert. While proposed approach will denote the combination of the multicast algorithm with the Alert mechanism.

Figure 5 illustrates simulation results for a heavily

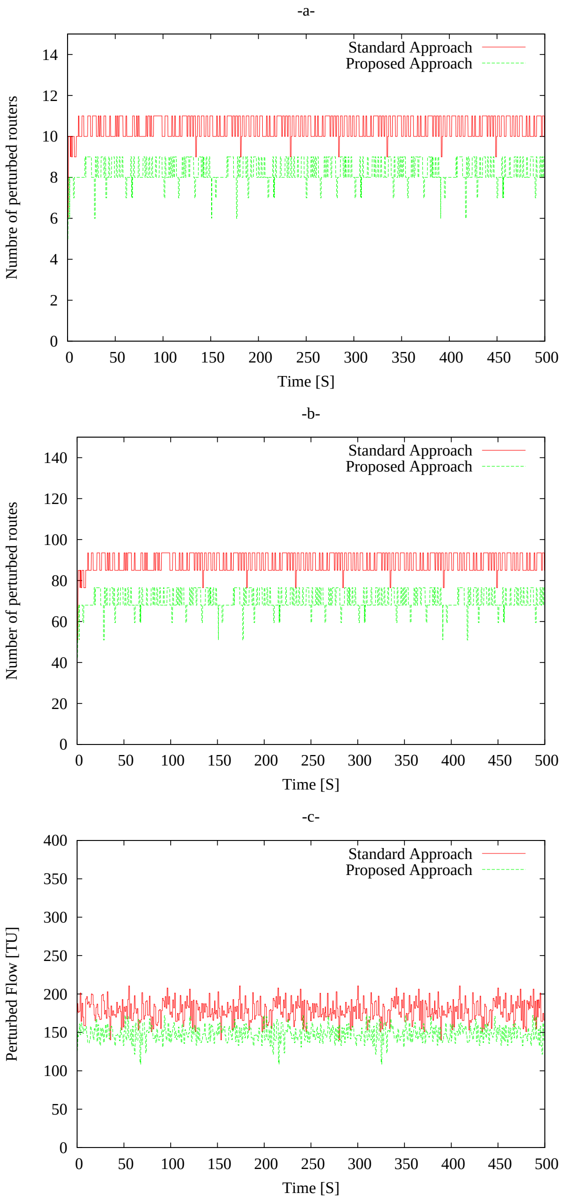

Fig. 5. Simulation results for 80 nodes network and high network charge (one simulation run, α=0.5).

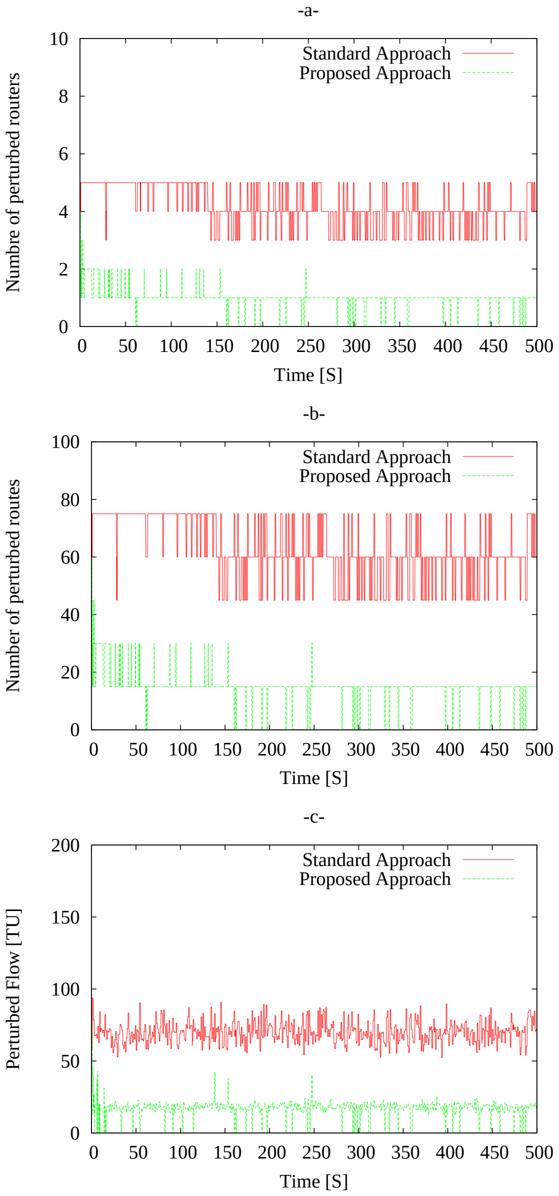

Fig. 6. Simulation results for 80 nodes network and average network charge (one simulation run, α=0.13).

loaded network (α=0.5). Figure 5.a shows that the number of perturbed routers obtained with the standard approach reaches eleven routers when the traffic matrix is filled up and it oscillates around this values. Our approach reduces this value to oscillates around eight routers and it reaches six routers in the best cases. We observe that for the traffic value α=0.5 almost 20% of the routers are perturbed. In this case the performance of our algorithms approaches those of DVMRP. The same analysis can be done for the Figures 5.b and 3.c. Indeed, because of the high network load, our algorithms can not find substitute routes to achieve an efficient load-balancing and consequently it can not reduce the number of perturbed routers, perturbed routes and the quantity of the perturbed flow.

For an average network charge (α=0.13), **Figures 6** show that our approach results are significantly better than those obtained by the standard approach. The numbers of perturbed routers, perturbed routes and the quantity of the perturbed flow, presented in **Figure 6.a**, **Figure 6.b** and **Figure 6.c** , exhibit that our algorithm presents performance four times better than DVMRP. In these figures, the spades correspond to the fluctuations

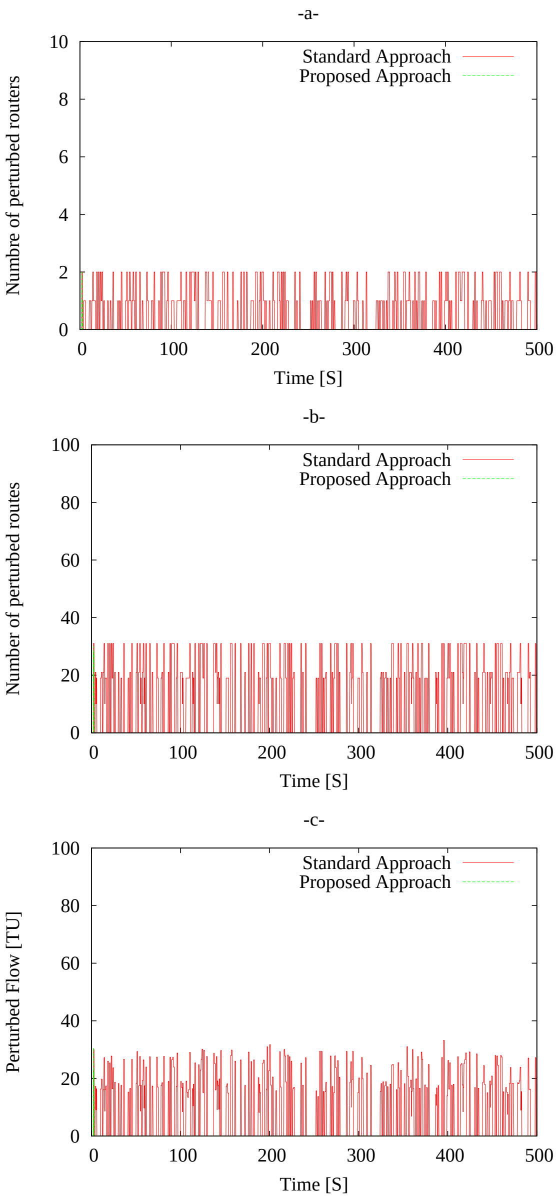

Fig. 7. Simulation results for 80 nodes network and low network charge (one simulation run, α=0.06).

in the traffic that provoke additional router saturation. Our algorithms react by finding a new (better) routes to reduce immediately the number of perturbed routers. In **Figure 6.c**, we observe that our algorithms reduce the quantity of perturbed flow to a third.

The graphs in **Figure 7**, show that even in unloaded network (α=0.06), the standard approach presents its limits. Since we register in some cases two perturbed nodes. On the opposite, our proposed approach finds quickly an efficient routing with no perturbed routers even with the traffic fluctuations.

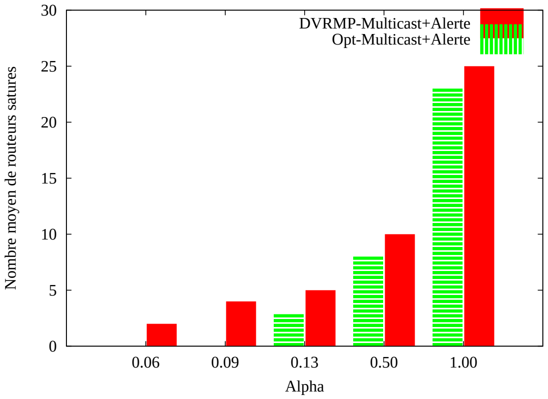

Fig. 8. The number of perturbed routers depending on the traffic load averaged for series of simulations runs.

To investigate the influence of the traffic load on the performance of our approach, we used averaged series of simulation runs (100 network topologies). Each series had a different load by specifying the parameter α, which varies from light load $\alpha = 0.06$ to saturating load $\alpha = 1$. Figure 8 shows that for the saturating load value almost half of the network routers are perturbed. In this case the performance of our algorithms approaches those of the standard approach. The average values in Figure 8 confirm those shown in Figures 5, 6 and 7. Clearly, the performance of our approach decrease when the the parameter α increases.

VI. CONCLUSION

We have presented a novel approach to manage IP micro-mobility using intra-domain multicast with alert mechanism. Our algorithms achieve efficiently two major functions in the mobile network: mobility management and network congestion avoiding. In terms of multicast performance, our algorithm achieves an optimized multicast in terms of the number of the used links. Also, it provides minimal break in service since it is based on handovers prediction.

In this paper, and with the context and the goals of TWINBOARD project, our simulation results show that with a good and a priori established traffic engineering, our proposed approach performs a reliable intra-domain handover with congestion avoiding. Our multicast algorithm outperforms DVMRP because of its minimal number of perturbed routers.

In the future, we plan to conduct further simulations to investigate real handover scenarios. We also would like to investigate the extention of our approach to support dynamic multicast group membership.

REFERENCES

[1] Y. Benallouche and D. Barth, “Optimized multicast tree for handover in a two-nodes mobile network architecture based on an all-IP infrastructure,” *Proceedings of the Fourth International Conference on Wireless and Mobile Communications (ICWMC’08), Athens, 2008, pp. 179-184*.

[2] A. Ballardie, “Core Based Trees (CBT Version 2) Multicast Routing:Protocol Specification,” IETF, Internet Draft, RFC 2189, September 1997.

[3] S. Deering, “Protocol Independent Multicast-Dense Mode (PIM-DM):Protocol Specification,” IETF, Internet Draft, RFC 2365, July 1998.

[4] D. Estrin, “Protocol Independent Multicast-Sparse Mode (PIM-SM):Protocol Specification,” IETF, Internet Draft, RFC 2362, June 1998.

[5] M. R. Garey and D. S. Johnson, “Computers and intractability. A guide to the theory of NP-completness,” San Francisco, W. H. Freeman, 1979.

[6] A. Helmy, M. Jaseemuddin and Ganesha Bhaskara, “Efficient Micro-Mobility using Intra-domain Multicast-based Mechanisms (M&M),” In ACM SIGCOMM Computer Communication Review, Vol. 32, No. 5, 2002, pp. 61-72.

[7] A. Helmy, “A Multicast-based Protocol for IP Mobility Support,” In ACM SIGCOMM Second International Workshop on networked Group Communication (NGC 2000), Novembre 2000.

[8] N.K. Karthirkeyab and P. Narayanasamy, “A Novel Mobility Based Bandwith Reduction Algorithm in Cellular Mobile Network,” *In International Journal of Computer Science and Network Security, Vol.8 ,No.5, 2008, pp. 62-69*.

[9] C. Lund and M. Yannakakis, “On the hardness of approximating minimization problems,” *In Journal of the ACM (JACM), v.41 n.5, p.960-981, Sept. 1994*.

[10] J.Moy, “Multicast Extension to OSPF,” IETF, Internet Draft, RFC 1584, March 1994.

[11] C. Perkins, “IP Mobility Support,” RFC 2002, Internet Engineering Task Force, October 1996.

[12] G.N. Rouskas and I. Baldine, “Multicast Routing with end-to-end delay and delay variation constraints,” *In IEEE JSAC, April 1997, pp. 346-356*.

[13] T.C. Schmidt and M. Wählisch, “Analysis of Handover Frequencies for Predictive, Reactive and Proxy Schemes and their Implications on IPv6 and Multicast Mobility,” *Proceedings of the fourth International Conference on Networking (Networking – ICN 2005), Reunion Island, 2005, Part II, Lecture Notes in Computer Science 3421, pp. 1039–1046*.

[14] T.C. Schmidt and M. Wählisch, “Performance Analysis of Multicast Mobility in a Hierarchical Mobile IP Proxy Environment,” *Proceedings of the TERENA Networking Conference, 2004*.

[15] W. Su, S.J. Lee and M.Gerla, “Mobility Prediction and Routing in Ad hoc Wireless Network,” *In International Journal of Network Management, vol.11(1), 2001, pp.3-30*.

[16] K. Suh, D.-H. Kwon, Y.-J. Suh, and Y. Park, “Fast Multicast Protocol for Mobile IPv6 in the fast handovers environments,” IETF, Internet Draft, February 2004.

[17] B. Wang and J.C. Hou. “Multicast Routing and its QoS Extension:Problems, Algorithms, and Protocols,” IEEE Networks, January/February 2000.

[18] D. Weitzman and C.Partridge, “Distance Vector Multicast Routing Protocol,” IETF, Internet Draft, RFC 1075, November 1998.

[19] M. Weisser, J. Tomasik and D. Barth, “Congestion Avoiding Mechanism Based on inter-domain Hierarchy,” In Springer Berlin/Heidelberg, editor, IFIP Networking, volume 4982, pp. 470-481. LNCS, 2008.

[20] The Next Generation Mobile Networks project WEB pages. See URL http://www.ngmn-cooperation.com.

[21] The OMNET++ Simulator. See URL http://www.omnetpp.org.

[22] The Brite Generator. See URL http://www.cs.bu.edu/brite/.

[23] WiMAX Forum. WiMAX Forum Mobile System Profile. 06-07.