An Agent-based Approach for Multicast Applications in Mobile Wireless Networks

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Abstract- **In this paper we propose a mobility support for multicast systems in a radio environment. This mobility support permits to a multicast mobile host (MMH) to maintain the connection to a multicast group, when it is moving from a network to another, with low connection loss occurrence or group joint delay. With this aim, an agent-based architecture has been designed and implemented. The mobility support acts in a *transparent* way, without any changes in MMH software, in network protocols and in multicast system applications. This architecture makes predictions about MMH movement and performs a reservation of resource in advance, by means of a re-creation in advance of the multicast tree. The effectiveness of our proposal has been tested with simulation test fields.**

I. INTRODUCTION

In last years, the growing diffusion of multimedia and interactive systems (e.g. cooperating and videoconference sessions) in the computer networks, with need of user mobility, has started the development of new applications, protocols and tools.

When an application must send the same information to more than one target, multicast is often used, because it is much advantageous than multiple unicast or broadcast links in terms of resource allocation. In fact, the presence of a multicast router tree, permits to duplicate the transmitted packets only if strictly required to reach the final targets (for each tree splitting); while, in unicast links, one packet is sent for each receiver and in broadcast links, one packet is sent in all networks of the autonomous system considered.

In conventional multicast algorithms [1], a multicast group is a collection of hosts each registering itself to that group. So, if a host wants receive a multicast message, it first joins that particular group. This mechanism permits to build the multicast router tree, for each multicast sender.

In this scenario, another main trend is the Internet mobility support. With more and more notebooks and portable personal computers participating in communication, mobility has become an indispensable feature.

By considering a radio environment, when a MMH is moving between different networks, it could wait several seconds before that the multicast traffic reaches it (due to that conventional multicast systems have not any mobility support). Many works have investigated the possibility to support mobility in multicast systems; furthermore, to ensure this service, advance resource reservation is often discussed [2] [3] [4] [5].

The communication scenario considered in this paper is a radio cellular system, with cells containing each a base station (BS) and some MMHs. The BS has a complete list of all MMHs present in its cell, and, for each MMH, has a list of all multicast groups currently joined by it; furthermore, it is directly connected to the IP core network. When a MMH moves from one cell to another, to the classical radio handover procedure is added a new multicast handover procedure, driven by the BS, to implement the multicast group joint in advance.

In particular, the resource reservation in advance implemented in this work is guaranteed in a *transparent* way. The system is based on multicast agents, which, with respect to [2] and [3], ensures the mobility without that the MMH must cooperate to manage the support. So, when a MMH is moving between different networks, the multicast agents predict its movement, by means of received power considerations on the radio links, without any MMH information supply.

This *transparent* mobility support has been conceived due to that: mobile hosts, such as palmtops, have lower processing speed and memory capacity, if compared with static hosts; wireless links between MMHs and BS have lower bandwidth, if compared with a wired link; mobile hosts use stand-alone power as battery-cells (the operations number executed should be minimal to reduce power consumption). Then, to have *no MMH overload in terms of memory, energy resources and operations executed,* and to have *no MMH software changes*, a completely *transparent* mobility support, managed by external entities, has been introduced.

The paper is structured as follows: in Section II the mobility problem in a multicast communication is explained and in Section III the multicast agent functions are described. System implementation details and simulation results are reported in Section IV. Finally, Section V reports some conclusions.

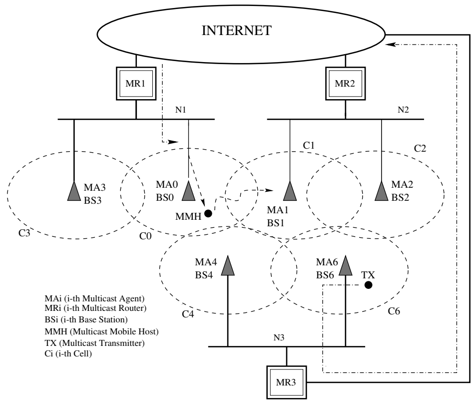

Fig. 1. Example of cellular radio multicast scenario

II. MULTICAST AND MOBILITY

To understand the mobility problem in a multicast communication, let us refer to Fig. 1, where a cellular radio multicast scenario is depicted.

From the multicast point of view, the MMH is moving from the network N1 to the network N2, connected to Internet by means of the multicast routers, MR1 and MR2, respectively. Furthermore, from the radio links point of view, MMH is moving from the cell C0, served from the base station BS0 to the cell C1, served from the base station BS1.

Let us underline that a multicast host, in order to receive multicast packets, must perform, in the start-up phase, a request to the multicast router serving its network, by using the Internet Group Management Protocol (IGMP) [1]; then, it must wait for the multicast tree update and for the multicast packet flood. With this, if on N2 is not present any multicast host joined to the same MMH multicast groups, when MMH arrives on C1 it should notify to MR2 its joint request and waits. This implies the loss of multicast packets (characterized by multicast groups not still joined by MR2) for a certain latency time, called in the following *handover latency* and considered as main system merit figure.

The *handover latency* is given by the sum of the following delays: the time from the MMH arrival in the cell C1 to the reception of the periodic IGMP query from the multicast router MR2; the time to send an IGMP report to the router; the time to update the multicast tree, in order to include MR2 in the multicast path; the multicast packets propagation time through the new multicast tree.

The *handover latency* is frequently long, equal or greater than one second; so its impact is disastrous if the handover rate is high (e.g. in an picocell environment with MMH high speed).

III. MULTICAST AGENTS

To avoid long *handover latency* it is necessary to implement a mobility support to maintain the multicast connection with continuity and without information loss. This is performed by means of multicast agents (MAs), that are located in correspondence of each BS, as in Fig. 1.

The main MA functions are:

- *discover the target cells where each MMH is moving*;
- *make the multicast group joint in advance in the target network, if necessary, for each MMH*;
- *increase the efficiency of the wireless link.*

By referring to Fig. 1, the advance reservation consists in an IGMP request performed in advance by MA1 (on N2), in order to join the multicast groups of MMH **before** that MMH moves in C1. In this way, when MMH makes the radio handover to C1, the multicast tree is yet updated and the multicast packet flood is yet present on BS1.

To increase the radio link efficiency, a little routing capability is inserted in the MAs: each MA transmits only the multicast packets relative to groups joined by the MMH present in its cell, even if it receives all multicast traffic reaching MR (also that regarding groups joined by MMHs active in other cells connected to the same MR).

On the other hand, the presence of multiple MAs, each in one cell (even if connected to the same MR), avoid that the MA makes an IGMP request to MR if the MMH is moving from a cell connected to the same MR, due to that the group joint is still active.

A. Status Vectors

To manage the mobility support, each MA has a list of the MMHs present in its cell and for each MMH the list of the joined multicast groups and the indication of the received power. This last feature is made possible by the identity between MA and BS. So the local status vector for each j-th wireless MMH connected to the generic c-th cell is defined as:

$$L_j^c = (IP_j, RX_j^c, IPJMA_j, L\_last\_reg_j^c, IPM1_j, IPM2_j, \dots)$$

where IP_j is the MMH IP address; RX_j^c is the MMH received power expressed in dB; $IPJMA_j$ is the current IP address of the next visited MA; $IPM1_j, IPM2_j, \dots$ are the IP addresses of the multicast groups joined by MMH; $L\_last\_reg_j^c$ is the last time in which a MMH joint request for at least one group in the set $IPM1_j, IPM2_j, \dots$ has been performed.

On the other hand, to perform the multicast handover procedure in a *transparent* way, each MA must know at least the received powers of all MMHs active in the adjacent cells and make the flood of these powers to all adjacent MAs. This permits to implement the movement prediction procedure, as described in the following. So, the further status vector, known by MA, relative to the j-th MMH in the adjacent cell a, is:

$$F_j^a = (IP_j, RX_j^a)$$

In order to allow the identification of MMHs present in other cells, let us consider a CDMA system, as transmission technique, that also joints the UMTS proposals.

These F_j^a vectors are updated and flooded to all adjacent MAs with a rate sufficient to follow the fastest MMH, and stored by each receiving MA in the vector:

$$A_j^{c,a} = (IP_j, RX_j^a, IPMA_a)$$

where $IPMA_a$ is the IP address of the MA flooding the F_a vector.

In order to track and maintain the multicast group joint status, each c-th MA holds multicast group status vectors, each containing the IP address of the generic multicast group joined by at least one active MMH, IPM_i, the last time in which this group has been registered to the multicast router, $M\_last\_reg_i^c$, and a register, num_i^c, counting the number of active MMHs (radio linked) joined to that group:

$$M_i^c = (IPM_i, M\_last\_reg_i^c, num_i^c)$$

B. MMH Movement Prediction

The knowledge of the MMH powers, received in the current cell, and of the MMH powers, measured by others adjacent MAs, permits to each multicast agent to predict the next cell in which each MMH is moving and is performing the radio handover.

A L_j^c vector is created for each new MMH switched on inside the c-th cell or coming from an adjacent one. In the former case, the L_j^c vector is created directly by the c-th MA, while in the latter one it is acquired from the last cell visited by MMH. For each new MMH switched on, no one $IPMk_j$ is set, and the $IPJMA_j$ is fixed equal to the c-th MA IP address, $IPMA_c$.

The basic steps, followed to implement the movement prediction procedure, are: each MA measures all MMH powers by decoding the received packets, if possible; on the basis of the L_j^c vectors and of the source IP address of the received packet, establishes if the MMH is active in the current cell or not; if not the F_j^a is compiled; every T_f seconds the F_j^a are updated and flooded to the adjacent MAs (with known IP address), which update the $A_j^{c,a}$ vectors. The life time of the status vectors F_j^a and $A_j^{c,a}$ is equal to T_f.

In this way, each MA has a complete list of the powers received from any adjacent MA, relative to all MMHs active in the current cell. So, each MA can derive in advance the MMH movement and predict the next cell visited by MMH. In fact, if we suppose that the j-th MMH is moving from the cell c to the x one, then, RX_j^c is decreasing while the RX_j^x is increasing. This prediction is revised at the end of each status vector update (performed every T_f seconds).

To implement the movement prediction, the generic c-th MA (MA_c) executes the following algorithm, by assuming to have N MMHs and n MAs in the system:

for $j = 1, \dots, N$
  MA_c select $x | RX_j^x = \max_{\substack{a=1,\dots,n \\ a \neq c}} (RX_j^a)$ with $RX_j^a \in A_j^{c,a}$
  if $RX_j^x > RX_j^c - H$ and $IPJMA_j \neq IPMA_x$ then
    $IPJMA_j = IPMA_x$
    TX L_j^c to $IPMA_x$
  else $IPJMA_j = IPMA_c$

In particular: the MA_c, for each j-th MMH in the L_j^c vector list, selects the MA_x characterized by the strongest received power, RX_j^x, by scanning the $A_j^{c,a}$ vectors. The multicast handover is performed if $RX_j^x > RX_j^c - H$ and $IPJMA_j \neq IPMA_x$, where H is the hysteresis threshold of the radio handover (expressed in dB) which happens if the condition $RX_j^x > RX_j^c + H$ is verified. When the multicast handover condition is verified, the MA_c sets $IPJMA_j = IPMA_x$ and sends the L_j^c vector to the MA_x (with address $IPMA_x$). If the multicast handover condition is not verified the MA_c sets $IPJMA_j = IPMA_c$.

When the MA_x receives the L_j^c vector, it performs the multicast reservation in advance for the j-th MMH, with details described in Section III. The control condition $IPJMA_j \neq IPMA_x$ is inserted to avoid that, for each F_j^x update and flood, starts a L_j^c vector transmission to the MA_x.

Let us note that the described MMH movement prediction is not coinciding with the radio handover procedure, due to the different use of the threshold H; in fact, the former is driven by the condition $RX_j^x > RX_j^c - H$ and the latter by the condition $RX_j^x > RX_j^c + H$.

C. Resource Reservation Procedure

The resource reservation in advance procedure permits to reduce the multicast transmission loss and delay when a MMH makes the handover to a new cell.

To explain the resource reservation algorithm executed by the generic MA_x, let: $\mathrm{MA}_x \Leftarrow L_j^c$ mean that MA_x receives the L_j^c vector from MA_c; MMH_j(on/off) mean that MMH_j is switching on or off; MMH_j(IGMP) mean that MMH_j generates a periodic IGMP report; m be the number of multicast groups registered in the cell x; CT be the current time; DEL_j=FALSE/TRUE be a MMHj switched on/off flag, initialized to FALSE for all MMHs. With this we have:

if $\mathrm{MA}_x \Leftarrow L_j^c$ then
  MA_x creates $L_j^x = L_j^c$
  $\forall\, IPMk_j \in L_j^x$
    if $IPMk_j \notin \{M_1^x, \dots, M_m^x\}$ then
      MA_x IGMP joint for $IPMk_j$
      MA_x creates new M_i^x ($M\_last\_reg_j^x = CT$, $num_j^x = 0$)
if MMH_j(on) then
  MA_x creates L_j^x ($L\_last\_reg_j^x = CT$, $IPJMA_j = IPMA_x$)
  $\forall\, IPMk_j \in L_j^x$
    if $IPMk_j \in M_i^x \subset \{M_1^x, \dots, M_m^x\}$ then $num_i^x{+}{+}$
    else MA_x creates new M_i^x ($M\_last\_reg_i^x = CT$, $num_i^x = 1$)
if $RX_j^x > RX_j^c + H$ then
  $\forall\, IPMk_j \in L_j^x$
    if $IPMk_j \in M_i^x \subset \{M_1^x, \dots, M_m^x\}$ then $num_i^x{+}{+}$
if MMH_j(off) or $RX_j^a > RX_j^x + H$ then
  $\forall\, IPMk_j \in L_j^x$
    if $IPMk_j \in M_i^x \subset \{M_1^x, \dots, M_m^x\}$ and $num_i^x > 0$ then $num_i^x -$
–
if MMH_j(off) then DEL_j=TRUE
if MMH_j(IGMP) for IPM_j then
  if $IPMk_j \notin L_j^x$ then MA_x inserts $IPMk_j$ in L_j^x
  $L\_last\_reg_j^x = CT$
  if $IPMk_j \notin \{M_1^x, \dots, M_m^x\}$ then MA_x creates new M_i^x ($num_i^x =$
1, $M\_last\_reg_i^x = CT$)

$\forall IPJMA_j = IPMA_a$ and $a \neq x$ then

if $RX_j^a > RX_j^x + H + H_0$ then DEL_j = TRUE

if CT mod $(T_\alpha/10)$=0 then

if $CT - L\_last\_reg_j^x > T_\alpha$ or DEL_j=TRUE then

MA_x removes L_j^x

DEL_j=FALSE

if $CT - M\_last\_reg_j^x > T_\alpha$ then

MA_x removes M_i^x

IGMP unjoint for IPM_i to MR

$\forall\ num_i^x \neq 0$ MA_x forwards IPM_i multicast packets

When the MA_x receives the L_j^c vector or a new MMH is switching on in the x-th cell, the MA_x creates the new entry L_j^x; then, it scans the M_i^x vector list looking for the $IPMk_j$ entry. If this entry is not found, MA_x performs the $IPMk_j$ group joint to the MR and creates the M_i^x vector with $IPM_i = IPMk_j$ and $M\_last\_reg_i^x$ set to the current time. When a new MMH is incoming from another cell, if the $IPMk_j$ entry is not present, num_i^x is set to 0, otherwise it is maintained to the current value. On the other hand, when the new MMH is switching on, if the $IPMk_j$ entry is not present, num_i^x is set to 1, otherwise it is incremented of one unit.

Every time the radio handover of the j-th MMH to the cell x is performed, all num_i^x in M_i^x with $IPM_i = IPMk_j$ (where $IPMk_j \in L_j^x$) are incremented of one unit. The num_i^x value is decremented of one unit (with minimum value equal to zero) when a MMH, joined to the multicast group characterized by status vector M_i^x, is leaving (in the radio handover sense) the cell x or it is switched off.

Even if the multicast packets of all joined groups are reaching all MAs connected to MR, only those relative to multicast groups effectively joined by the MMHs active in the x-th cell are forwarded. In particular, this forward is performed only for packets addressed to groups characterized by M_i^x vector with $num_i^x \neq 0$, i.e. with at least one MMH (joined to that group) effectively active in the cell x (from the radio point of view). This permits to maintain high the spectral radio efficiency.

In our implemented system the last visited MA_c maintains the L_j^c entry until the condition $RX_j^x > RX_j^c + H + H_0$ is verified, where H_0 is a further power threshold parameter expressed in dB. This last condition introduces an overlap time in which the c-th cell and the new x-th cell have both the j-th MMH informations (L_j^c and L_j^x, respectively). This permits to have continuity in the multicast communication during the radio handover, and represents a generalization to the multicast case of a radio soft handover mechanism. This multicast soft handover permits also to avoid problems when MMH returns quickly in the cell c or makes a ping-pong between the cells c and x.

Let us discuss the life time of the vectors L_j^x and M_i^x. When the j-th MMH generates the periodic IGMP report for the multicast group $IPMk_j$, the MA_x refreshes the $L\_last\_reg_j^x$ and $M\_last\_reg_i^x$ of L_j^x and M_i^x vectors, respectively (if they exist), with the actual time. On the other hand, the MA_x creates a new M_i^x with $num_i^x = 1$ and/or adds the relative $IPMk_j$ to the L_j^x; in both cases the MA_x refreshes the $M\_last\_reg_i^x$ and $L\_last\_reg_j^x$ fields with the actual time. The vectors L_j^x and M_i^x are periodically scanned and removed when the differences between the actual time and the $L\_last\_reg_j^x$ and $M\_last\_reg_i^x$ values overcome a suitable threshold T_α. The scan period is assumed $T_\alpha/10$ and T_α should be selected so that the multicast soft handover condition results to be prioritary with respect to the timeout mechanism.

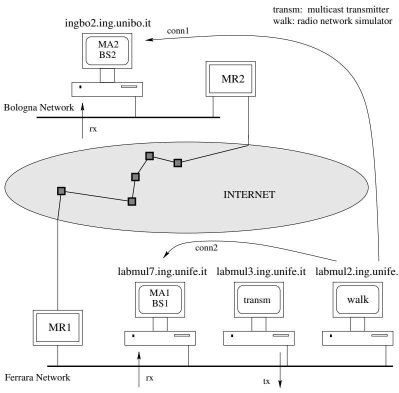

Fig. 2. Multicast agent and network setup

When the M_i^x vector is deleted, the MA_x performs an IGMP unjoint to MR for the relative multicast group. Let us observe that MR knows all groups joined by the MAs linked to it; so, even an IGMP unjoint is incoming to MR by a MA, MR effectively performs the unjount only if no other MAs are joined to that group.

Due to that more than one MMH could be joined to the same multicast group, and then they perform all a cyclic IGMP report for it, in order to reduce the signalling addressed to the MR, the MA makes the joint report to that group cyclically, by avoiding the relay of all MMH requests. The MA relay to the MR is performed immediately only when incomes a MMH report relative to a not yet registered group.

IV. IMPLEMENTATION AND SIMULATIONS

To evaluate the effectiveness of our proposed mobility support, we have implemented the MA functions on hosts with Linux operating system and we have built a radio multicast simulator to model the MMH mobility.

The radio environment has been created by considering a homogeneous hexagonal grid, with one MA-BS at the center of each cell and a configurable cell size. To avoid border effects, this structure is wrapped onto itself.

A set of MMHs (MMH_k, with $k = 1, ..., N$) has been considered and for each MMH_k we have assigned: a set of multicast groups, which can be different for each MMH; an average speed v, equal for all MMHs; a walking model, chosen from five different possibilities (linear, pseudo-linear, rotative, pseudo-rotative and mixed) and equal for all MMHs; a initial movement direction for a given walking model, chosen randomly for each MMH.

The radio channel has been modeled by considering path-loss and shadowing [6] [7], so that the simulated

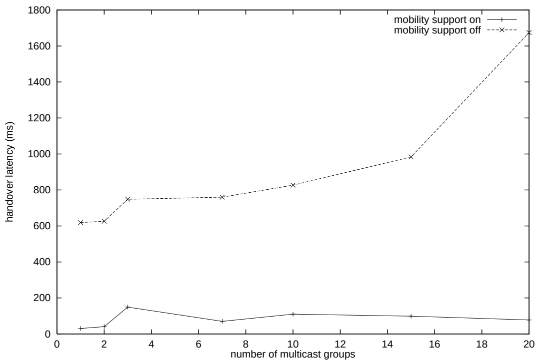

Fig. 3. Handover latency as a function of the number of multicast groups with and without multicast mobility support

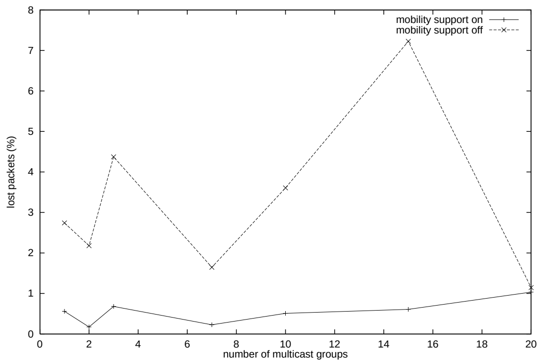

Fig. 4. Fraction of lost packets as a function of the number of multicast groups with and without multicast mobility support

MMH received powers are close to a real fading channel.

The multicast simulator moves each MMH and realizes the multicast handover between cells, by following the procedures described in Sections III and III, based on received power considerations. When a MMH moves from a generic BS to an adjoining one, the process associated with MMH moves with it. In this way, a simulation tool in which processes are really in movement in the network (walking between static hosts) has been created.

The system implementation has involved the networks of the University of Ferrara and of the University of Bologna. These system parameters have been considered: the cell size 3.5Km, the first handover threshold $H = 14$dB, the second handover threshold $H_0 = 8$dB, the update and flood time $T_f = 2$s, the timeout time $T_\alpha = 60$s, the mobile speed $v = 100$Km/h and a linear walking model.

A general network setup is reported in Fig. 2. A multicast transmitter has been located on the Ferrara network (*labmul3.ing.unife.it*) and two BSs have been considered: BS1 in Ferrara (*labmul7.ing.unife.it*) and BS2 in Bologna (*ingbo2.ing.unibo.it*). The radio network simulator has been implemented on a Ferrara host (*labmul2.ing.unife.it*).

One of the performed tests has involved a single MMH moving from BS1 to BS2, by supposing that the multicast traffic received by MMH is not still present on the Bologna network. The choice to have a single MMH has been done to better track the joint/unjoint procedures in the two involved networks. The traffic source has been programmed to generate a periodic traffic with a period of 100ms.

In Fig. 3 the handover latency in ms is reported, as a function of number of multicast group, with and without multicast mobility support. The figure reports a single field trial for each group set. The multicast mobility support gives a high performance enhancement and makes the handover latency quite insensitive to the number of multicast groups. Let us remark that the trend variability appears due to that the trials, for each different number of multicast group, have been performed in different time instants and for different network loads.

In the same test bed condition the fraction of lost packets has been measured, with trend reported in Fig. 4. The gap between the case with and without mobility support is due to the high handover rate, forced in the system to underline the effectiveness of the mobility support. Let us remark that if the mobile speed, and then the handover rate, is decreased the two curves tend to match each other.

V. CONCLUSIONS

The paper has proposed a new mechanism to obtain a *transparent* mobility support for multicast receivers in a radio network.

All mobility support is managed by multicast agents, which transparently permit to reduce the multicast communication loss and the time latency in the MMH cell change.

To model the user mobility a radio simulator has been built, which takes into consideration the propagation channel (path loss and shadowing) and various MMH walking models. This radio simulator is used to implement a MMH movement prediction, based on the received powers, which permits to implement a resource reservation in advance procedure, by means of a multicast soft handover.

The proposed system has been implemented and tested with good results and improvement in the performance with respect to a situation without mobility support.

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