# INTEGRATED IP MULTICAST IN MOBILE AD HOC NETWORKS WITH MULTIPLE ATTACHMENTS TO WIRED IP NETWORKS

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**Abstract** - Little has been accomplished to-date in bringing together the traditional IP multicast model used in fixed networks and multicast routing protocols for wireless ad hoc networks. We analyse the provision of an integrated IP multicast service in which mobile hosts can seamlessly participate in IP multicast sessions regardless of their point of attachment to the network (e.g. fixed network, ad hoc network, etc.). We propose a multicast architecture in combination with a new ad hoc multicast routing protocol called MMARP. It combines the efficiency of multicast ad hoc routing protocols with the support of standard-IP nodes without an impairment in the overall performance. Our empirical studies on the handover between different access routers shows that the proposed approach clearly outperforms the traditional single-hop wireless multicast handoff in several orders of magnitude.

**Keywords** – Multicast, handover, ad hoc-to wired, MMARP

## I. INTRODUCTION

IP Multicast is suited for efficient multipoint communications among a group of nodes. It has emerged as one of the most researched areas in networking. The problem of efficient packet distribution to a specific group of destinations has been researched since the late 80's and most of the routers nowadays support IP multicast routing protocols. The main benefit of IP Multicast is that the bandwidth consumption for group communications is dramatically reduced compared to unicast-based group communications. This is of particular interest for 'all-IP' and 'beyond 3G' mobile networks consisting of a high number of user terminals using applications which are typically interactive, multiparty and bandwidth-avid.

Many projects like the IST project MIND (Mobile IP-based Network Developments)[1] have researched the extension of IP-based radio access networks to include ad-hoc wireless elements within the access infrastructure as a natural evolution towards 'beyond 3G' systems. In this ad hoc fringe, a user terminal employs those of other users as relay points to provide multi-hop paths between mobile nodes and the fixed access network architecture.

The provision of an integrated IP multicast service in such an heterogeneous scenario consisting on traditional IP core networks interconnecting a variety of wireless and wired access networks and technologies is extremely complex and has some particular requirements [2] which are not commonly met by proposed solutions. There are specific solutions for wireless ad hoc networks, but the real challenge is their effective and efficient integration with (fixed) IP multicast protocols to achieve a seamless IP multicast service in which group members from any of these network types can take part in the same IP multicast session. Furthermore, mobile nodes should be allowed to move among these types of networks without any service disruption.

To our knowledge, for the specific problem of IP multicast interworking between IP access networks and wireless and mobile ad hoc networks, there are not satisfactory solutions so far. The typical intra-domain IP multicast protocols for fixed networks (i.e. IGMPv2[3]) for multicast group membership and PIM-SM[4] for IP multicast routing) are not able to deal with the quick and unpredictable link changes which characterise ad hoc networks. They would consume too much overhead to keep updated distribution paths in such variable topologies. In addition, multicast ad hoc routing protocols like CAMP[5], ODMRP[6], and ADMR[7] among others, incorporate specific functionality which enables them to cope with the particular characteristics of ad hoc networks but they are only suitable for isolated ad hoc networks. These protocols do not provide any means to interoperate with the protocols used in the fixed IP networks and they do not support the attachment of standard IP multicast nodes to the ad hoc extension. In fact, the only few proposals to connect ad hoc networks to the Internet, like the one by Lei and Perkins[8] have only considered the case of unicast traffic.

In this paper we propose an integrated IP Multicast solution for ad hoc network extensions consisting of a novel IP multicast architecture and the Multicast MAnet Routing Protocol (MMARP). MMARP is a new multicast ad hoc routing protocol based on the same basic mechanisms as other ad hoc multicast routing protocols but including special functionalities to deal with the complexity of supporting traditional IP nodes whilst interoperating smoothly with fixed IP networks.

The novelty of our approach is not only the provision of such an integrated IP multicast solution, but also the way in which the functions are divided among the fixed and ad hoc nodes so that the interworking is achieved without a noticeable impairment in the overall performance. In fact, MMARP nodes are able to intercept and process standard IP multicast messages. They further permit standard IP nodes to seamlessly participate in IP multicast communications as they do when attached to a fixed IP network.

The remainder of the paper is organised as follows: section II describes the operation of the MMARP protocol and its architecture. Empirical results are presented in section III. Finally, section IV gives some conclusions and presents some future work.

## II. THE MMARP APPROACH

The MMARP protocol is especially designed for mobile ad hoc networks (MANETs). It is fully compatible with the standard IP Multicast model and it allows standard IP nodes to take part in multicast communications as they usually do. Key to this is that MMARP supports the IGMP protocol as a means to interoperate both with access routers and standard IP nodes. The interoperation with access routers is performed by the Multicast Internet Gateways (MIGs) which are the ad hoc nodes situated just one hop away from the fixed network (see. Fig.1). Every MMARP node may become a MIG at any time. The only difference in behaviour between a MIG and a normal MMARP node is that the MIG is responsible for notifying the access routers about the groups memberships within the ad hoc fringe. This approach allows MMARP to work with any IP multicast routing protocol in the access and core network. Therefore, MMARP operation is shielded from intra-domain and inter-domain multicast routing protocols. This operation and the proposed MMARP architecture [9] is presented in Fig. 1.

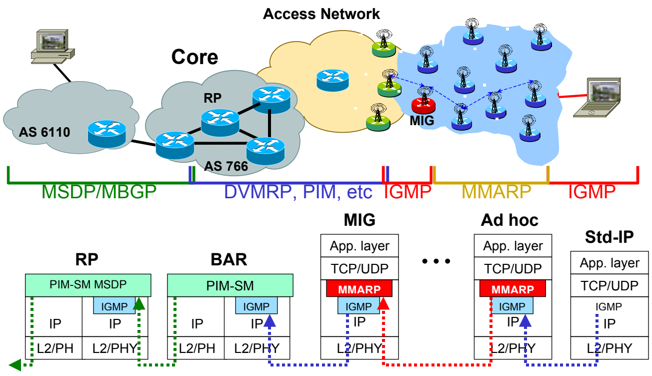


Fig. 1. Proposed MMARP architecture

For the remaining text we use the terms standard IP source or standard IP receiver to refer to a traditional IP Multicast source or receiver and we use the term ad hoc sender or ad hoc receiver to refer to pure MMARP ad hoc nodes.

### *A. MMARP overview*

MMARP uses an hybrid approach to build a distribution mesh similar to the one used by ODMRP[5] Routes among ad hoc nodes are established on-demand, whereas routes towards nodes in the fixed network are maintained proactively. This offers a good trade-off between efficiency and smooth interworking with the fixed network while still having a good protection against link breakages (see Fig. 2). However, the way in which the mesh is created is different from ODMRP due to the special requirements which MMARP nodes have to face. For example, MMARP nodes can participate in the mesh creation process on behalf of standard IP nodes or even on behalf of the access router (AR). In addition, they behave so that the standard IP multicast model can be preserved (i.e. making all the traffic generated within the ad hoc fringe to be delivered to the AR). These specific differences are explained in the next subsections.

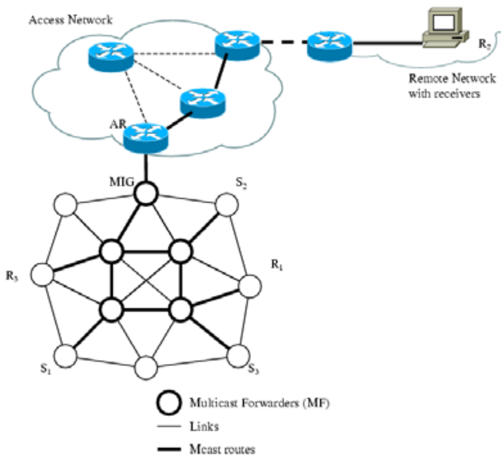


Fig. 2. Multicast mesh after request/reply phase

The reactive part consists of a request phase and a reply phase. When an ad hoc node has new data to send, it periodically broadcasts a MMARP_SOURCE message which is flooded within the entire ad hoc network to update the state of intermediate nodes as well as the multicast routes. These messages have an identifier which allows intermediate nodes to detect duplicates and avoid unnecessary retransmissions. When such a message is received by an ad hoc node for the first time, it stores the IP address of the previous hop and rebroadcasts the packet. When one of these messages arrives at a receiver, or at a neighbour of a standard IP receiver, it broadcasts a MMARP_JOIN message including the IP address of the selected previous hop towards the source. When an ad hoc node detects its IP address in an MMARP_JOIN message, it recognises that it is in the path between a source and a destination. It then activates its MF_FLAG (Multicast Forwarder Flag) and rebroadcasts a MMARP_JOIN message containing its previously stored next hop towards the source. In this way, a shortest multicast path is created between the source and the destination. When there are different sources and receivers for the same group, the process results in the creation of a multicast distribution mesh like the one presented in Fig. 2.

The proactive part of the protocol is simply based on the periodic advertisement of the MIGs as default multicast gateways to the fixed network. As the TTL of IGMP messages is fixed at one, the reception of an IGMP Query can be used by ad hoc nodes to detect that they are MIGs and activate its MIG_FLAG. MIGs periodically broadcast a MMARP_DFL_ROUTE message which is flooded to the whole ad hoc network. The reception of this message informs intermediate nodes about the path towards multicast sources in the access network. When the MMARP_DFL_ROUTE message reaches a receiver or a neighbour of a standard-IP receiver, this node initiates a joining process similar to the one that we have just described for the reactive approach. When the MIG receives the MMARP_JOIN message, it then sends an IGMP Report towards the FHMR, ensuring the IP multicast data from sources in the fixed network reach the destinations within the ad hoc network extension. In fact, MIGs will keep on answering to IGMP Queries from the access routers on behalf of the whole ad hoc extension.

The protocol incorporates local repairing mechanisms to overcome link breakages during the creation of the distribution mesh. Whenever a node is unable to deliver a MMARP_JOIN message to its next hop after four retries, it broadcasts a MMARP_NACK message to its one-hop neighbours. Upon the reception of this message, the neighbours use their own route to reach that next hop. Should any of them not know an alternate path, they repeat the process until a path is found. Although this recovery process does not offer optimal routes, it offers a quick recovery before the next topology refresh.

Once the mesh is established, the data forwarding is very simple: data packets addressed to a certain multicast group are only propagated by ad hoc nodes which have their MF_FLAG active for that group. When such a data packet arrives at a node whose MF_FLAG for that group has not expired, it checks that it is not a duplicate and in that case retransmits the packet. In any other case the packet is dropped.

### *B. Standard IP Multicast support*

The protocols used by standard IP nodes to perform their basic operation (such as ARP, or IGMP) were designed to operate in BMA (Broadcast Medium Access) networks. However, in multihop ad hoc networks, the link layer has a different semantics. The neighbours of a node are able to receive the frames it sends but it is not guaranteed that they are able to directly communicate among all of them. In traditional ad hoc routing protocols without explicit support for standard IP nodes this is not a problem because each ad hoc node sends its own source announcement or join message. In order to be compatible with the standard IP multicast model, MMARP nodes in the neighbourhood of a standard IP node have to send MMARP_SOURCE or MMARP_JOIN messages on behalf of the standard IP node. This means that messages generated by standard IP nodes, may be received by all neighbours and processed independently, creating unnecessary paths.

The MMARP protocol has been designed to avoid unnecessary generation of these messages. It includes a field in its header which facilitates the identification of the node which actually triggered the sending of the control message; this allows ad hoc nodes to identify all the MMARP packets which are triggered by a specific standard IP node, independently of the ad hoc neighbour which actually generated it. Thus, ad hoc neighbours of standard IP nodes and intermediate ad hoc nodes are able to detect these types of MMARP_SOURCE and MMARP_JOIN messages as duplicate and avoid the creation of unnecessary paths.

## III. EMPHIRICAL RESULTS

### *A. The Testbed and Equipments*

We have set up an indoor 802.11b multicast wired-to-wireless ad hoc network testbed (see figure 2) to evaluate the performance of our MMARP-based seamless IP multicast approach for wireless ad hoc access networks compared to traditional IP multicast handovers.

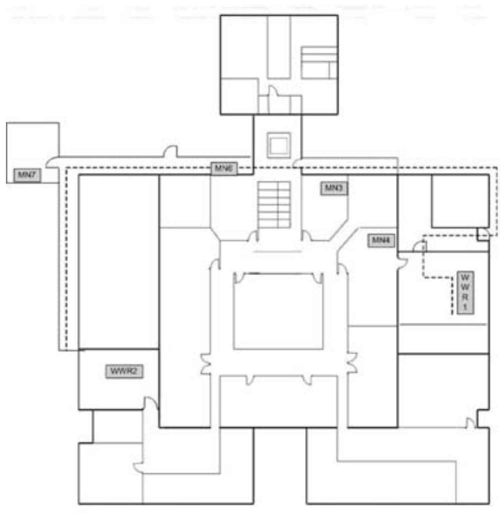


Fig. 3. Topology and testbed scenario

The testbed consists of six x86-compatible PCs and a laptop. Different processor and memory configurations are used, since there are not any specific hardware requirements. In fact, all of these PCs are able to support the workload of the experiments. Three out of the six PCs are acting as MMARP-enabled nodes running Red Hat Linux 7.2 with the 2.4.17 kernel. They have a Lucent 802.11b PCMCIA card as their unique interface. The nodes labelled as WR (Wireless Router) and WWR1(Wired-to-Wireless Router) and WWR2 are PCs running FreeBSD 4.6 OS. The WWR nodes are equipped with two NICs, one of them being a Lucent WaveLan PCMCIA card to provide coverage for the wireless area, while the other one is a 100 Mbps Ethernet NIC. The Wired Router (WR) contains three 100 Mb/s Ethernet NICs, two connected to the WWR1 and WWR2 and the other one to which nodes in the wired part are connected. The Sender and Receiver nodes are both running Red Hat 7.2 with kernel 2.4.17. The sender is a x86-compatible desktop with a 100 Mb/s Ethernet card whereas the receiver is a laptop PC equipped with a Lucent 802.11b-compatible PCMCIA wireless interface. The wireless channel we have used for our experiment is the one operating at 2.422 GHz supporting a rate of 2 Mb/s. We have previously checked that this channel was not used by any other wireless devices. All the WaveLan NICs are operated in ad hoc mode.

*B. Handover Experiments*

In order to assess the effectiveness of the MMARP protocol when changing from one access router to the other, we have evaluated its performance in the scenario depicted in Fig. 3. An standard-IP multicast receiver will move following the path which is shown in the same figure while it maintains a multimedia session with a source placed in the wired network. That will require a handover between the two different access routers. We measured the quality of the handover comparing the standard IP multicast case to the case in which the receiver connects through an MMARP-based ad hoc access network.

We show in Fig. 4 the evolution of the loss rate at different data rates during the multimedia session. As it can be noted, when the receiver is close enough to WWR1 there are no losses at all. Then, as the distance to that router increases, so do packet losses. After 30s of session, packet losses reach 100% until the receiver is able to join again the IP multicast group at WWR2. This long period of losses is clearly explained by the fact that, according to IGMP operation, the receiver does not issue an IGMP report to join WWR2 until it receives from the router an IGMP Query. The time between IGMP Queries is long enough as to permit that the receiver could eventually loose completely WWR1 coverage without having being able to join WWR2. In fact, that also explains that the duration of the handover could be different in different experiments. This depends mainly on the time that remains until the next periodical IGMP Query is issued by the router when the receiver arrives to the new WWR. As it is shown in the figure, the case when we use our MMARP-based handover offers a better performance, given that MMARP nodes are already aware of the different routes to the fixed network and the MIGs can send the IGMP Reports in advance. So, as it is noted in Fig. 4, with MMARP the loss rate never goes beyond 14%, and in fact, they are most of the time at a 0% expect around the 45s, which corresponds to the point in the path in which the signal strength is poorer and the collision probability is higher as long as there are many MMARP nodes which are reachable at that point (see corner between MN3 and MN6 in Fig. 3). This shows how the proactivity of MMARP regarding the announcement of the MIGs results in a better performance without an important increase in the overall overhead.

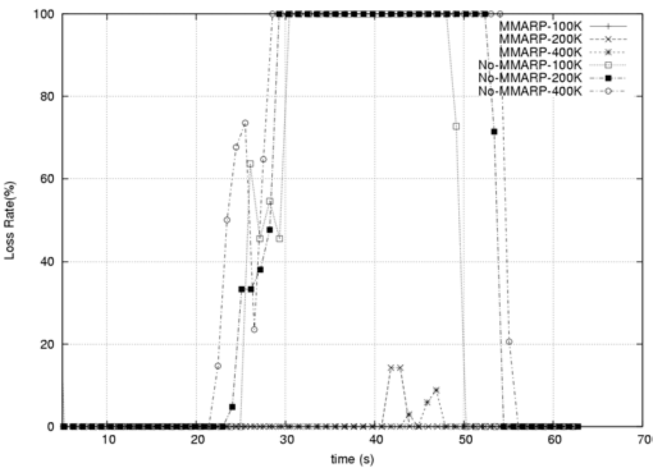


Fig. 4. Loss rate during the handoff

This same trend is also depicted in figures regarding the total number of packet losses during the handoff for the different data rates which are presented in Table 1. As it is illustrated, the total packet losses for the standard IP Multicast handoff are much higher than those for the MMARP-based scheme. Given that the time intervals in which the standard IP multicast handoff is losing 100% of the packets are very similar for the different data rates, the total number of packet losses increases almost proportionally to the data rate. However, in the MMARP based handover, the total packet losses are pretty much reduced.

Table 1.- Total packet losses during handoff

| | No-MMARP | MMARP |
|---|---|---|
| 400 Kb/s flow | 991 pkts | 6 pkts |
| 200 Kb/s flow | 530 pkts | 6 pkts |
| 100 Kb/s flow | 218 pkts | 0 pkts |

The packet losses which are produced when using the MMARP-based handoff are due to the collisions which are produced in the zone covered by MN3 (see Fig. 3). In that particular point in the path there are 5 nodes, namely WWR1, MN3, MN4, MN6 and the receiver, competing for the medium. This explains why for the 100 Kb/s flow there are no losses at all, and why this issue only comes up with higher data rates. As is it also illustrated in Fig. 4, during the rest of the session just before arriving at that point and just after leaving that point MMARP is able to deliver 100% of the IP Multicast data packets for all the data rates used.

Regarding the inter-arrival jitter, Fig. 5 shows how, if we do not take into consideration the obvious increase during the blackout periods, the standard IP multicast handoff approach presents very stable jitter. This is mainly due to the fact, that communications between the receiver and WWRs are just done within a 1-hop range and without interferences or collisions from other nodes.

The inter-arrival jitter in the MMARP-based handoff shows some fluctuations due to the randomness of the media access due to the contention at the MAC layer. However, it is generally able to deliver all the data packets just within a small variation in the order of a few milliseconds most of the time. Of course, there is a clear advantage when using the MMARP-based handoff if we consider the interval from 22s to 50s in which the standard approach just delivers 0% of the packets whereas MMARP is able to maintain the expected jitter values within only some small deviations.

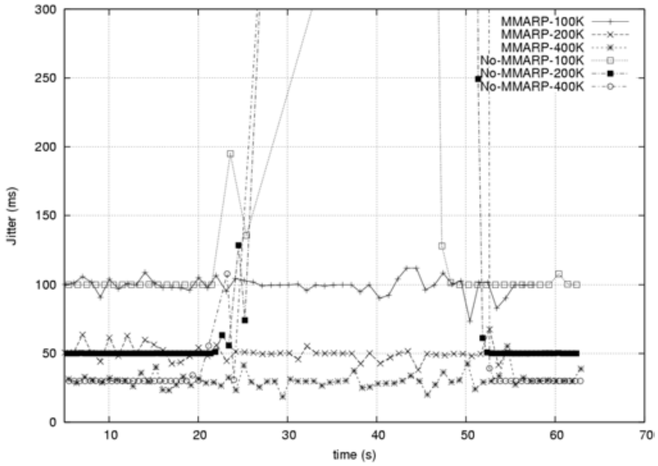


Fig. 5. Jitter variation during IP Multicast handoff

Thus, given the overall results of the experiments, we believe that the use of ad hoc multicast routing protocols supporting interworking with fixed networks can help very much at improving the performance of IP multicast local mobility.

## IV. CONCLUSIONS AND FUTURE WORK

Currently there is not a real solution to seamlessly support efficient IP multicast communications in future heterogeneous wireless scenarios. We present our solution for ad hoc networks extending fixed IP access networks. It consists of a novel architecture and a new multicast ad hoc routing protocol called MMARP. This approach is the first to our knowledge being able to support seamless roaming from multicast nodes (including traditional IP multicast hosts) between traditional IP multicast networks and ad hoc network extensions. In the authors' opinion, in addition to the proposed solution, it is also an important contribution the demonstration through empirical experimentation that this kind of extensions driven by MMARP are able to easily extend IP multicast edge-coverage in a cost-effective way, without an impairment in the overall throughput. The results show that at different data rates, the proposed approach offers a much better performance in terms of loss rate, total packet losses and inter-arrival jitter.

For future work, we are working towards the optimisation of the selection of paths in terms of stability, signal strength and overall end-to-end link quality, different router prefixes and user/application preferences.


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