SCALABLE MULTICAST COMMUNICATIONS FOR AD HOC EXTENSIONS ATTACHED TO IP MOBILE NETWORKS

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Abstract - To date, IP multicast for fixed and mobile networks has been considered as two separate problems; however, within the framework of the MIND IST Project, we are providing an integrated multicast architecture suited for both types of network. This paper presents the MIND Multicast Architecture for "beyond 3G" mobile and wireless networks including ad hoc extensions. A comparative study is presented which demonstrates that an efficient architecture is even more important than the protocols used. In addition, it is demonstrated that the MIND multicast architecture is potentially more efficient than that of UMTS and could offer the same theoretical bandwidth savings that native IP Multicast achieves in fixed networks.

Keywords – Multicast, ad hoc, architecture.

I. INTRODUCTION

IP Multicast technology provides efficient multipoint communications among a group of nodes and has emerged as one of the most researched areas in networking. The problem of efficient packet distribution to an specific group of destination has been researched since the late 80's and currently the majority of network equipment supports multicast routing protocols. The main benefit of IP Multicast is that the bandwidth consumption for group communications is dramatically reduced, something of particular interest for all-IP and "beyond 3G" mobile networks where the number of terminals is high and the applications tend to be interactive and consume greater bandwidth. In fact, IP multicast could represent important added-value for an operator in reducing network costs and differentiating their service offering from the others.

In IST project MIND[1] the network architecture is based on an IP Core network which interconnects all the different access networks an operator deploys. In addition, the MIND project introduces a novel feature, the extension of the access network by ad hoc networks which are used to connect several terminals without the need of network infrastructure. In this ad hoc fringe, a user terminal employs those of other users as relay points for providing multi-hop paths between distant nodes and the fixed architecture. The main goal of the MIND multicast architecture is providing efficient multipoint communications in such an environment.

Many multicast routing protocols have been proposed in the literature for ad hoc networks; however, these assume that all the nodes have special protocol stacks and are in ad hoc networks isolated from the Internet. Multicast routing protocols used in the Internet such as PIM-SM [2] do not perform well in ad hoc networks where the topology is highly dynamic. Equally, multicast ad hoc routing protocols such as ADMR[3] are not directly applicable to this challenging problem since they are not able to interoperate with IP Multicast routing protocols. Thus, a new architecture and protocols need to be proposed.

The remainder of the paper is organised as follows: Section II outlines some of the most relevant requirements that were identified in our studies. Section III describes our proposed multicast architecture and compares it with some other approaches. In Section IV we model our multicast architecture as well as an UMTS-like approach. Section V presents some results comparing our architecture against the UMTS-like approach. Finally, Section VI comments on the conclusions and future work.

II. MULTICAST REQUIREMENTS

There are several approaches to exchanging multicast datagrams between the Internet and the ad hoc fringe; however, most of these are not valid because they cannot interoperate with the technologies already in use. Thus, the first step towards an efficient multicast architecture is the identification of the requirements which need to be met. Of those identified in our studies the most relevant are:

Interoperability with the Internet. The mechanisms used in the different parts of the MIND network should be interoperable with Internet protocols.

Unchanged terminal APIs. The MIND network should not require any change to the protocol stacks of standard IP nodes.

Address management. Appropriate address management procedures should be provided so that the routers to perform such multicast-related procedures as Reverse Path Forwarding (RPF) checks.

Effective routing within the ad hoc fringe. Internal ad hoc routing mechanisms should also be efficient in providing effective routes between ad hoc nodes.

Scalability. The basic multicast principle of scalability to support a large number of simultaneous users should be preserved.

Low signalling overhead. Ad hoc network environments require very low signalling protocols for efficiency sake.

Resilience. Several gateways to the BAN should be supported to eliminate single points of failure.

Robustness. Effective routing should be guaranteed even in presence of rage conditions.

Inter-domain multicast routing. Solutions should not affect the inter-domain multicast routing protocols being used in the administrative domain.

III. MIND MULTICAST ARCHITECTURE

There are different ways to connect the ad hoc network fringe to BRAIN Access Networks (BAN) and to other fixed networks. The performance obtained will depend greatly on the architecture that is selected. We will focus here on network layer multicasting without taking into account any specific link layer for the ad hoc fringe.

A. Multicast interoperation with the Internet

For multicast hosts the process of taking part in multicast communications is quite straightforward. When they wish to send multicast traffic they simply use a class-D address as a destination and send the datagrams. When they are interested in receiving multicast traffic, they use the Internet Group Management Protocol IGMP[5] as a request to their First Hop Multicast Router (FHMR). This simple operation may become quite complex, however, when dealing with an ad hoc fringe attached to a fixed network:

1. IGMP uses IP datagrams with a time-to-live (TTL) of one hop for the communication between hosts and routers. Thus, only directly connected hosts are able to join multicast groups since IGMP is not directly applicable to multi-hop ad hoc network fringes in which mobile nodes can be several hops away from the BAN.

2. When a source starts sending multicast packets the FHMR should be able to intercept those packets and inform its neighbours using any multicast routing protocol (e.g. PIM-SM). This means that in an ad hoc fringe in which hosts are not directly connected to the FHMR some special mechanism needs to be implemented to ensure that traffic reaches the FHMR for every source.

Multicast routers usually perform a process called “RPF-check” on every incoming packet. This process drops any packet which arrives at an interface which that router would not use to reach the source of the packet. Thus, the typical flat addressing architecture used in the ad hoc network fringe is no longer valid and every ad hoc node in the same extension needs to belong to the same subnet. This is also applicable to the interaction with micro–mobility protocols such as BCMP[4].

B. General analysis of candidate architectures

We have studied a number of alternatives for where to place First Hop Multicast Router (FHMR), of these the most promising are:

- **FHMR in the BAN edge.** This is basically the same approach as that in which tunnels are created from the fringe of the access network.
- **Multicast ad hoc fringe.** This approach proposes using an ad hoc multicast protocol inside the ad hoc fringe and standard IP multicast protocols in the fixed network.

The first approach is conceptually the UMTS multicast architecture – except that UMTS does not accept multi-hop ad hoc routing. For MIND, we have selected a multicast ad hoc fringe as our baseline architecture because the UMTS approach exhibits some scalability and performance shortcomings. In fact, it requires the implementation of changes in the host’s protocol stack and this solution leads to excessive overhead and requires the BRAIN Access Router (BAR) to store individual membership information in a per group basis causing scalability problems. Moreover, inter ad hoc nodes communications are very inefficient as all the packets go through the BAR even when there are no interested parties in the Internet. The routing is quite sub-optimal because even for two hosts directly connected, the multicast datagrams will go first to the BAR and then return to the destination. Finally, the total bandwidth consumption is increased because for each datagram in the multicast session, one copy should be distributed by the BAN to each ad hoc node that joined the group.

In the ad hoc fringe approach the protocol’s efficiency is not reduced by using extra headers since tunnels are not needed. Finally, the BAR will only need to distribute one copy of the packets to all the nodes in its downstream interface instead of needing to forward one copy to each of the mobile nodes belonging to the group. Thus, a real multicast efficiency and scalability is achieved. In addition, when one of the downstream nodes sends a packet to a multicast group G in the uplink direction, the BAR will not need to forward this packet to any other downstream nodes that requested it since the ad hoc multicast routing protocol will ensure that packet reaches the destinations within the ad hoc fringe. Thus, the BAR does not need to store individual group membership state per mobile node, a task which is not scalable.

C. Description of the selected architecture

In the MIND multicast architecture there are three constituent parts: the fixed network, the BAN and the ad hoc fringe. These are shown in Fig. 1.

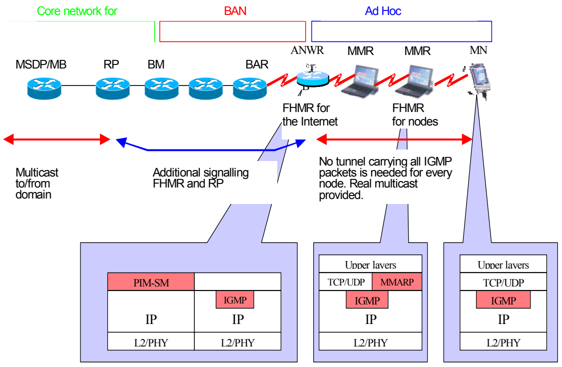

Fig. 1. MIND Multicast architecture

The MIND approach is based on the idea of confining the new functionalities within the ad hoc fringe and using standard protocols for the interaction with non-ad hoc nodes. It does not matter which IP multicast routing protocol is used in the BAN: we can interoperate in the same way with all of them. Thus, no changes are needed in standard IP nodes and routers. Mobile nodes will behave according to the standard IP Multicast model in which nothing additional is required for sending and IGMP needs to be used for receiving.

However, as IP Multicast protocols are not suitable for the ad hoc network fringe, we will use our specific ad hoc protocols here. An example for receiving a multicast flow is shown in Fig. 2. The BAR and RP are standard multicast-enabled routers running PIM-SM. Mind Mobile Routers (MMR) are ad hoc nodes and MN is an standard Internet mobile host. The complexity of achieving native multicast and efficient paths between the elements of the ad hoc network fringe is realised by means of the MIND Multicast Ad hoc Routing Protocol (MMARP). As we will show in the next section this approach offers a better performance than using tunnelling between the MNs and the BAR.

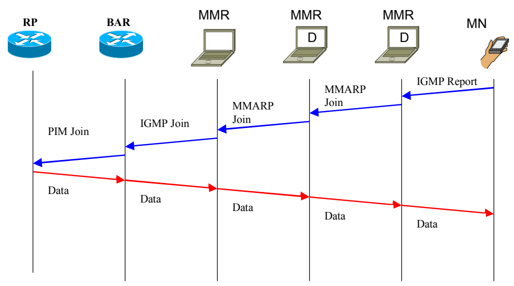

Fig. 2. ad hoc fringe example

MMARP is the key contribution to the MIND multicast architecture ensuring interoperability of the ad hoc nodes. The results achieved with this solution will depend strongly on the performance of MMARP. To achieve interoperability MMARP will need to address these additional problems (among others):

- Periodical flooding of default routes; this is the only way for ad hoc nodes to reach the Internet and such flooding may damage the routing performance.
- Periodical changes in node's behaviour. A node will have to detect dynamically when it is directly connected to the FHMR. In our case this is achieved through the reception of IGMP Queries.

Multiple attachment to the BAN. MMARP should be aware when several nodes are directly attached to the FHMR to avoid causing duplicate packets to be injected into the ad hoc extension or vice versa.

D. Strengths and drawbacks analysis

This architecture covers the majority of the identified multicast requirements. The main benefits of the approach are as follows:

- Solves the TTL problem of IGMP by using a dual protocol approach
- Avoids extra overhead and state stored by avoiding tunnels
- Maintains the performance of native multicast
- Frees the BAR from having to redistribute multicast datagrams between ad hoc nodes. MMARP performs this task.
- Inter–operates with the Internet
- Does not require the behaviour of Internet hosts to be changed.

IV. MODELLING OF THE ARCHITECTURES

Let G be the set of active groups in the ad hoc extension. Thus, |G|=n is the number of active groups. Let S be the set of active sources both in the ad hoc extension and the fixed part of the network. Then, |S| is the number of active sources. Let |Sg| be the number of active sources for group number g. Let us assume (without any loss of generality) that each group has a similar number of senders being the mean value:

$$|S_1| = |S_2| = \ldots = |S_n| = \sum_{j=1}^{n} \frac{|S_j|}{n} \quad (1)$$

Let R be the set of receivers in the ad hoc fringe of the network. Thus, |R| is the number of receivers in the ad hoc extension. Let |Rg| be the number of active receivers for group G. Let us assume (without any loss of generality) that each group has a similar number of receivers being the mean value:

$$|R_1| = |R_j| = \ldots = |R_n| = \sum_{j=1}^{n} \frac{|R_j|}{n} \quad (2)$$

We will derive the equations for the number of entries in the fringe routers, the individual bandwidth consumption and the total bandwidth consumption.

A. FHMR in the BAN fringe (UMTS-like)

In this case, the state maintained (number of entries) in the BAR for a group g is 1+|Rg|.

One entry for the interface towards the Internet plus one additional entry per destination. Which means that the total state for the ad hoc extension can by calculated as:

$$|E| = n + n * \sum_{j=1}^{n} |R_j| = n * (1 + |R|) \quad (3)$$

Let bw be the bandwidth consumption of a single data packet sent by a source Sj without taking into account the header overhead due to the tunnel itself. The total bandwidth consumption in a group j is derived as follows:

$$BWj = \left(|S_j| * bw * |R_j|\right) + k\left(\sum_{i=1}^{|R_j|-1} |S_j| * bw * i\right) \quad 0 \le k \le 1 \quad (4)$$

Note that we take into account that the source sending the packet does not need to receive it again from the BAR. In addition, k is a constant value between 0 and 1 whose value depends strongly on the topology created by the routing algorithm.

The best case occurs when all the receivers are directly connected to the BAR. In that case, one datagram is sent per source and per destination. Thus *k*=0. The worse case occurs when all the receivers form a chain from the BAR to the last receiver. In that case the sum of the bandwidth consumption in the ad hoc fringe is calculated as the sum of the bandwidth consumed in the different branches.

Thus the total bandwidth consumption in the ad hoc fringe can be calculated as:

$$BW = \left(\sum_{j=1}^{n} |S_j|\right) * bw * \left(\sum_{j=1}^{n} R_j\right) + \left(\sum_{j=1}^{n} k_j * |S_j| * bw * \left(\sum_{i=1}^{|R_j|-1} i\right)\right) =$$

$$bw * \left[\left(|S| * |R|\right) + \sum_{j=1}^{n} k_j * |S_j| * \left(\sum_{i=1}^{|R_j|-1} i\right) \right] \quad (5)$$

It is also important to note that the maximum bandwidth consumption takes place in the first link from the BAR to the ad hoc fringe. This value is always:

$$MaxBW = |S_j| * bw * |R_j| \quad (6)$$

B. Multicast Ad hoc fringe

In this case, the state maintained (number of entries) in the BAR for a group g is 2. One entry for the interface towards the Internet plus one additional entry for the interface towards the ad hoc fringe. Which means that the total state for the ad hoc fringe can by calculated as:

$$|E| = 2n$$

Let *bw* be the bandwidth consumption of a single data packet sent by a source *Sj*. The total bandwidth consumption in a group j is derived as follows:

$$BWj = |S_j| * bw\left(1 + \left(k|R_j| - 1\right)\right) \quad (0 \le k \le 1) \quad (7)$$

We have considered that the source sending the packet does not need to receive it again from the BAR. In addition, *k* is a constant value between 0 and 1 whose value depends greatly on the topology created by the routing algorithm.

The best case takes place when all the receivers are directly connected to the BAR. In that case, because of the shared medium capabilities of the ad hoc fringe, just one datagram is sufficient to reach all the receivers. Thus *k*=0. The worst case occurs when all the receivers form a chain from the BAR to the last receiver. However, even in this case, the maximum bandwidth required over any of those links is just:

$$MaxBW = |S_j| * bw \quad (8)$$

Thus the total bandwidth consumption in the ad hoc extension can be calculated as:

$$BW = \left(\sum_{j=1}^{n} |S_j|\right) * bw * \sum_{j=1}^{n} \left(1 + \left(k_j |R_j| - 1\right)\right) =$$

$$|S| * bw * \sum_{j=1}^{n} \left(1 + \left(k_j |R_j| - 1\right)\right) \quad (9)$$

V. RESULTS

From the previously derived equations, we can compare both approaches to establish quantitative differences between them. In order for the comparisons to be accurate, we assume the same topology (value of *k*) and the same bandwidth for the sources (*bw*). We show the results for different values of k. The number of active groups has been fixed at 10 –not a particularly high value. In addition, for the bandwidth comparisons we assume *bw*=46kbps which is typical for an RTP/UDP/IP good quality audio flow and the number of senders is fixed at 5. For a higher number of active groups or senders and greater bandwidth, the differences between both approaches are even greater.

A. State stored in border routers

The number of entries that need to be stored in a multicast router per interface, per source and per group provides a good measure for the scalability of the architecture. If we consider the number of entries stored in the BAR, in the case of tunnels this is proportional to the number of receivers which clearly does not scale well. In the case of using our ad hoc routing protocol within the ad hoc fringe, the number of entries scales perfectly providing this number remains constant independently of the number of receivers that join the group. This is shown in Fig. 3. In the first case the BAR needs to keep track of each pair (S,G) rather than keeping the forwarding state for the whole interface (*,G) (as in the case of having a multicast ad hoc fringe).

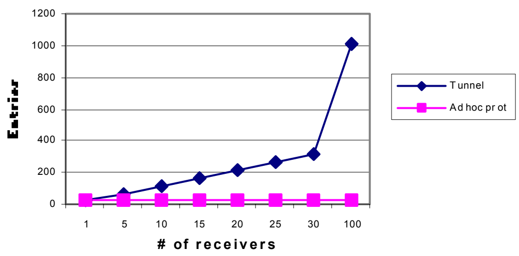

Fig. 3. Stored entries in both approaches

B. Total bandwidth consumption

The total bandwidth consumption in the whole ad hoc extension is also an interesting parameter. Fig. 4 shows the variation in the bandwidth consumption as the number of receivers increases. As shown, as the number of active groups increases the differences are greater. In fact, it is important to note that even comparing the worst case of the dual protocol approach with the best case of the tunnel approach, theoretically the latter cannot be better.

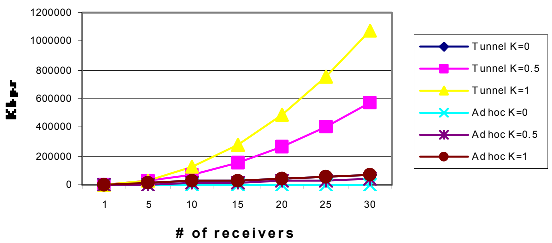

Fig. 4. Total Bandwidth consumption

C. Maximum bandwidth in one link

Finally, the parameter which most clearly describes the differences between both approaches is the bandwidth over one individual link rather than the whole ad hoc fringe. These results are shown in Fig. 5. As the number of receivers increases from 1 to 100, the bandwidth consumption in the BAR interface towards the ad hoc fringe is fixed for the multicast ad hoc fringe approach (that is the real benefit of native multicast). However, in the case of the tunnel-based approach, the bandwidth consumption reaches nearly 230 Mbps for 100 receivers compared with just 2 Mbps in the ad hoc fringe approach.

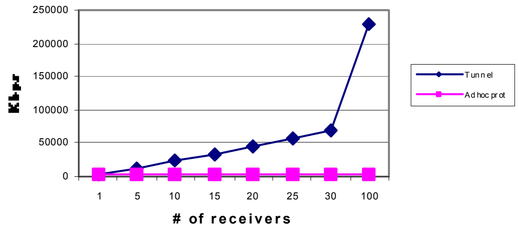

Fig. 5. Maximum bandwidth

VI. CONCLUSIONS AND FUTURE WORK

Providing efficient and scalable multicast communications in a mobile ad hoc network fringe attached to micro-mobility domains and fixed networks is a very complex problem. However, offering multicast communications is particularly interesting for "beyond 3G" network operators because of the high number of terminals that can b e supported and the savings in terms of bandwidth consumption that result.

We have shown that the design of the architecture is the most significant point in achieving efficient network performance. We now plan to propose extensions that allow standard ad hoc multicast routing protocols interoperate with the Internet independent of the protocol which is being used in either part of the access network and ad hoc network fringe.

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