Multicast Routing in Internet with Mobile Hosts

Kuochen Wang and Ying-Wei Huang
Department of Computer and Information Science
National Chiao Tung University, Hsinchu, Taiwan, ROC
Email: kwang@cis.nctu.edu.tw

Abstract

In this paper, we discuss the problems of providing multicast routing to mobile hosts in mobile computing environments. In such an environment, the main challenge of multicast routing is *group member mobility*. We propose a *heuristic* multicast routing algorithm that aims at delivering multicast packets efficiently and reduces multicast latency. The key idea of our approach is to set up an efficient multicast tree rooted at the home network of the source and to adjust the tree according to the current locations of other group members. To reduce *reconstruction overhead* of the multicast tree, we eliminate the reconstruction overhead caused by frequently to-and-fro movements of group members between networks by using *Mobile IP tunneling*. In addition, we use a *local* multicast routing mechanism that only delivers multicast packets to the base stations that group members currently dwell and their surrounding base stations instead of all base stations in a local network. Simulation results show that our proposed method outperforms a well known method by reducing 9% - 79% join time and 9% - 60% multicast latency as mobility increases, and causes less than 14% reconstruction overhead.

1 Introduction

The rapid growth of wireless communication networks makes anytime and anywhere Internet services come true. However, group member mobility as well as dynamic group membership challenge multicast routing in mobile computing environments. All previous studies in multicast routing for mobile computing environments were designed to be backward compatible with multicast routing protocols in wired networks. These studies can be classified into *broadcast* and *proxy* approaches [1], which will be reviewed in Section 2.2. In this paper, we propose a heuristic multicast routing algorithm that ensures a multicast tree rooted at the home network of the source and the tree is adjusted according to the current locations of other group members. In Section 2, we present a survey of the challenges of group member mobility and the existing multicast routing in mobile computing environments. In Section 3, our design approach is proposed. The simulation model and simulation results are shown in Section 4. Finally, some concluding remarks are given in Section 5.

2 Existing Multicast Routing Algorithms

2.1 The Problems of Mobile Multicast Routing

In a mobile computing environment, there are two main problems caused by group member mobility. The first problem is *latency*. Any group member experiences latency to receive multicast packets when it moves to an idle network where no other group members dwell. The latency consists of join time and handoff delay. The longer the latency is, the higher the packet loss rate is. Consequently, an efficient multicast routing algorithm is expected to have low join time. The second problem is *source mobility*. When the source moves to an idle network, the whole multicast tree can be invalid in that the multicast tree is rooted at the wrong router. In Distance Vector Multicasting Routing Protocol (DVMRP) [2], each multicast router will check if multicast packets arrive through the right interface, which is the reverse path to reach the source via the shortest path. This check will fail when the source moves to another network [3]. Consequently, the source mobility will trigger to construct the whole multicast tree again when DVMRP is used, which results in extreme overhead.

2.2 Existing Mobile IP Multicast Approaches

To deal with multicast routing in a mobile networking environment, most proposed multicast routing protocol can be classified into two approaches: *broadcast* [3][4] and *proxy* [5][6][7][8]. We briefly review these two approaches here.

Barke et al. [3] proposed a broadcast approach and pointed out several significant problems in mobile internetworking. In this approach, each network joins the multicast tree. Consequently, each multicast packet is sent to all routers in the networks. Each router then forwards the multicast packet in its service network. The main drawback is scalability, which makes the broadcast approach only works well in small networks such as several campus networks.

The IETF Mobile IP proposed a proxy approach, *bi-directional tunnel*, to deal with mobile multicast routing [2]. Group members that move to some foreign network set up a bi-directional tunnel to their home networks. The bi-directional tunnel allows group members to receive or send multicast packets to or from their home networks. However, it suffers from long multicast routing delivery when both the source and other group members are not in their home networks. Another drawback is the *tunnel convergence* problem when multiple group members that belong to different home networks visit the same foreign network [6]. This will cause seriously duplicated multicast packet deliveries. Chikarmane et al. [8] proposed another proxy approach, *MoM protocol*, to deal with the tunnel convergence problem. In [6], Chikarmane et al. extended the idea of proxy approach to DVMRP, Multicast Open Shortest Path First (MOSPF) and Core Based Trees (CBT) for mobile multicast routing. However, it still suffers from long multicast latency, which challenges real-time multicast applications.

3 Proposed Heuristic Multicast Routing Algorithm

3.1 Network Model for Multicast Routing

The network model we adopt is a graph $G = (V, E)$ with node set V and edge set E as shown in Figure 1 [9]. Each edge e in E is associated with a parameter $C(e)$. $C(e)$ denotes the link capacity or the distance on edge e. It can also be the utilization of a link. In addition, we make the following assumptions:

- Each node in the graph is a router that supports host mobility and multicasting for all mobile hosts that visit the network associated this router.

- For each base station in some network, its local router knows where its surrounding base stations are.

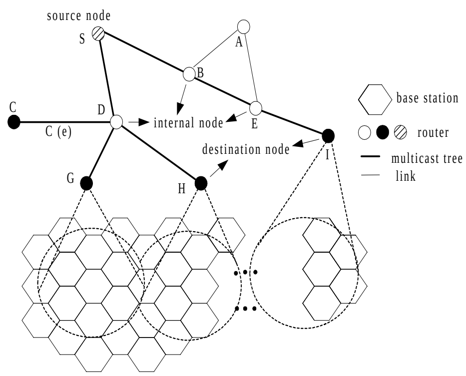

Figure 1: The architecture of wireless LANs connected by wireline backbone network.

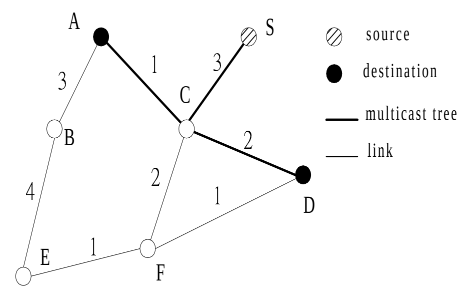

Figure 2: An example multicast routing tree.

- Each mobile host acquires a care-of address from its current resident foreign network when it is away from its home network.

3.2 Leaving and Joining the Multicast Tree

In Figure 2, a multicast tree is composed of four nodes, where S is the source, C is an internal node, and A and D are destination nodes. When a node wants to leave a multicast tree, it sends a leave request to its parent in the multicast tree. After sending the leave request, the node is pruned from the multicast tree if it is a leaf (for example, node D). This operation is repeated by its parent along the path from the node to the source until a destination node is reached. Otherwise, it is marked as an internal node (for example, node C) that is responsible for relaying multicast packets to its children. When a node wants to join a multicast tree, it sends a join request to the source. The first on-tree node that the join request reaches begins to set up a shortest path to connect the new node. Assume E wants to join the multicast tree and sends a join request to S. The join request will travel a shortest path to S, that is E, F, C, and S. Because C is the first on-tree node that the join request reaches, it sets up a shortest path to connect E. The shortest path is C, F and E.

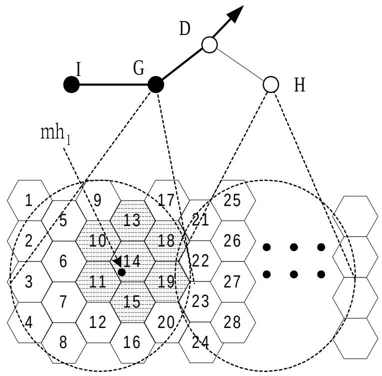

Figure 3: An example local multicast routing mechanism.

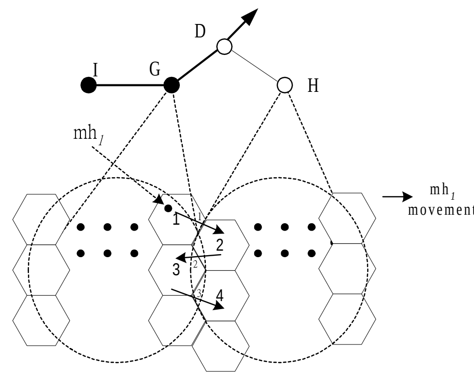

Figure 4: An example group member mobility.

3.3 Local Multicast Routing Mechanism

To avoid flooding all base stations with multicast packets in local networks, each multicast packet is only forwarded to the base stations that group members currently dwell and their surrounding base stations. In Figure 3, for example, routers G and I join the multicast tree, $group_1$, and each router serves several base stations. G and I periodically detect which base stations have group members by using IGMP. Assume that G detects a member, mh_1, in base station 14. Then G forwards each multicast packet to base station 14 and its surrounding base stations. That is, seven base stations 10, 11, 13, 14, 15, 18 and 19 will receive multicast packets. In this way, no mater which neighboring base station that mh_1 moves to, it will only suffer from handoff delay before it receives multicast packets.

3.4 Host Mobility

3.4.1 Mobility of Multicast Group Destinations

When a group member, a destination, moves between base stations in a local network, we use the local multicast routing mechanism to forward multicast packets to that member. Since the base station that a group member dwells and its surrounding base stations will receive multicast packets, that member will only suffer from handoff latency before receiving multicast packets no matter which base station it moves to. Now we discuss group member mobility between networks. As shown in Figure 4, routers D, G, and I are on-tree nodes and each router serves several base stations. mh_1 is a group member and dwells in base stations 1. Assume mh_1 takes three movements. To reduce the reconstruction overhead, we use the Mobile IP tunneling to deal with frequent to-and-fro movements of group members between local networks.

We define that a group member moves from a base station in a network to its adjacent base station in another network as an unstable movement. As shown in Figure 4, the first movement of mh_1 from base station 1 in router G to base station 2 in router H is an unstable movement. Since mh_1 may move back to router G, in this case, we use the Mobile IP tunneling to deliver multicast packets to mh_1 from router G to router H instead of invoking router H to join the multicast tree. Consequently, router G sets up a Mobile IP tunnel for mh_1. The tunnel for mh_1 will be deleted if the following situations occur.

- mh_1 moves back to router G or moves to another adjacent base station in router H.
- Router H detects that there are other mobile hosts that want to become group members in its service network.

In this way, the three movements of mh_1 shown in Figure 4 will not result in adjusting the multicast tree three times.

3.4.2 Mobility of Multicast Group Source

To deal with the source mobility efficiently, the sending of multicast packets is implemented by using the Mobile IP tunneling. When the source wishes to send multicast packets, it follows the following rules:

- If the source is in its home network, it uses link-level multicast to propagate multicast packets downstream through the multicast tree.
- If the source is away from its home network, it sets up a Mobile IP tunnel between its current foreign network and its home network. Multicast packets are unicasted to the home network of the source through the Mobile IP tunneling. Once the home network of the source

receives the multicast packets, it uses link-level multicast to propagate multicast packets downstream through the multicast tree.

4 Simulation Model and Experimental Results

4.1 Simulation Model

The network topology used in the simulation model is a random graph. In this random graph, edges are introduced between pairs of nodes u, v with a probability related to the distance between them. The edge probability is given by

$$p(u, v) = \beta exp(-d(u, v)/L\alpha)$$

where $d(u, v)$ is the distance from node u to v, L is the maximum distance between two nodes , and α and β are parameters in the range (0, 1] [10]. We assume that each mobile host will leave its current network, such as its home network or some foreign network with probability m which is in the range (0, 1). In addition, the following assumption is made in our simulation.

- The multicast tree consists of a fixed number of group members. In this way, the reconstruction overhead of the multicast tree is only caused by the group member mobility.

4.2 Experimental Results

In the following simulations, we compare our proposed method with Chikarmane method [6][8] in terms of join time, multicast latency, and reconstruction overhead of the multicast tree. Chikarmane method [6][8], a well-known proxy approach, was modified from the bi-directional tunnel proposed by IETF Mobile IP [5].

4.2.1 Multicast Latency Comparison

Figure 5 shows the comparison of multicast latency between our proposed method and Chikarmane method [6]. The vertical axis represents the multicast latency efficiency, which is defined as follows:

$$multicast\ latency\ efficiency = \frac{\delta_{\mathrm{ch\_l}} - \delta_{\mathrm{p\_l}}}{\delta_{\mathrm{p\_l}}}$$

where $\delta_{\mathrm{ch\_l}}$ is the multicast latency of Chikarmane method [6] and $\delta_{\mathrm{p\_l}}$ is that of our proposed method. In Chikarmane method, when group members are away from their home networks with high probability, they will be in some foreign networks for a long time. In this situation, multicast packets are delivered to the home networks of group members

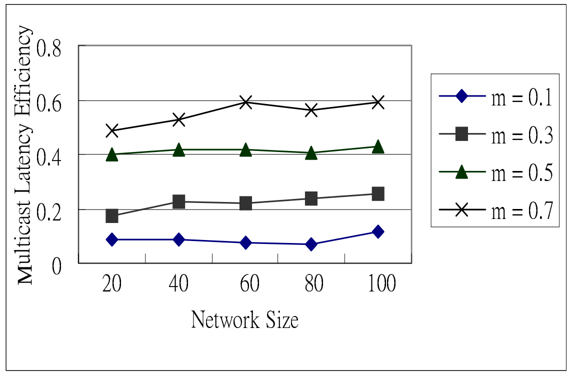

Figure 5: Comparison of multicast latency.

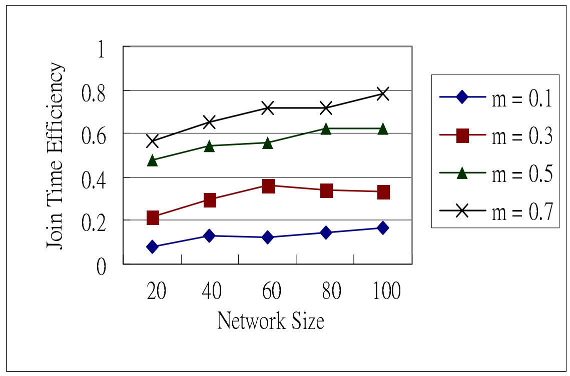

Figure 6: Comparison of join time.

first and then tunneled to some foreign networks. As a result, it delivers multicast packets in an inefficient way and causes long multicast latency. Figure 5 shows the phenomenon as m is high.

4.2.2 Join Time Comparison

Figure 6 shows the comparison of join time between our proposed method and Chikarmane method [6]. The vertical axis represents the join time efficiency, which is defined as follows:

$$join\ time\ efficiency = \frac{\delta_{\mathrm{ch\_j}} - \delta_{\mathrm{p\_j}}}{\delta_{\mathrm{p\_j}}}$$

where $\delta_{\mathrm{ch\_j}}$ is the join time of Chikarmane method [6] and $\delta_{\mathrm{p\_j}}$ is that of our proposed method.

4.2.3 Reconstruction Overhead Comparison

In this section, we use an analytical model to evaluate the reconstruction overhead [11][12] of our approach. The reconstruction overhead is associated with two parameters, the *population distribution* in a network and the network's *life cycle* duration. Group members can leave or join a multicast tree at will, which results in *Poisson* process and a memoryless property. Therefore, we use an

$M/M/\infty$ queue with arrival rate λ and service rate μ to represent the population distribution in the multicast group [13]. The equilibrium probability, $\pi_{\rm k}$, that there are k group members in a network is

$$\pi_{\rm k} = \frac{\overline{N_m}^k}{k!} e^{-\overline{N_m}}$$

where $\overline{N_m}$ is the expected number of group members in a network.

When a group member moves to an idle network, the idle network will be invoked to join the multicast tree. Then the reconstruction overhead, which is due to updating routing tables, occurs. The updating information will propagate throughout the whole networks. We assume that a group member moves to an adjacent base station in an idle network with probability p that is in the range (0, 1). Thus, when a network becomes active, it will cause $(1-p)\cdot r\cdot \pi_0$ router-updates, where r is the number of multicast routers in Internet.

During a life cycle, each multicast router exchanges group membership information with its neighbors, which results in periodical router-updates. Consequently, a network will regularly have $r\cdot E[Y]$ router-updates, where $E[Y]$ is the expected life cycle time in a network. Since the reconstruction overhead of a multicast tree is proportional to the number of router-updates [11], the reconstruction overhead is defined as follows:

$$reconstruction\ overhead = \frac{(1-p)\cdot r\cdot \pi_0}{r\cdot E[Y]}$$

where

$$E[Y] = \frac{e^{\overline{N_m}+\lambda\cdot T_L}}{\lambda}$$

and T_L is leave latency. More details on $E[Y]$ was presented in [11]. On average, there are $\overline{N_m}$ group members in a network. By the *little* rule, we have

$$\overline{N_m} = \lambda\cdot t$$

where t, *sojourn time*, is the duration for a group member to dwell in a network. Higher sojourn time means lower mobility. There are two situations that make the reconstruction overhead approach zero. When the sojourn time is very large, our proposed approach tends to behave like the static multicast routing, which makes adjusting the multicast tree unnecessary. When the sojourn time is very small, group members will have high mobility. Before a router, which did not join the multicast tree, detects that there is a group member in its service network, the group member may already move out of its service network. This also makes adjusting the multicast tree unnecessary. Figure 7 shows the phenomena.

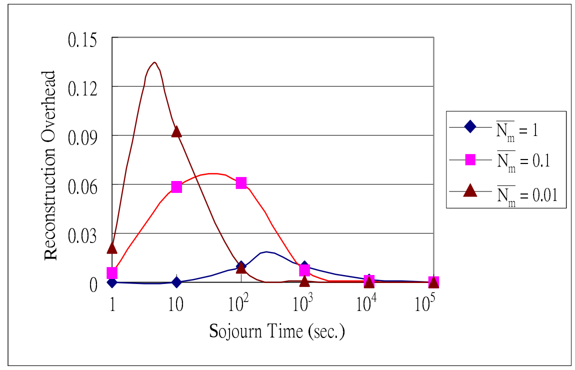

Figure 7: Reconstruction overhead.

5 Conclusions

We have described a new approach to provide multicast routing to mobile hosts in mobile computing environments. The key idea in our approach is to set up an efficient multicast tree rooted at the home network of the source and to adjust the tree according to the current locations of other group members. Simulation results show that our approach outperforms a well known approach by reducing 9% - 79% join time and 9% - 60% multicast latency as mobility increases, while causes less than 14% reconstruction overhead.

6 Acknowledgements

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