A New Multicast Protocol in Hierarchical Micro-Mobility Environments*

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***Abstract* - To reduce the control message overhead due to frequent handoffs in mobile IP, micro-mobility protocols have been proposed. In this paper we present a new approach for providing multicast services in a hierarchical micro-mobility environment. The proposed protocol builds a shared multicast tree around a core. When a node moves to a new cell, it is attached to the tree using the remote subscription mechanism if necessary. But with an efficient packet forwarding mechanism the packet loss during hand-offs is minimized. Through the simulation we show that the proposed protocol delivers multicast packets more reliably with less overhead on the network than other multicast protocols for mobile environments.**

I. Introduction

Mobile IP is the current standard for supporting macro-mobility in IP networks and provides a framework for allowing users to roam outside their home networks. Whenever a mobile node moves between neighboring base stations, its movement should be notified to its home agent. If the mobile node is highly mobile, overhead due to this registration becomes excessive. To reduce overhead in mobility management, micro-mobility protocols such as Cellular IP[1], TeleMIP[2] and HAWAII[3] have been proposed. In a micro-mobility environment, a mobile network consisting of a large number of cells is called a domain. There are many domains that are connected to the Internet core. Intra-domain handoffs are handled by micro-mobility protocols and are not visible outside the domain while inter-domain handoffs are processed by macro-mobility protocols that are mobile IP. We developed a new micro-mobility environment and through simulation showed that the proposed micro-mobility environment reduces signaling overhead, provides smooth and efficient handoffs, and scales well for unicast services[4].

Multicast is an efficient mechanism for sending packets to a group of receivers and used in many application areas such as teleconferencing, multiparty games, software distribution services, etc. To send packets to multicast group members, a multicast routing algorithm builds multicast packet delivery trees among senders and receivers. There has been much research effort on multicast routing algorithms in fixed networks and mobile networks but multicasting in micro-mobility environment has received little attention.

In this paper we present a new multicast routing protocol in a micro-mobility environment proposed by us. The proposed multicast routing protocol builds a shared multicast tree and does not assume any unicast micro-mobility protocols. When a multicast group member node moves to a new cell, the protocol attaches the member node to the multicast tree using the remote subscription mechanism to guarantee the minimum cost packet delivery path to the member node. But to avoid the packet loss due to the set-up time associated with the remote subscription, we use the packet forwarding mechanism using a carefully chosen internal router as a forwarding agent.

The rest of the paper is organized as follows. Section 2 explains related works. Section 3 describes the proposed multicast routing algorithm. Section 4 presents results of performance evaluation using simulation and is followed by the conclusion in Section 5.

II. Related Works

IETF proposed two approaches to support mobile multicast: bi-directional tunneling and remote subscription[5]. With bi-directional tunneling, mobile hosts send and receive all multicast mobile IP tunnels from their home agents. This approach handles source mobility as well as recipient mobility, and in fact hides host mobility from all other members of the group. But the drawbacks are two-fold: triangle routing problem and tunnel convergence problem. Due to the first problem the routing path for multicast delivery can be far from optimal. The second problem limits its scalability. Home agents with multiple mobile group members away from home must replicate and

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deliver tunneled multicast packets to each of them, regardless of at which foreign networks they reside. Harrison et al proposed a protocol called MoM to solve the tunnel convergence problem in bi-directional tunneling[6].

Remote subscription on a foreign network is the simplest option for obtaining multicast services since it does not have any special encapsulation requirements, and operates using existing protocols. With this option, the mobile host is required to re-subscribe to the multicast group on each foreign network and must use a co-located care of address. If the mobile host is highly mobile, however, packets will be lost owing to the long set-up time associated with multicast subscription.

The MMA(Multicast by Multicast Agent) protocol introduces a multicast agent, where a mobile host receives a tunneled multicast packet from a multicast agent located in a network close to it or directly from the multicast router in the current network. While receiving a tunneled multicast datagram from a remote multicast agent, the local multicast agent may start multicast join process, which makes the multicast delivery route optimal. The authors compared the performance with bi-directional tunneling, remote subscription, and MoM protocols and showed that the MMA protocol reduces data delivery path length and decreases the amount of duplicate copies of multicast packets[7]. But it was not quite clear how to determine the good forwarding agent without much computation or communication.

III. Description Of Multicast Routing Protocol

In this section we describe the proposed multicast routing protocol in a hierarchical micro-mobility environment proposed in [4]. We first explain the micro-mobility environment then the multicast routing protocol.

We explain the structure of the hierarchical micro-mobility environment in the context of unicast services. As in the figure 1, a domain is structured into two levels. The upper level consists of the domain root router(DRR), connecting routers that are just regular routers, and paging area rouers(PARs). It can take an arbitrary topology and uses network specific routing. The lower level is comprised of paging areas, each of which consists of a PAR and base stations(BSs). It has a tree topology and uses host-specific routing. The purpose of adopting this two level hierarchy and using both network-specific routing and host specific routing is to reduce the routing table size as much as possible, eliminate the unnecessary limitations on the network topology, and also minimize the control signal overheads in mobile nodes. The purpose of introducing paging areas is to reduce the control messages required to handle handoffs. If a mobile node is idle and moves from one cell to another in the same paging area, it does not notify its movement to the DRR and, therefore, saves control messages. Regarding an idle mobile node, a DRR

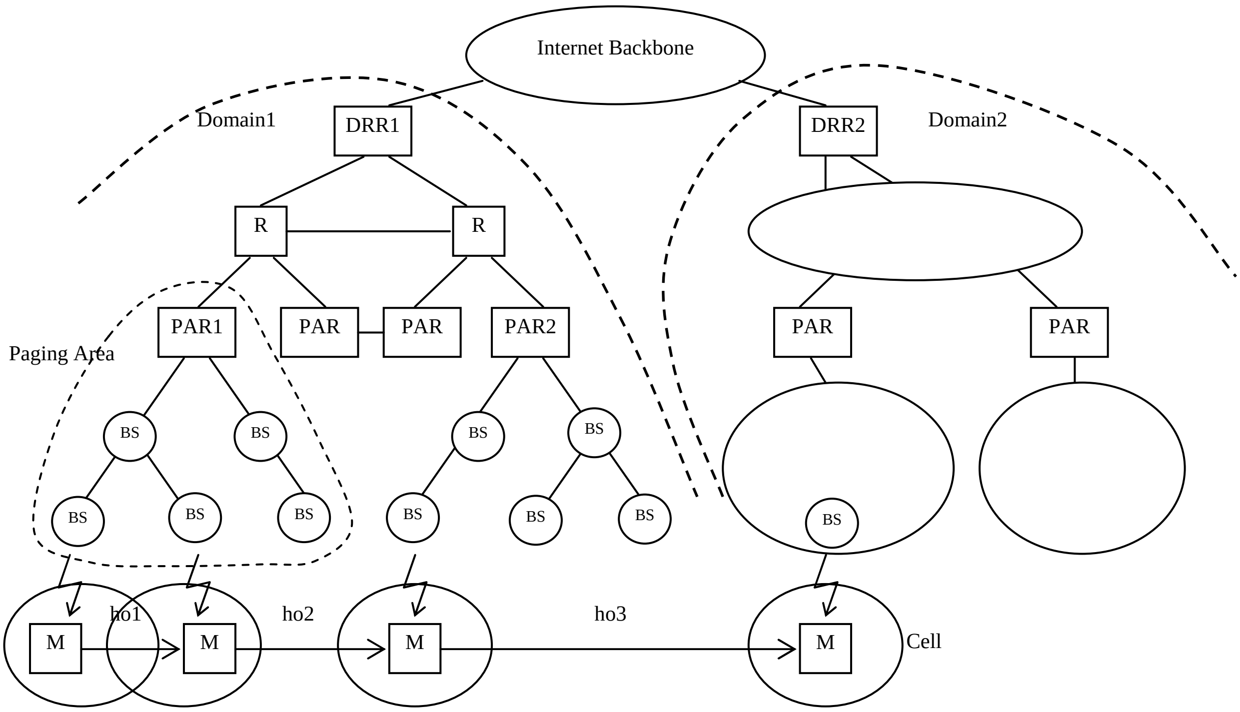


Fig. 1. Micro-Mobility Environment

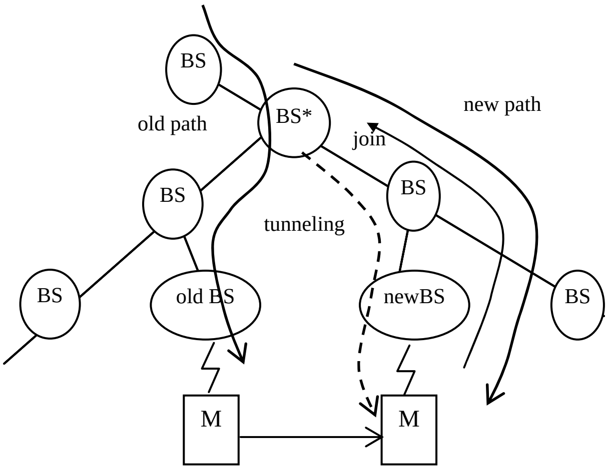


Fig. 2. Intra-Paging Area Handoff

knows only the paging area in which the mobile node resides but does not know which cell it belongs to. When a message has to be delivered, the exact location of the mobile node is found using paging mechanism.

Now we explain the multicast routing protocol. Multicast members build a multicast delivery tree in the form of a bidirectional shared tree around a core. The core is determined by the group initiator that creates the multicast group. If the group initiator can predict domains in which multicast members will reside, it finds the geographical center of DRRs of those domains in the Internet backbone using the algorithm proposed in [8]. If the group initiator cannot predict such domains but can assume that multicast members will be uniformly distributed among domains, it randomly selects one among the candidate geographical centers of all DRRs. Candidate centers can be calculated a priori.

A mobile node wishing to join a multicast group as a receiver or sender notifies its BS by sending a join request toward the core. The join message travels until it reaches a multicast tree node (BS or router) or the core. When a mobile node has messages to multicast, it sends them to its BS, which deliver them along the bidirectional multicast tree to all group members.

There are three cases in handoffs: intra-paging area, inter-paging area, and inter-domain. They are depicted as ho1, ho2, and ho3, respectively in the figure 1. When a mobile node moves to a new network, it notifies the new BS of the following information.

- The address of the BS of the old network
- The address of the PAR of the old network
- The address of the DRR of the old network

We assume that each BS knows its PAR and DRR addresses. Comparing the PAR and DRR addresses of the new network, the new BS can determine what type handoff it is as follows.

```
If (old DRR is not equal to new DRR)
     inter-domain handoff
else if (old PAR is not equal to new PAR)
     inter-paging area handoff
else
     intra-paging area handoff;
```

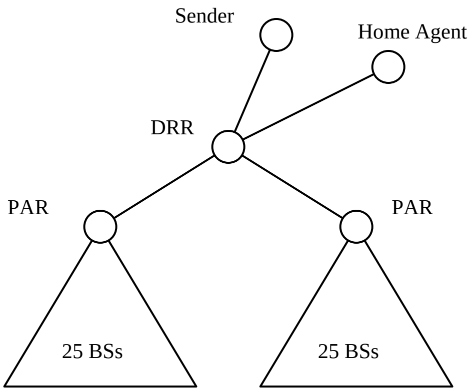
We first explain how the intra-paging area handoff works with the figure 2.

```
Mobile node M notifies new BS of its arrival;
if (M is the first group member in new BS) {
     New BS requests crossover BS (starred BS in the
          figure 2) of old and new BSs to tunnel multicast
          packets so that it can relay them to M;
     New BS connects to multicast tree by sending join
          request;
     After receiving join ack, new BS asks crossover BS to
          stop tunneling;
     /* Now multicast packets arrive through the new path
          */}
else {
     /* New BS is already connected to the tree. So nothing
          to do */}
```

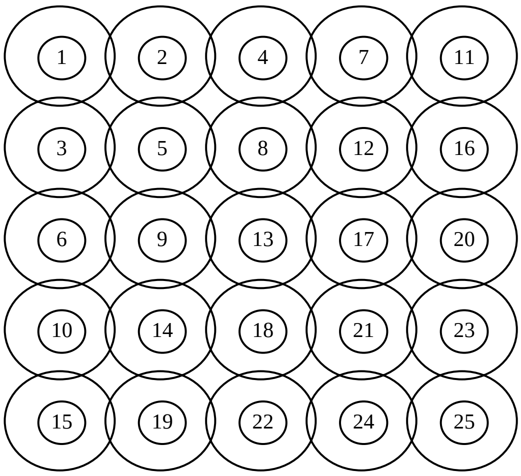
If there already exists a group member in the new cell, a mobile node, M, receives packets from the new BS. Otherwise the new BS receives multicast packets from the crossover BS through tunneling and relays them to M.

The crossover BS of old and new BSs is defined to be the BS which is the closest common ancestor of old and new BSs. Therefore, the crossover BS is used as a forwarding agent of multicast packets and this happens to be the closest forwarding agent from M. Because we assume that each BS knows the topology of the paging area to which it belongs, the crossover BS can be located without spending much time. In the meantime, the new BS sends join request toward the core. After it is connected to the tree, it asks the forwarding agent to stop tunneling because multicast packets are arriving through the new path. After detecting M’s leaving, the old BS checks if M was the last member in its cell. If so, the old BS sends a leave message toward the core.

Inter-paging area hand-offs and inter-domain handoffs are handled similarly. But the forwarding agent becomes the PAR of the old BS, PAR1 in the case of ho2 (inter-paging area handoff), and the forwarding agent becomes the DRR of the old BS, DRR1 in the case of ho3



(a) Logical Topology



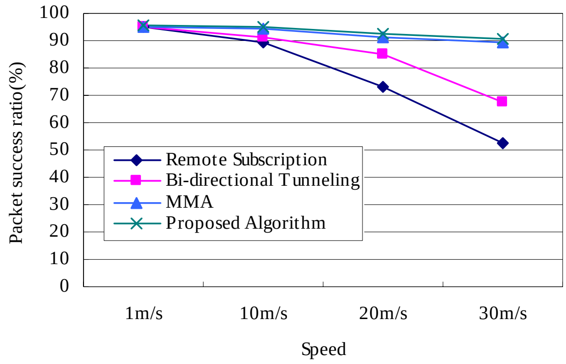
(b) Physical Topology of Base Stations

Figure 3. Simulation Environment

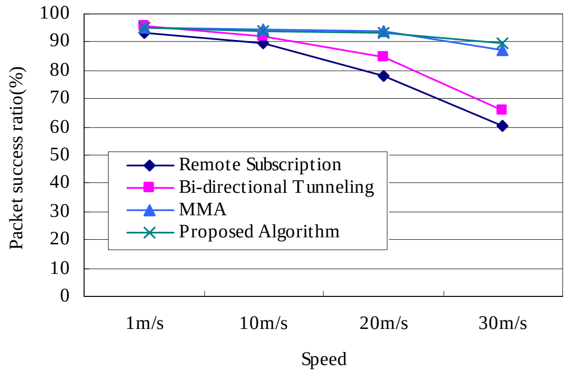
(inter-domain handoff) in the figure 1. So far we explained handoffs for receiver members. Handoffs of sender members are processed similarly except that the direction of the data delivery is reversed.

The proposed algorithm hides node mobility within a domain to the outside and increases the stability of the multicast delivery tree. It uses remote subscription mechanism to make the delivery path to the mobile node as short as possible and at the same time uses the packet forwarding mechanism using the nearest base station or router as a forwarding agent to minimize the packet loss during the remote subscription being processed.

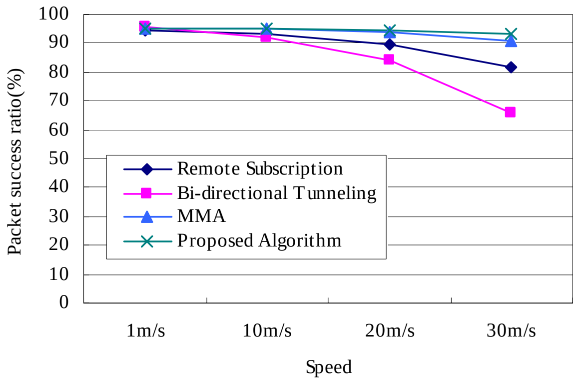
IV. Performance Evaluation



(a) 1 mobile node



(b) 10 mobile nodes



(c) 30 mobile nodes

Fig. 4. Success Ratio for 4 Protocols

In this section we compare the performance of the proposed protocol with other protocols through the simulation using NS2. The two protocols from IETF, remote subscription and bi-directional tunneling, are included in the comparison because they set the basis for the performance comparison. The MMA protocol is also included because it is shown that it has better performance than many other multicast protocols in mobile environments including the MoM protocol[7]. We show that our protocol is better than MMA.

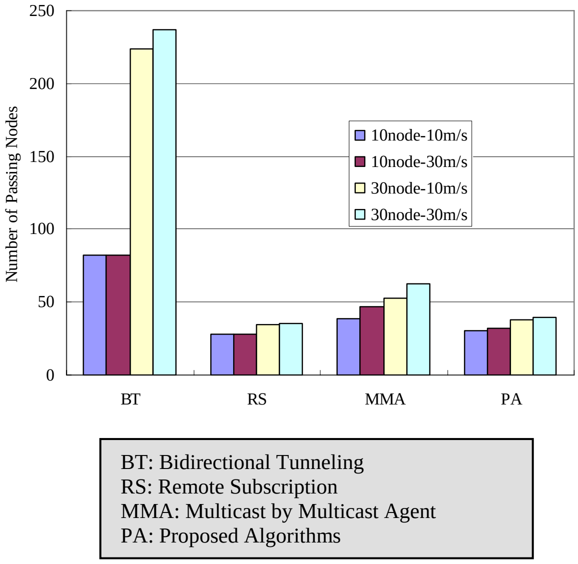


Fig. 5. Node counts

The logical environment for simulation consists of a sender, a home agent, and a single domain consisting of two paging areas as in the figure 3 (a). Each paging area is composed of 25 base stations and the physical topology of these 25 base stations within a paging area is shown in the figure 3 (b). The bandwidth of a wired link is set to 10 Mbps and the bandwidth of a wireless link is assumed to be 1 Mbps. In the simulation we increase the number of mobile nodes from 1 to 30 and the speed of a mobile node from 1m/s to 20m/s. We also assume that there is only one multicast group with the sender node residing outside the foreign domain.

The metrics used to compare the performance of protocols are the packet delivery success ratio and the total number of nodes that a single multicast packet from the sender visits until it is delivered to all the group members. The success ratio and the node count are obtained for each multicast packet and then averaged over all the multicast packets. The first metric evaluates how well a protocol performs in reliably delivering a multicast packet to all member nodes. The second metric assesses how much overhead a protocol puts upon a network during the delivery of a multicast packet.

The figure 4 shows the simulation results for measuring success ratios of four protocols. It shows that the proposed protocol has the best success ratio while the bi-directional tunneling has the worst success ratio. It also shows that the success ratio decreases as the speed of a node gets faster. In case of bi-directional tunneling, when a node moves to a new cell, it has to register to its home agent and build a new tunneling path between its home agent and itself and this process takes quite a long time. Until this process is completed, multicast packets cannot be delivered to the mobile node, therefore, resulting in the worst success ratio. In case of remote subscription, when a node moves to a new cell, it sends a join request to the multicast tree if necessary. Until this join request is processed, the multicast packets are not delivered to the mobile node. In general processing a join request takes a long time (although it takes a less time than building a new bi-directional tunnel) and, therefore, it results in poor success ratio. The proposed protocol sends a join request like the remote subscription but it also sends a packet forwarding request to a nearby forwarding agent. In general handling packet forwarding consumes much less time than processing a join request and, therefore, the proposed protocol achieves the better success ratio than two IETF protocols. The MMA protocol is slightly worse than the proposed one because the forwarding agents in MMA can be further away from the new base station than the forwarding agents in the proposed protocol and there can be more packets that arrive too late and are classified as lost packets in case of MMA.

The figure 5 shows the simulation results for node counts. Bi-directional tunneling suffers from not only the triangular routing problem but also the duplicated tunnel problem and has the worst node counts. Remote subscription always builds the near optimal multicast tree and it achieves the best node counts. In case of the proposed protocol, when a node moves to a new cell, packets are forwarded from a forwarding agent until the join request is processed, which results in a slightly longer delivery path until the join request is completed. But the simulation result shows that this effect is negligible. Although remote subscription has the best node counts, it suffers from the critical drawback that it cannot receive packets until a join request is processed. The node count of the MMA protocol is slightly worse than the proposed protocol because the forwarding agent in MMA can be further away from the new base station than the proposed protocol.

V. CONCLUSION

To reduce the control message overhead due to location and mobility management, micro-mobility protocols have been proposed. In this paper we presented a new protocol for efficiently providing multicasting services in hierarchical micro-mobility environments. The proposed multicast routing protocol builds a shared multicast tree and does not assume any unicast micro-mobility protocols. Node mobility within a domain is hidden to the outside and the protocol increases the stability of the multicast tree. It uses both the remote-subscription approach and the mechanism of packet forwarding via nearby forwarding agent to provide seamless packet delivery to group members in spite of frequent handoffs. Through the simulation it is shown that the proposed protocol achieves high packet delivery success ratio and makes the length of the packet delivery path only slightly longer than the optimal case. Although we did not include MoM in our simulation, we can infer that the success ratio and the node count of MoM are worse than those of the proposed protocol because it is shown that MoM is worse than MMA in [7] and we showed that the proposed protocol is better than MMA.

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