Mobility Management Based on Proxy Mobile IPv6 for Multicasting Services in Home Networks

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Abstract — Advances in broadband Internet access and enhanced performance of mobile devices have enabled seamless mobile IPTV service between indoor and outdoor. Mobile IPTV service is based on mobile multicasting to support efficient group communication. However, mobile multicasting has two constraints that we consider: a tunnel convergence problem and high handover latency. To reduce the two constraints, we propose a mobile multicasting model that is feasible for PMIPv6 domain. The proposed model removes tunnel convergence and reduces router processing. We then propose a fast handover scheme using a context transfer mechanism suitable for the proposed model. We also show that the proposed scheme outperforms previously proposed schemes in terms of packet delivery cost and handover latency.

Index Terms — Proxy Mobile IPv6, efficient multicast delivery, fast multicast handover.

I. INTRODUCTION

High performance of wired and wireless home network technologies has enabled multimedia streaming services such as IPTV service, which is expected to be a promising service for home use. Furthermore, enhanced CPU performance and memory capacity have made streaming service possible on mobile devices. Such changes in computing have forced many ISPs to migrate simple data services to mobile IPTV service to create new revenue; thus, they need both efficient IP mobility management and multicast mechanisms to provide seamless indoor and outdoor mobile IPTV service. Fig. 1 presents a simple network architecture to introduce the requirement of mobility management, where the home gateway (HGW) is expected to play the role of foreign agent (FA).

IPTV service is generally a kind of group communication; therefore, an IP multicasting mechanism is required to allow an IPTV source to transmit a single IP packet to multiple mobile users at the same time. However, we cannot directly apply traditional IP multicasting mechanisms to such a mobile environment, because multicasting mechanisms, including both multicast routing and membership management, have been designed for static hosts [1]. In particular, in this paper, we consider two serious problems in applying multicast mechanisms to the mobile environment.

Several multicasting schemes have been proposed for mobile networks. A common approach of the schemes is delivery of the multicast packet to mobile member nodes located in several foreign networks over bi-directional tunnels. Each tunnel is built per node by using Mobile IP. When a mobile node (MN) running Mobile IP receives multicast packets from a home network, the packets are thus delivered over a bi-directional tunnel via the home agent (HA). If an HA receives multicast packets destined for an MN, the packets are encapsulated twice with the Home-of-Address (HoA) and Care-of-Address (CoA) of the MN. Thus, if each MN located in the region covered by its HA moves to an area covered by a single foreign agent (FA), duplicated multicast packets transmitted over several tunnels increase the delivery cost. We refer to this problem as the tunnel convergence problem [2], as shown in Fig. 2. It causes unnecessary waste of network bandwidth and excessive processing overhead at the FA.

Fig. 1. Network environment to support mobility indoors and outdoors

Fig. 2. Tunnel convergence problem

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Contributed Paper
Manuscript received June 10, 2009 0098 3063/09/$20.00 © 2009 IEEE
To solve the tunnel convergence problem, V. Chikarmane et al. [3] presented the mobile multicast (MoM) scheme, where the FA selects an HA from among several tunneling the same multicast data as a designated multicast service provider (DMSP). Consequently, the scheme can reduce redundant multicast packets; however, this leads to significant signaling overhead and requires complex processing at both the HA and FA. In addition, all MNs experience service disruption caused by DMSP re-selection if the current DMSP is the HA of an MN willing to hand off.

Y. Min-hua et al. proposed another alternative [4], the Mobile Multicast Gateway (MMG) scheme, to solve the tunnel convergence problem. MMG can get multicast packets through in two ways. First, it gets multicast packets explicitly by joining a multicast group, but it cannot join the group. Thus, the first MH that wants to join the multicast group should send an IGMP Membership Report message to its home network and get multicast packets through a bi-directional tunnel. Thus, the MMG of the foreign network intercepts the packets implicitly for multicast delivery to other nodes willing to receive them. However, the MMG has difficulty intercepting packets destined for other receiving nodes. In such a case, the scheme increases packet delivery cost in proportion to the distance between the MN of a foreign network and the MMG of a home network.

The second problem is the great delay experienced by executing handover, membership management, and multicast tree update for seamless communication whenever MN moves to a foreign network. If an HA does not support multicast router functionalities, an MN should discover a multicast router (MR) and send notification by multicast listener discovery (MLD) query/report messages, including requests to join a group communication. However, the maximum query period for MLD is 125 seconds, as specified in [1]. Such a query/report delay is too long to apply to the real world.

To decrease multicast handover latency, J. Wu et al. [5] proposed the multicast support agent (MSA) scheme, and S. Yoo et al. [6] proposed the Fast Mobile IPv6 Multicast (FMIPv6-M) scheme; however, these two schemes require modification of MNs to support fast handover and lack robustness because of sudden breaks in wireless links.

To provide efficient mobile multicast service related to above-mentioned two problems, we propose a network model to support mobile multicasting based on Proxy Mobile IPv6 (PMIPv6). Then we propose a faster multicast handover scheme than that of a general PMIPv6 handover. We also evaluate the performance of the proposed scheme in terms of packet delivery cost and handover latency.

II. NETWORK MODEL FOR EFFICIENT MULTICASTING

In this section, we propose a novel PMIPv6-based network model allowing for reduction in packet delivery cost for multicasting. PMIPv6 supports network-based local mobility within a PMIPv6 domain consisting of a Mobile Access Gateway (MAG) and a Local Mobility Anchor (LMA) [7]. A MAG, instead of an MN, performs movement detection and binding updates; therefore, unlike Mobile IP, MNs do not need to install any mobility-related protocol. Moreover, the PMIPv6 does not require IP reconfiguration procedures in the same PMIPv6 domain.

A. Proposed Network Model

To design a PMIPv6-based multicasting service, we consider the position of MR. Fig. 3(a) shows a simple solution, where both the MAG and the LMA contain the MR function; however, this strategy introduces a tunnel convergence problem similar to Mobile IP-based bi-directional tunneling schemes. Therefore, we separate the MR function from the LMA, as shown in Fig. 3(b), so the MAG can connect to both the LMA and the MR. Thus, multicast packets are delivered from the MR while unicast packets are delivered from the LMA via tunnels. However, the overhead for the routing update from both network models (see Fig. 3(a) and (b)) degrades the performance of PMIPv6 components. Consequently, we propose the network model depicted in Fig. 3(c), where the MAG contains only an MLD forwarding proxy (MLD-FP) function that has been proposed by the IETF [8]. Multicast packets without tunnel header are delivered from a local MR, while unicast packets with PMIPv6 tunnel header are delivered from LMA. An MLD-FP and separated data path of unicast and multicast lift the burden from MAG and LMA. As a result, the tunnel convergence problem is solved and routing processing overhead is reduced.
B. Performance Analysis

To analyze the performance of our scheme, we employ the method used in [4]; however, unlike that of [4], we assume that both home and foreign networks can support multicast, as shown in Fig. 4. In addition, we assume the following in calculating the equations presented in this paper:

- The architecture is hierarchically formed like a tree structure with an \( l \)-layer, where \( l \) denotes the number of routers from the highest to the lowest MR within the tree.
- In two hierarchical trees, all the bottom routers of one tree are HAs and those of the other are FAs.
- For the proposed PMIPv6 based network model, we consider a single home or foreign network as a single PMIPv6 domain.
- The hop count is \( h \) from the source to the top MR.
- HAs, FAs, and the MAG receive the same multicast data only when at least one MN exists.
- The number of HAs, FAs, and MAGs located at the \( l \)-th layer in a hierarchical tree is \( 2^l \).
- The number of HAs, FAs, and MAGs with at least one MN are \( N_{HAs}, N_{FAs}, \) and \( N_{MAGs} \), respectively.
- When an MN moves to a foreign domain, the identifier of HA (i.e., the number \( i \) of HA\( #i \)) is equal to the identifier of FA (i.e., \( j \) of FA\( #j \)), for example, HA\( 3 \rightarrow \) FA\( 3 \).
- \( C_{multicast}(N_x, y) \) expresses the multicast packet delivery cost from the source node to the \( N_x \) nodes located in the bottom layers.

We define the total packet delivery cost as the sum of hop counts of multicast packets passing through routers from the source to the lowest bottom router. An MN is located at a FA of a foreign network from an HA of a home network. For simple evaluation of performance, when the multicast data are delivered from a home network to a foreign network, we consider all multicast data should traverse the top MR of the home network and the top MR of the foreign network. The cost for bi-directional tunneling (B-D), MoM, and MMG schemes is as follows [4]:

\[
C_{B-D} = \frac{1}{m} [h + C_{multicast}(N_{HAs}, l) + m(l - 1 + h + l)].
\] (1)

In the B-D case, the first term in brackets in (1) represents the cost for a single multicast packet to arrive at the top MR of a home network from the source node. The second term is the cost for a multicast packet to arrive at \( N_{HAs} \) HAs through the binary tree (\( l \) layers). The third term is the cost for HAs to forward the tunneled packet to \( m \) MNs.

\[
C_{mult} = \frac{1}{m} [h + C_{multicast}(N_{HAs}, l) + N_{FAs}(l - 1 + h + l - 1) + N_{FAs}].
\] (2)

In the case of an MoM scheme, the first and second terms are the same as in (1). The third term in brackets in (2) represents the cost for tunnelled multicast packets to arrive at \( N_{FAs} \) FAs acting DMSP. The fourth term is the cost to forward a multicast packet to \( N_{FAs} \) MNs.

Two cases are used to calculate the cost of an MMG scheme (see section I). We assume that the top MR of a home network is MMG0 and the top MR of a foreign network is MMG1. Each distance between the source and MMG0, and between MMG0 and MMG1 is \( h \).

If MMG0 gets multicast packets from MMG1 by tunnel, then the cost is calculated as in (3) and we call it MMG_A.

\[
C_{MMG-A} = \frac{1}{m} [2 \cdot h + I + C_{multicast}(N_{FAs}, I) + N_{FAs}].
\] (3)

In equation (3), the first term in brackets is the sum of the cost required to send a multicast packet from the source node to the MMG0 and the cost required to send the packet via tunnels from MMG0 to MMG1. The second term is the cost required to forward a single tunnelled packet from MMG1 to the target MN. The third term is the cost for other MNs interested in the group to forward a multicast packet copied from MMG1. However, when MMG1 gets a multicast packet by joining a multicast group, the cost is calculated as in (4) and we call it MMG_B.

\[
C_{MMG-B} = \frac{1}{m} [h + C_{multicast}(N_{FAs}, I) + N_{FAs}].
\] (4)

In equation (4), the first term in brackets is the cost for one multicast packet to arrive at MMG1 from a source node. The second term is the cost for MMG1 to forward multicast packets to \( N_{FAs} \) FAs. The third term is the cost for \( N_{FAs} \) FAs to forward multicast packets to MNs.

In the proposed model, the cost of a tunneled packet is not required after handoff because PMIPv6 does not require tunnelled packet forwarding by HA or MMG.

\[
C_{PMIPv6} = \frac{1}{m} [h + C_{multicast}(N_{MAGs}, I) + N_{MAGs}].
\] (5)

In equation (5), the first term is the cost for the multicast packet to arrive at the top MR from the source node. The second term is the cost to forward a multicast packet to the MAG. The third term is the cost for MAGs to forward the multicast packet to \( N_{MAGs} \) MNs.
III. Fast Handover Scheme

A. Mobility Pattern and Handover Probability

Simply applying a PMIPv6 handover scheme to the proposed network model leads to service disruption as a result of the latency caused by MLD query/report. To solve this problem, we propose a fast handover scheme using the context transfer mechanism, as shown in Fig. 7. When an MN hands off, the MAG with MLD-FP predicts an MN’s direction of movement and transfers the context message, which includes the MN ID, the MN home network prefix, the current MAG address, and the multicast group address. The next MAG (nMAG) then checks whether a node is available to receive multicast data corresponding to the group requested by the previous MAG (pMAG). If no hosts are available to receive the requested group from pMAG, the nMAG starts a timer to check the arrival of the MN and joins the group by sending an MLD report. If the MN does not arrive at the nMAG during the specified time, the nMAG sends the MLD leave message to the MR to save bandwidth in wireless networks.

To analyze handover latency, as in [9], we use hierarchical cell structures consisting of a $k$-layer, as shown in Fig. 8.

Fig. 8(a) shows movement of an MN from $d_i$ to $d_{i+4}$ when the layer, $k$, is 2. Fig. 8(b) shows minimum and maximum distance range that an MN can move in a cell. Before attempting to calculate handover latency, we need frequency of occurrence of inter-MAG handover whenever an MN crosses a cell boundary; thus, we calculate the number of cells belonging to the MAG in (6).
We note that the real inter-MAG handover occurs at the border line, as given in (7), because only three of the six lines are adjacent to other cells.

\[ P_a = \frac{C_a}{C_{\text{Mag}}} = \frac{6k}{1 + \sum_{i=1}^{6i}}. \]

(7)

Thus probability \( P_a \), which is 1/2, should be multiplied by \( P_a \) to obtain inter-MAG handover probability \( P_{\text{MAG-HO}} \) as shown in (8).

\[ P_{\text{MAG-HO}} = P_a \times P_a = \frac{6k}{1 + \sum_{i=1}^{6i}} \times \frac{1}{2} = \frac{3k}{1 + \sum_{i=1}^{6i}}. \]

(8)

### B. Multicast Handover Latency

Total PMIPv6 handover time can be classified with L2 handover time and Proxy Binding Update (PBU) / Proxy Binding Acknowledgment (PBA) time, as in (9). Equation (10) shows MLD latency due to membership update.

\[ t_{\text{PMIPv6}} = t_{L2} + t_{PBU/PBA}, \]

(9)

\[ t_{\text{MLD}} = t_{\text{MLD-Query}} + t_{\text{MLD-Req_port}}. \]

(10)

Consequently, we can determine total handover latency by multiplying the inter-MAG handoff probability by the individual handover delay. Equations (11) and (12) show the latency. In the proposed scheme, an MN does not experience the delay caused by MLD operation.

\[ t_{\text{PMIPv6}}^{\text{MAG-HO}} (i) = \sum_{j=1}^{t_{\text{PMIPv6}} + t_{\text{MLD}}} \times P_{\text{MAG-HO}}. \]

(11)

\[ t_{\text{Fast PMIPv6}}^{\text{MAG-HO}} (i) = \sum_{j=1}^{t_{\text{PMIPv6}}} \times P_{\text{MAG-HO}}. \]

(12)

**IX. conclusion**

Advanced radio technology such as fixed mobile convergence (FMC) and femtocell technologies may enable seamless indoor and outdoor mobile service; however, in terms of IP mobility management, mobile IPTV based on IP multicasting has two constraints: the tunnel convergence problem and high handover latency. In this paper, we proposed a multicast network model using PMIPv6 to ensure efficient delivery of multicast packets. Moreover, we proposed a fast handover procedure that reduces multicast handover delay in the proposed network model. For the evaluation, we performed a numerical analysis. The results prove that our network model and handover scheme are well suited to mobile multicasting.

**ACKNOWLEDGMENT**

This work was partly supported by the IT R&D program of MKE/IITA [2008-F015-2] Research on Ubiquitous Mobility Management Methods for Higher Service Availability, and the Ubiquitous Computing and Network (UCN) Project of MKE [09C1-C1-20S].
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