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Supporting Multicast in CDMA Cellular Systems

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Abstract

This paper studies the issue of multicast support in CDMA cellular systems. The IETF Mobile IP has suggested two solutions for mobile multicast: remote subscription (MIP-RS) and bi-directional tunneling (MIP-BT). In this paper, we propose a new mobile multicast approach for CDMA cellular systems, which is based on MIP-RS. However, it is known that MIP-RS based approaches suffer from two important problems due to a handoff: multicast delivery disruption and packet losses. For the multicast delivery disruption, the proposed approach predefines all possible multicast paths. When a handoff occurs, the new multicast tree can be quickly reconstructed. For the packet losses, the proposed approach utilizes an intrinsic function of a CDMA cellular system: soft handoff, to reduce the recovery overhead of lost packets. Simulation experiments are performed to compare the proposed approach with previous approaches.

Keywords: CDMA, Mobile IP, mobile multicast, soft handoff.

1 Introduction

With rapid progress of wireless technology, users have been able to access Internet applications via cellular systems. Nowadays, many existing and emerging Internet applications need the support of multicast communication, such as video conferencing, distance learning, resource discovery, etc. This results in a great demand to provide multicast in cellular systems. The IETF Mobile IP working group has presented two basic methods for mobile multicast: remote subscription (MIP-RS) and bi-directional tunneling (MIP-BT) [1]. Till now, most of the existing mobile multicasting methods [3, 4, 5, 6, 7, 8, 9] are based on MIP-RS to reduce the effects of multicast delivery disruption and packet losses.

In this paper, we propose a new MIP-RS based approach for CDMA cellular systems. In the proposed approach, a virtual multicast tree is first constructed. While a mobile participant (mobile member) hands off, the new multicast tree is extracted from the virtual multicast tree, which can quickly correspond to the new locations of mobile members. This feature can avoid taking long time to reconstruct the new multicast tree. The other disadvantage for MIP-RS is the packet losses, especially the “out-of-sync” [4] problem, described as follows. Mobile members belonging to the same multicast group should receive the same multicast packets, regardless of at which foreign networks the mobile participants locate. However, due to differential transmission delays in foreign networks, when a mobile member moves from a foreign network to another, the multicast packet being received in the new foreign network may be ahead of that in the old foreign network. In such case, the handoff mobile member misses some multicast packets. To solve the out-of-sync problem, the proposed approach utilizes the soft handoff to make a handoff mobile participant correctly receive multicast packets from the old and new foreign networks without missing any packets.

The rest of this paper is organized as follows. Section 2 describes the background materials of this paper. Section 3 proposes our approach. Section 4 compares the proposed approach with previous approaches. Finally, concluding remarks are made in Section 5.

2. Background

This section first gives the system model used in this paper. Then, the mobile multicast is briefly introduced. Last, previous work is reviewed.

2.1 System Model

The CDMA cellular system considered in this paper is shown in Fig. 1. It contains four major components: mobile node (MN), radio access network (RAN), interconnection network, and Mobile IP network. The MN acts as a *multicast participant* (MP), which interacts with a RAN to obtain radio resources for performing multicast application services. The RAN provides the data transmission across air interface. The interconnection network is used to relay unicast or multicast packets between RANs and the Mobile IP network. With the Mobile IP network, it is divided into several foreign networks and has the following

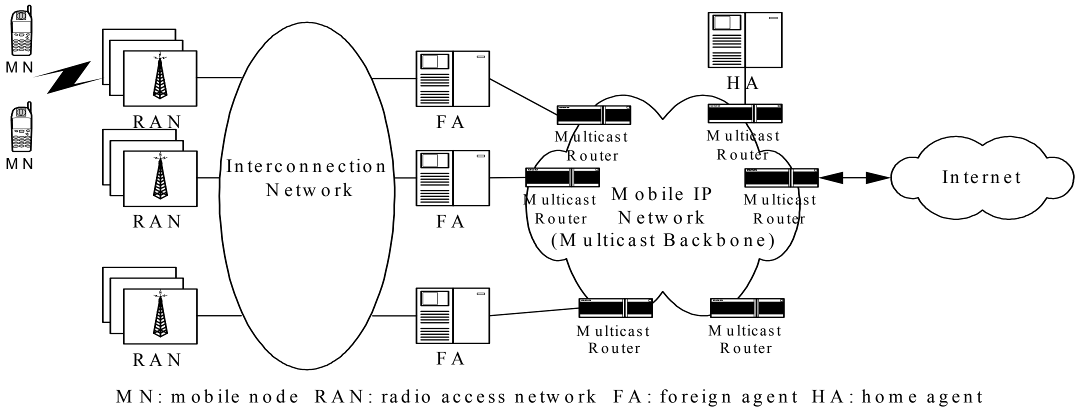

Fig. 1. Wireless mobile system model.

main entities: foreign agent (FA), home agent (HA), and intermediate multicast router. In each foreign network, a FA is allocated to be as the default multicast router for the MPs within its serving area. The FA also cooperates with the HA to support the Mobile IP functionality [1]. Intermediate multicast routers deliver multicast packets within the Mobile IP network.

2.2 Mobile Multicast

As described in section 1, the IETF Mobile IP working group has proposed two basic methods: remote subscription (MIP-RS) and bi-directional tunneling (MIP-BT) to support multicast in mobile environment. MIP-RS requires a MP to re-subscribe the multicast group whenever it moves from a foreign network to another (hands off between foreign networks). In the new foreign network, if no other group participants exist, a multicast path from the new corresponding FA is grafted on the current multicast tree. In the old foreign network, if no other group participants exist after the MP leaves, the multicast path for the old corresponding FA is pruned from the current multicast tree. The grafting and pruning of a multicast path are to reconstruct a new multicast tree for reflecting the new locations of MPs. With MIP-BT, a MP subscribes a multicast group through its managing HA. When a MP is away from its home network, the multicast tree is not changed as the MP moves. However, a multicast packet to the MP must be routed to the MP's HA, and then the HA encapsulates the packet destined to the MP by tunneling.

2.3 Previous Work

Many mobile multicast approaches have been proposed. The approach of [10] proposed a mobile multicast protocol, called MoM. A key feature of MoM is the use of designated multicast service providers (DMSPs). Each FA appoints one HA as its DMSP. The DMSP forwards only one multicast packet to its responsible FA. Although MoM solves the tunnel convergence problem, it does not promise no packet losses while a MP hands off to a new foreign network [4]. For solving packet losses in MoM, [11] presented an enhanced approach. The approach temporarily saves delivered multicast packets in the buffer of a DMSP. Each FA can requests lost multicast packets from its corresponding DMSP.

The approach of [3] presented a range-based mobile multicast (RBMoM) protocol. The basic idea of RBMoM makes use of the service range to limit the multicast path length and control the frequency of multicast tree reconstruction.

The approach of [4] proposed a MIP-RS based multicast protocol, called mobile multicast with routing optimization (MMROP). The main feature of the protocol is to solve the problem of packet losses due to out-of-sync.

The approach of [5] utilized anycast technology to support mobile multicast. Each MP uses anycast to automatically connect a nearest available multicast agent (FA or HA).

The approaches of [6, 7] introduce multicast agents for mobile multicast. They focus on how to reduce multicast path length and the amount of duplicate multicast packets.

The approach of [8] mainly discusses the issue of multicast reliability due to channel error. It divides a multicast path into several repair segments. For each repair segment, the approach of [8] adopts different reliable transmission mechanisms.

3. The Proposed Approach

This section presents a MIP-RS based approach for CDMA cellular systems.

3.1 Multicast Delivery Disruption

In the proposed approach, the basic idea for reducing the multicast delivery disruption is to organize a virtual multicast tree. The virtual multicast tree consists of all the possible multicast paths of a multicast group. Based on the virtual multicast

(a)

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● Selecting a node form the Mobile IP network as the core
  instead of the source of a multicast group.
● Finding the shortest path from the core to each FA in the
  Mobile IP network.
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(b)

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● Finding out the participated FAs in which MPs are located
● For each participated FA
      Sending a path-established message towards the core
      following the shortest route recorded in the FA.
  End For
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Fig. 2. The algorithm for constructing a multicast tree. (a) A virtual multicast tree. (b) A real multicast tree.

tree, each multicast group can quickly construct its initial multicast tree according to the locations of all existing MPs. Thereafter, while a MP hands off to a new foreign network, the new real multicast tree can be also quickly reconstructed from the virtual multicast tree. The feasibility of this basic idea is elaborated as follows.

The mobile multicast in this paper is studied under a CDMA cellular system. The CDMA cellular system belongs to one kind of wireless mobile systems. Usually, the source of a multicast group in the wireless mobile system is fixedly configured as one or more multicast application servers in the system. This can mean that the source mobility is usually not considered in a wireless multicast group. In [2, 3], they also mentioned that the source mobility is not suitable to be handled by using MIP-RS. Based on MIP-RS, the mobile multicast tree is constructed by the *participated FAs*. (the FAs with located MPs). Fortunately, as shown in Fig. 1, all FAs in a CDMA cellular system are located within a Mobile IP backbone network, not Internet. Unlike Internet multicast, the location information about all the FAs possibly participated in a wireless multicast can be known in advance. For a wireless multicast group, it is possible to off-line find out all the shortest paths from the source to all the FAs. These shortest paths consist of the virtual multicast tree of a wireless multicast group. The detailed algorithm is given in Fig. 2(a).

As shown in Fig. 2(a), the virtual multicast tree is constructed based on the CBT protocol [12]. Note that Fig. 2(a) only traces the multicast path information of all the possibly participated FAs. The virtual multicast tree exists based on the logical point of view. In practice, the virtual multicast tree cannot deliver any multicast packets to a MP. It is used to assist a wireless multicast group to quickly construct its real multicast tree (Fig. 2(b)). As shown in Fig. 2(b), the real multicast tree is constructed based on the source demand routing. Each participated FA uses its recorded shortest path information (Fig. 2(a)) to establish its multicast path with the core. Here, the messages of path establishment are sent from participated FAs to the core. Since the participated FAs and the core are not across Internet (they are within the Mobile IP backbone), the using of source demand routing does not introduce the security problem. On the other hand, the virtual multicast tree also gives an advantage in reducing the multicast delivery disruption due to a handoff. While a MP hands off to a new foreign network without existing MPs, the corresponding new FA is not necessary to find its shortest path with the core since the information of the shortest path is already recorded in the FA (see Fig. 2(a)).

The proposed approach first predefines the multicast paths of all possibly participated FAs. While constructing a multicast tree, it is not required to find the multicast paths of participated FAs. Similarly, when an MP visits a new foreign network due to a handoff, the multicast path of the corresponding new FA is neither found. Compared to the traditional MIP-RS based approaches, the proposed approach can reduce $O(\sum_{i=1}^{n_{FAs}} p_{FA_i})$ and $O(p_{FA_i})$ for the time of multicast tree construction and that of multicast delivery disruption, respectively, where p_{FA_i} is the number of connection paths between the core and FA_i, and n_{FAs} is the number of participated FAs in a wireless multicast group. The above two time reduction complexities are derived under the condition that each participated FA knows the information about all its connection paths with the core. In such condition, the traditional MIP-RS based approaches can easily find the shortest path of a participated FA by selecting the one with the lease cost among all its connection paths. Here, the time complexity of selecting the shortest path is $O(p_{FA_i})$.

If the information of connection paths cannot be known by each participated FA, Dijkstra’s algorithm is performed for finding the shortest path of each participated FA. In such case, the above two time reduction complexities are dominated by Dijkstra’s algorithm and become as $O(n^2)$, where n is the number of nodes in the Mobile IP network since FAs and the core are located within the Mobile IP network (see Fig. (1)).

3.2 Packet Losses

To solve the packet losses due to a handoff, the proposed approach utilizes soft handoff to make two multicast receiving pipes. The soft handoff is an

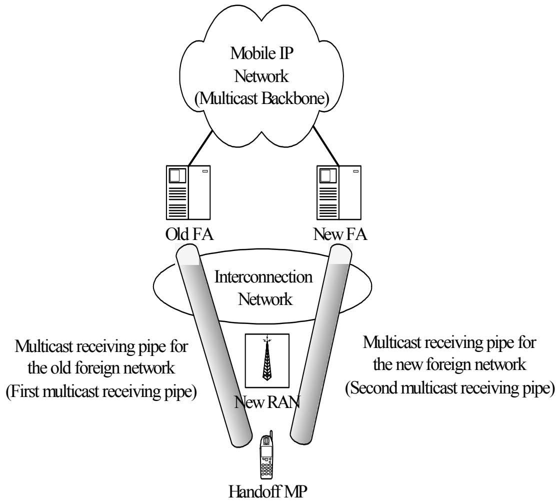

Fig. 3. Multicast receiving pipes of a handoff MP.

intrinsic function of a CDMA cellular system. It enables a handoff MP to simultaneously connect with its old and new foreign networks for a period of time. Similar to [4], the detection of packet losses is done by comparing the two multicast receiving sequences recorded on the old and new FAs of the handoff MP. Based on the detection result, the handoff MP takes appropriate actions to recover the lost multicast packets, described as follows.

- If the multicast receiving sequence of the new FA is behind (less than or equal to) that of the old FA, the handoff MP only needs to connect with the new foreign network since no multicast packets are lost in the old foreign network. As for the FA in the new foreign network, if it has not a multicast path with the current multicast tree, the previous MIP-RS based approaches need to take time for finding the shortest path from the core to the new FA. During the time, the handoff MP cannot receive any multicast packets. In contrast to the proposed approach, it predefines all the possible multicast paths (see section 3.1); therefore, it is not required to find the shortest path of the new FA. The connectivity between the handoff MP and the new foreign network can be completed immediately.

- Conversely, if the multicast receiving sequence of the new FA is ahead (greater than) that of the old FA, the out-of-problem is introduced. In such case, the handoff MP uses the soft handoff to initiate two multicast receiving pipes to connect with the old and new FA, as shown in Fig. 3. By the first multicast receiving pipe, the handoff MP can retrieve its lost multicast packets from the old FA. Unlike traditional soft handoff [9], the first multicast receiving pipe does not pass through the old RAN, which logically connects the handoff MP, new RAN, and old FA. Here, the reason why the new RAN can logically connect with the old FA is as follows. As shown in Fig. 1, there is an interconnection network to connect RANs with FAs. From the logic point of view, there exists at least one communication path between a RAN and a FA. Based on the above description, the time of maintaining the first multicast receiving pipe is not constrained by the strength of the pilot signal from the old RAN. It is determined by the time of receiving the lost multicast packets from the old foreign network, which is estimated as $\frac{seq_{new} - seq_{old}}{d_{old\_FA}}$, where seq_{old} and seq_{new} are the multicast receiving sequences in the old and new foreign networks, respectively, and d_{old_FA} is the delay for delivering a multicast packet from the core, along the old FA's multicast path, and finally to the handoff MP. During the maintenance time, the new FA can continuously transmit its received multicast packets to the handoff MP. After the maintenance time ends, the old multicast receiving pipe of the handoff MP is cut off.

Compared to the approach of [4], the proposed approach is not required to store the lost multicast packets in a FA's buffer. In addition, the proposed approach also allows the handoff MP to receive new multicast packets while recovering the lost multicast packets. However, the handoff MP in the proposed approach needs to equip a buffer for making the correct receiving order. If the handoff MP does not receive all its lost multicast packets, the multicast packets received from the new FA are kept in its buffer. Using the buffer, the handoff MP can receive multicast packets in the correct order. Here, the maximum size of the handoff MP's buffer is dependent on the maintenance time of the first multicast receiving pipe and the number of multicast packets newly received by the new FA during the time.

4 Comparison

The main contribution of the proposed approach is to improve the disadvantages of traditional MIP-RS From section 2.3, we know that only [4] concerns the same problem with our paper. To quantify the effectiveness of the proposed approach over the approach of [4], simulation experiments are performed as follows.

4.1 Simulation Setup

The simulation model used in this paper is similar to those used in [13]. Based on the simulation model, 20 random graphs are generated from a 25*25 coordinate grid to be the topologies of the Mobile IP network, respectively. Then, 20 different multicast trees are constructed from a generated random graph using the CBT algorithm. The number of MPs in the serving area of a FA is varied between 0 and 50. Next, each simulation run is based on a multicast tree to perform join, leave, and handoff operations for 1000 units of time. To understand the effect of different multicast traffic on the approach of [4] and that on the proposed approach, the operations (join, leave, and handoff) in a simulation run are appropriately arranged to generate 4 different traffic intensities (Erlangs): 10, 25, 50, and 100, respectively.

4.2 Simulation Results

4.2.1 Multicast Tree Construction

With the assistance of the virtual multicast tree, the proposed approach is not required to find the shortest path of each participated FA while constructing an initial multicast tree. Compared to the approach of [4], the proposed approach can significantly reduce the cost of multicast tree construction. The cost is represented as the number of hops involved for constructing a multicast tree. As shown in Fig. 4, the reduction of multicast tree construction is independent of the variance of the multicast traffic intensity.

4.2.2 Multicast Delivery Disruption

While a handoff, the approach of [4] needs to find the shortest path of the newly visited FA if the FA is not involved in the multicast tree. The finding of the shortest path disrupts the multicast delivery to the handoff MP for a period of time. Moreover, for recovering lost multicast packets, there is a tunneling transmission in the approach of [4] to send the lost multicast packets. This tunneling transmission blocks the handoff MP to receive multicast packets from the new foreign network for a period of time. In contrast to the proposed approach, it is not required to find the shortest path of the new FA. In addition, the proposed approach does not block the handoff MP to receive the new multicast packets while recovering lost multicast packets (see sections 3.1 and 3.2). Compared to the approach of [4], the proposed approach does not incur the time for finding the shortest path and the tunneling transmission delay in the multicast delivery disruption due to a handoff. The magnitudes of these two reduction factors are dependent on the distance between the new FA and the core and the distance between the old and new FAs, respectively. The above two distances are not affected by the multicast traffic intensity, but the first distance is related to the height of a multicast tree. As shown in Fig. 5, the average reduction of multicast delivery disruption is irrelevant to the multicast traffic intensity, but it is related to the average height of a multicast tree.

4.2.3 Buffer Requirement

While a handoff, some multicast packets are lost due to out-of-sync. To solve this problem, the approach of [4] need to equip a buffer at a FA for collecting the lost multicast packets. Before receiving all the lost multicast packets, the handoff MP in the approach of [4] cannot receive multicast packets from the new foreign network. However, the approach of [4] does not describe how to avoid the handoff MP losing the multicast packets delivered from the new FA. In contrast to the proposed approach, the soft handoff is utilized to make two multicast receiving pipes for receiving the lost and new multicast packets in the correct order. The buffer is not required to be equipped at a FA for receiving the lost multicast packets. In addition, while recovering the missing multicast packets, the proposed approach still allows the handoff MP to simultaneously receive new multicast packets delivered from the new FA. However, the handoff MN needs to equip a buffer to rectify the receiving order of lost and new multicast packets (see section 3.2). As shown in Fig. 6, we can see that the buffer of a handoff MP is small. The proposed approach can reduce the buffer requirement at least 83% ($1-\frac{\text{the buffer requirement for the proposed approach}}{\text{the buffer requirement for the approach of [4]}}$) by comparing with the approach of [4].

5 Conclusion

This paper has proposed a new MIP-RS based approach for efficiently supporting multicast in CDMA cellular systems. The proposed approach off-line predefines all the possible multicast paths of a multicast tree. When a handoff occurs, the proposed approach is not required to take time to find the new multicast path. Compared to the approach of [4], the improvement of the multicast delivery disruption has been quantified in Fig. 6. For the packet losses due to a handoff, the proposed approach utilizes the soft handoff to make a handoff MP simultaneously receive multicast packets from the old and new foreign networks in the correct order. Unlike the approach of [4], the proposed approach enables the handoff MP to receive new multicast packets while recovering lost multicast packets.

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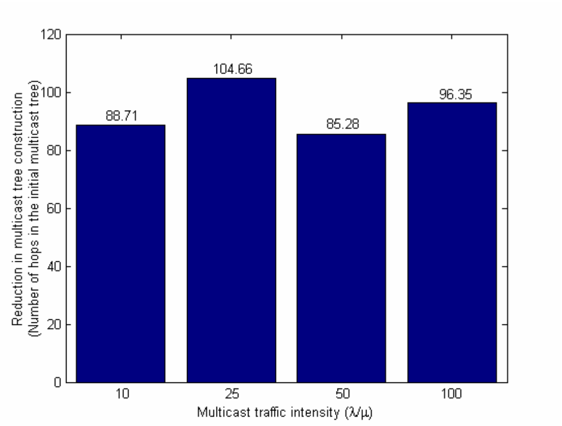

Fig. 4. Average reduction in multicast tree construction.

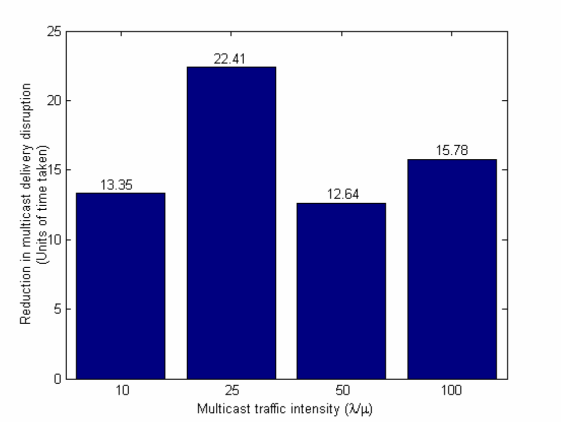

Fig. 5. Average reduction in multicast delivery disruption.

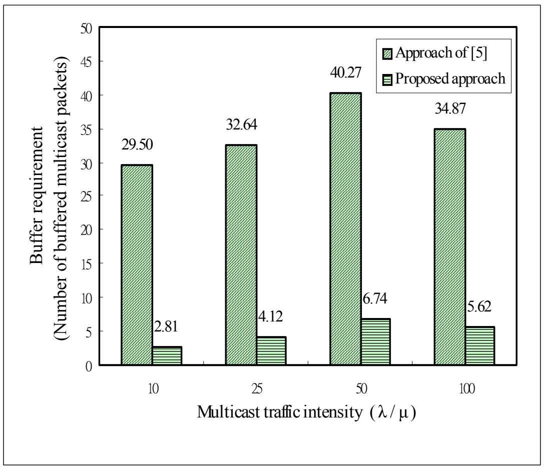

Fig. 6. Comparison of average buffer requirements.

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