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An Active Multicasting Mechanism for Mobile Hosts in Wireless Networking Environments*

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SUMMARY To support mobile multicasting in wireless networks, we present a new active multicasting mechanism which makes use of the state characteristic of multicast agent. In this mechanism, a multicast agent just locates the position for roaming hosts when it does not forward multicast packets. Upon reception of multicast packets, the multicast agent adjusts the service range to achieve an appropriate balance between routing efficiency and the overhead of multicast tree reconstruction. Therefore, a lot of unnecessary tree reconstructions are eliminated during the time when none multicast packet is transferred and multicast delivery path is near optimal because of the limited service range of multicast agent in the active state. To justify the effectiveness of our proposed scheme, we develop an analytical model to evaluate the signaling overhead. Our performance analysis shows that the proposed scheme can significantly reduce the system overhead and multicast routing is near optimal. The other important contribution is the novel analytical approach in evaluating the performance of mobile multicast routing protocol.
key words: *mobile multicast, active multicasting mechanism, wireless network, routing*

1. Introduction

Mobile IP [1] provides an efficient and scalable mechanism for host mobility in the wireless network. However, Mobile IP would result in a high signaling cost to update the location of a mobile host (MH) if it performs handoff frequently. In order to minimize signaling cost, Cellular IP [2], [10], [14] adopts IP paging mechanism to eliminate unnecessary binding update messages when a MH is idle. Cellular IP is capable of distinguishing active and idle MHs and tracks the location of idle hosts in an approximate and efficient manner. Therefore, MHs do not have to update their location after each handoff. This reduces air interface traffic and extends battery life. When packets need to be sent to an idle MH, the host is paged using a limited scope broadcast and in-band signaling. A MH becomes active upon reception of a paging packet, and then starts updating its location until it moves to an idle state again.

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Of course, in wireless mobile networking environments, users still require particular network applications, such as the dissemination of textual information, multipoint communications, and distributed systems functions, for which a multicast mechanism is more efficient.

The well-known mobile multicasting schemes are the remote subscription scheme and the bidirectional tunneling scheme [3], [4], both of which are proposed to support mobile multicasting routing by IETF Mobile IP Working Group. The remote subscription scheme (RS), whenever a MH moves to a new foreign network, always re-subscribes to its desired multicast groups. This scheme is simple and has the advantage of delivering the multicast data on the shortest path from source to receivers. However, frequent handoff brings about the overhead of reconstructing multicast tree since the number of multicast tree reconstruction is dependent on the frequency of host's handoff. In the bidirectional tunneling scheme (BT), MHs send and receive all multicast data using the unicast Mobile IP tunneling service from their home agent (HA). This scheme does not reconstruct multicast tree and so minimizes the cost of multicast tree maintenance. However the scheme handles mobile multicast just like using multiple unicast transmissions to simulate one multicast transmission, which is a waste of valuable bandwidth resource. In addition, BT has the tunnel convergence problem.

To solve the tunnel convergence problem of bidirectional tunneling, the MoM [6] scheme uses the Designated Multicast Service Provider (DMSP) and avoids duplicate data being tunneled to the common foreign agent (FA). This scheme has the advantage of reducing the multicast traffic. However, as the number of host's handoff is increased, this scheme requires frequent DMSP's handoff and register processing. What's more, it still has the problem of long routing path.

The RBMoM [7] scheme is a hybrid scheme of the remote subscription and the bidirectional tunneling. It introduces the multicast agent, called MHA. RBMOM tries to tradeoff between the shortest data delivery path length and the frequency of multicast tree reconstructions by controlling the service range of a MHA. The service range is determined by the maximum hop distance value that the MHA allows. If the FA of the new foreign network that a MH moves to is within the service range of a MHA, the MHA is responsible for tunneling the multicast packets to the FA of the new foreign network. When a MH moves to a new foreign network which is out of the MHA's service range, it requests the

FA of current network to join the multicast tree and serves as a new MHA for the MH. The service range restricts the maximum length of the tunnel between a MH and its MHA.

The RBMOM protocol, however, fixes the service range of MHA without considering whether the MH is receiving multicast data or not. If a MH has not received multicast data for a long time, a small service range will cause a number of unnecessary tree reconstructions. In this paper, we propose an active multicasting mechanism for mobile hosts based on dynamic service range, which utilizes the state characteristic of multicast agent. When a multicast agent has not forwarded multicast packet for a certain period of time, it is changed to idle state. Under such state, the multicast agent just locates the position for roaming hosts and none reconstructing operation is executed since no multicast packet is transferred. Until the multicast agent receives a multicast packet, it becomes active and the same mechanism as that in RBMoM is used to ensure that the routing path is near optimal. Therefore, the signaling overhead is minimized by eliminating unnecessary join and prune operations and multicast routing is also efficient.

This paper is organized as follows. Section 2 presents the detailed procedures of the proposed scheme. In Sect. 3, we develop an analytical model to derive the overhead functions of tree reconstructions and data delivery for mobile multicasting algorithms. The performance of the proposed scheme is demonstrated in Sect. 4. Section 5 summarizes the paper.

2. Active Multicasting Mechanism for Mobile Hosts

If we do not reconstruct multicast tree when MH moves among networks, the routing path is far from being optimal. But tree reconstruction may also lay heavy load on the network since a lot of processing and transmitting overhead is produced. Thus, most mobile multicasting schemes intend to enhance performance by well trading off between the shortest delivery path and the frequency of multicast tree reconfiguration without inducing more complexity. Can we reduce reconstruction overhead greatly and at the same time do not increase any multicast delivery cost? As we know, Cellular IP reduces unicast signaling cost greatly by adopting IP paging mechanism to eliminate unnecessary binding update messages when a MH is idle. We borrow the idea from Cellular IP that employs state characteristic of the network. Since multicast agent does not receive or send multicast packet all the time, none multicast delivery cost can be saved if we reconstruct the multicast tree due to host mobility during the time when multicast agent has not forwarded any multicast data. Therefore, the proposed scheme distinguishes the idle mode of multicast agent from active mode. If a multicast agent has not forwarded multicast packets for a certain period of time, it becomes idle, during which it is unnecessary to reconfigure the multicast tree. The only thing for the multicast agent is to locate the position for the roaming hosts in its affiliated networks. It seems that the multicast agent acts as an anchor which tracks the location for roaming MHs and thus it is called Anchor Multicast Agent (AMA). Until the AMA receives multicast packets, it becomes active. Under such state, the AMA controls the service range to tradeoff between the shortest delivery path and the frequency of the multicast tree reconfiguration. By restricting the service range when the AMA forwards multicast packets, the packet delivery path can be limited. Therefore, the system overhead is minimized by eliminating unnecessary reconstructing operations and offering near optimal routing path.

However, the first arrival multicast packet will be transmitted in AMA's idle state before it completes the state update. To reduce the delivery delay in idle state, the service range of AMA in idle state is restricted to an allowed maximum value.

2.1 Data Structures

Figure 1 illustrates the data structures used by the proposed scheme. Each AMA maintains a *state table* to record the group identification, the active timer value, current state and its service range. In addition, there are two lists in AMA, the *MH list* and the *forwarding list*. The *MH list* records the mobile hosts to be served and their locations are recorded in the *forwarding list*. The *forwarding list* is a set of FAs to which AMA forwards multicast packets by the unicast tunneling. Each FA maintains a *visitor information table* which records the group identification, the multicast agent which is responsible for forwarding multicast packets to current network for the specific group, the visitors and when these visitors expire. Each MH maintains a *group information table* to keep track of the group ID, the multicast agent and its current location.

2.2 MH's Arrival at a New Foreign Network

When a MH moves to a foreign network and requests a multicast group membership, it registers with the FA of the new foreign network. To avoid problems incurred by DMSP handoff, such as data loss and extra processing overhead, the oldest multicast agent selection policy is used. So if the FA of the foreign network has been served by an AMA (i.e., the

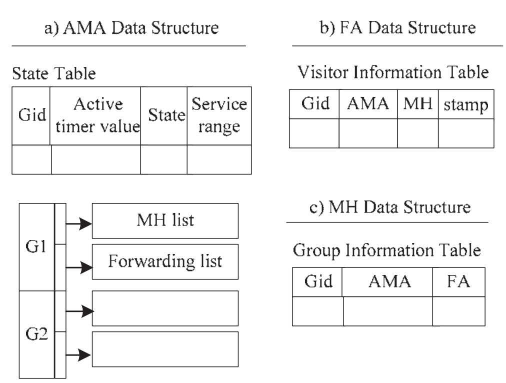

Fig. 1 Data structure of AMA, FA and MH.

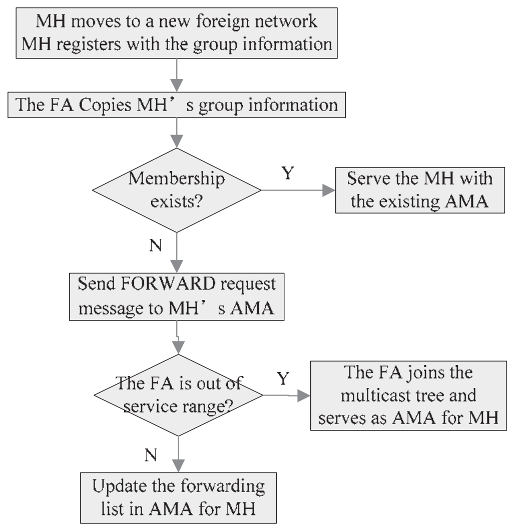

Fig. 2 MH moves to a new foreign network.

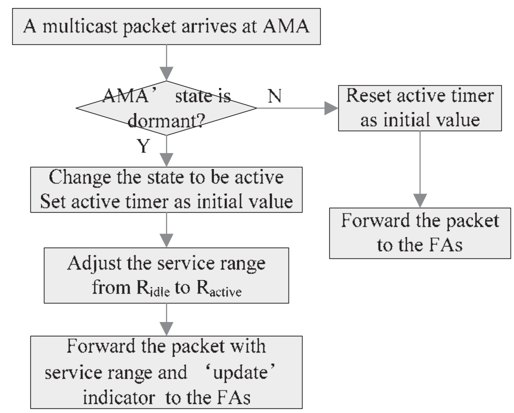

Fig. 3 Multicast packets arrive at an AMA.

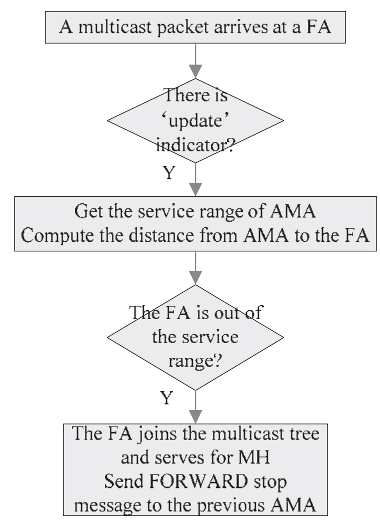

Fig. 4 Multicast packets arrive at a FA.

MH is not the first member of the foreign network), the MH may continue to receive multicast packets since the FA uses local multicast to deliver the packets to all group members in its network. If the MH is the first member of the foreign network, but the FA has already been a tree node. Under this situation, the FA will add a new entry for the MH and deliver multicast packets in native multicast over its local link. Otherwise, the FA requests the MH's AMA to forward multicast packets. By computing the hop distance that the message from the FA travels, the AMA checks if the FA is within its service range. If the AMA's state is idle, its service range is very large and it is not so easy for the MH to move out of the range. Thus, the reconstruction operations are decreased greatly. At the same time, the service range in AMA's active state is set small in order to get an optimal routing path for packet delivery. If the FA is still within its service range, the AMA is responsible for tunneling multicast packets to the FA of the foreign network where the MH resides. Otherwise, the FA should join the multicast tree and becomes a new AMA serving for the MH.

2.3 Expiration

When active timer expires, AMA becomes idle and adjusts the service range accordingly. The service range is much bigger in idle state than that in active state in order to reduce unnecessary reconstruction operations.

If a MH expires at a foreign network, the FA deletes the corresponding entry from the *visitor information table* and checks if the group that the MH subscribes to is null. If so, the FA should send a *forwarding stop* message to the group's AMA.

2.4 Multicast Packets' Arrival at AMA

Upon reception of a multicast packet, the AMA resets its active timer to the initial value and forwards the packet to the FAs recorded in the *forwarding list* if it is in active state. Otherwise, the AMA is activated. It resets the active timer and adjusts the service range to trade off between the shortest delivery path and the frequency of the multicast tree reconfiguration. The multicast packet is extended by encapsulating the service range of the AMA and an 'update' indicator, and then tunneled to the FAs recorded in the *forwarding list*. The FA that receives the 'update' indicator should re-examine whether it is out of the service range.

2.5 Multicast Packets' Arrival at FA

When a multicast packet arrives at the foreign network where the MH resides, the FA decapsulates the packet, and then checks whether an '*update*' indicator exists or not. If the '*update*' indicator is found, the FA gets the service range of the AMA and computes the hop distance to the AMA. The distance is calculated by the hops that the packet from the AMA travels. If it is out of the service range, the FA should join the multicast tree and becomes an AMA serving for the MH. Meanwhile, the MH sends *forwarding stop message* to the previous AMA. If there is no '*update*' indicator, the AMA is still responsible for tunneling packets to the FA and the FA then uses local multicast to deliver the packets to all group members in its network.

2.6 Adaptive Group Management

The AMA uses *Membership Query* messages to request for host membership status. In active state, the AMA sends a *Membership Query* at every regular interval in order to identify whether any members are still interested in the multicast group. However, in idle state, since the AMA does not provide any multicast service, the interval of *Membership Query* messages is prolonged. Upon reception of a *Membership Query*, the MH will send back a *Membership Report* message in order to let the AMA know of the membership status. This ensures less message exchange taking place and therefore reduces network overload.

3. Analytical Model

The overhead of tree reconstruction and multicast routing efficiency are the most important factors that affect the performance of mobile multicasting algorithms. In this section, we develop an analytical model to derive the overhead functions of the tree reconstruction and multicast data delivery for RBMoM and the proposed algorithm, respectively. The proposed active multicasting mechanism for mobile hosts is named as DRBMoM (dynamic service range based mobile multicast) since the service range of multicast agent will change according to its state. We will not consider the DMSP handoff overhead since old multicast agent selection policy is used and DMSP handoff problem is avoided.

We define the following parameters for our analysis in the rest of this paper.

- T: The time interval during which the overhead of tree reconstruction and data delivery of RBMoM and DRBMoM will be compared.
- W: The number of nodes. Each node represents a subnet or a FA in the subnet.
- v: The handoff rate of mobile host in unit time.
- N: The number of MH's handoff during T (or the number of nodes that MH crosses over during T).
- M: The number of multicast packet arriving at AMA during T.
- λ: The multicast packet arrival rate. (To minimize the signaling cost, we factor in the fact that mobile users will not actively receive multicast packets much of the time.)
- R: The service range of multicast agent.
- R_{MHA}: The service range of MHA in the RBMoM scheme.
- U: The number of initial multicast nodes (routers) in the network.
- q: The probability that the node where the MH resides is a multicast router.
- $F(j,R)$: The number of tree reconstructions after MH handoffs j times on condition that the service range of multicast agent is R.

3.1 Tree Reconstruction Overhead

In the RBMoM scheme, if a MH moves out of the service range of its MHA, the FA of the foreign network where the MH resides will join the multicast tree without considering whether the MH is receiving multicast packets or not. If the FA has already joined the multicast group, tree reconstruction operation is replaced by MHA's handoff. Therefore, the FA of the foreign network determines whether to join the multicast tree by computing the hop distance to the MH's MHA and checking if membership exists already in the current network after each *movement* (a *movement* represents a handoff of MH).

We denote $H(j,m)$ as the number of tree reconstructions after j *movements* on condition that the latest DMSP handoff happened at the mth *movement*, which means the FAs of the subnets that the MH has crossed over are not multicast nodes during the latter $j-m$ *movements*. So $F(j,R)$ can be obtained as follows:

$$F(j,R) = \sum_{m=0}^{j} H(j,m) * P\{LastDMSPhandoff = m\} \quad (1)$$

Where $P\{LastDMSPhandoff = m\}$ is the probability that the latest DMSP handoff happened at the mth *movement* during j *movements*. Whether the FA of the subnet that the MH moves to is a multicast agent is an independent event. So

$$P\{LastDMSPhandoff = m\} = \begin{cases} q(1-q)^{j-m}, & \text{if } 0 < m \le j \\ (1-q)^{j}, & \text{if } m = 0. \end{cases} \quad (2)$$

From (2), (1) can be rewritten as follows:

$$F(j,R) = \begin{cases} \sum_{m=1}^{j} H(j,m) * q(1-q)^{j-m}, & \text{if } 1 \le m \le j \\ H(j,0) * (1-q)^{j}, & \text{if } m = 0. \end{cases} \quad (3)$$

We can use iterative method to compute $H(j,m)$. There is no multicast agent in the subnets where the MH resides during the latter $j-m$ *movements*. Let G denote the number of tree reconstructions under such condition. Then

$$H(j,m) = \begin{cases} F(m-1,R) + G(j-m), & \text{if } 1 \le m < j \\ G(j), & \text{if } m = 0. \end{cases} \quad (4)$$

In (4), $F(m-1,R)$ is the number of reconstructions during the former $m-1$ *movements*. $G(j-m)$ is the number of reconstructions during the latter $j-m$ *movements* in which there is no multicast agent encountered by MH. So (3) can be further rewritten as follows:

$$F(j,R) = \begin{cases} \sum_{m=1}^{j} [F(m-1,R) + G(j-m)] * q(1-q)^{j-m}, & \text{if } 1 \le m \le j \\ G(j) * (1-q)^{j}, & \text{if } m = 0. \end{cases} \quad (5)$$

Let HN denote the total number of *movements* and RN denote the reconstruction times. Then G can be expressed as follows:

$$G(m) = \sum_{k=0}^{m} kP\{HN = m, RN = k\}. \quad (6)$$

The maximal number of tree reconstructions is

$$maxReconstructNum = \left\lceil \frac{m+1}{R+1} \right\rceil - 1. \quad (7)$$

From (7), (6) can be rewritten as

$$G(m) = \sum_{k=0}^{maxReconstructNum} kP\{HN = m, RN = k\} = \sum_{k=0}^{\lceil \frac{m+1}{R+1} \rceil - 1} kP\{HN = m, RN = k\} \quad (8)$$

From (8), (5) can be rewritten as follows:

$$F(j, R) = \begin{cases} \sum_{m=1}^{j} \left[F(m-1, R) + \sum_{k=0}^{\lceil \frac{j-m+1}{R+1} \rceil - 1} kP\{HN = j-m, RN = k\} \right] * q(1-q)^{j-m}, & \text{if } 1 \le m \le j \\ \sum_{k=0}^{\lceil \frac{j+1}{R+1} \rceil - 1} kP\{HN = j, RN = k\} * (1-q)^{j}, & \text{if } m = 0. \end{cases} \quad (9)$$

We propose an iterative algorithm to obtain $P\{HN = m, RN = k\}$. Because one time of reconstruction needs at least $R+1$ *movements*, m *movements* can be divided into the former $R+1$ *movements* and the latter $m-(R+1)$ *movements*. During the former $R+1$ *movements*, if a MH moves forward all the way, reconstruction will happen once and the distance to the multicast agent becomes zero. Otherwise, reconstruction will not happen and the distance to the multicast agent is denoted as D. In order to get the reconstruction times we should add this distance to the latter $m-(R+1)$ *movements*.

If a MH moves forward all the way, the distance to the multicast agent is $R+1$ after $R+1$ *movements*. If MH moves backward once, the distance becomes $R-1$. If MH moves backward twice, the distance becomes $R-3$. Thus, the probable values of D are $R-1$, $R-3 \ldots (R \bmod 2)+1$. Such set is denoted as MR. Let P_{iF}^{k} denote the probability that a MH moves forward at the ith *movement* on condition that the distance to the multicast agent is k after the former $i-1$ *movements*. After this *movement*, the distance becomes $k+1$. Similarly, let P_{iB}^{k} denote the probability that a MH moves backward at the ith *movement* on condition that the distance to the multicast agent is k after the former $i-1$ *movements*. After this *movement*, the distance becomes $k-1$. For example, when R equals 2, if the number of reconstructions is zero after 3 *movements*, D can equal one. The probability is calculated as follows:

$$P\{HN=3, RN=0, D=1\} = P_{1F}^{0} P_{2B}^{1} P_{3F}^{0} + P_{1F}^{0} P_{2F}^{1} P_{3B}^{2} \quad (10)$$

So, we can get

$$P\{HN = R+1, RN = 0\} = \sum_{l \in MR} P\{HN = R+1, RN = 0, D = l\}. \quad (11)$$

$$P\{HN = R+1, RN = 1\} = P_{1F}^{0} P_{2F}^{1} \cdots P_{iF}^{i-1} \cdots P_{(R+1)F}^{R} \quad (12)$$

Note that the interconnection between two subnets means that a MH can moves freely between them. Let the nodes and edges represent subnets and interconnections between subnets. The probability of moving forward or backward depends on the degree of nodes such that

$$P_{iB}^{k} = \begin{cases} \frac{1}{d(i)}, & \text{if } i > 1 \\ 0, & \text{if } i = 1. \end{cases} \quad (13)$$

$$P_{iF}^{k} = 1 - P_{iB}^{k}. \quad (14)$$

Where $d(i)$ is the degree of node i, i. e., the number of edges that connect to the node. When a MH moves out from the multicast agent, it must move forward.

Thus, we have

$$P\{HN = m, RN = k\} = \begin{cases} 1, & \text{if } k = 0 \text{ and } m < R+1 \\ 0, & \text{if } k > maxReconstructNum \text{ or } k > 0 \text{ and } m < R+1 \\ \sum_{l \in MR} P\{HN = R+1, RN = 0, D = l\} \cdot P\{HN = m-(R+1)+l, RN = 0\}, & \text{if } k = 0 \text{ and } m \ge R+1 \\ \sum_{l \in MR} P\{HN = R+1, RN = 0, D = l\} \cdot P\{HN = m-(R+1)+l, RN = k\} + P\{HN = R+1, RN = 1\} \cdot P\{HN = m-(R+1), RN = k-1\}, & \text{if } 0 < k \le maxReconstructNum \end{cases} \quad (15)$$

The total number of *movements* during T is

$$N = vT \quad (16)$$

From (1) and (13), the function of the number of reconstructions in the RBMoM scheme during T can be obtained as follows, which can be worked out through Eqs. (9) and (15).

$$\Pi_{RBMoM} = F(N, R_{MHA}) \quad (17)$$

In order to evaluate the overhead in the DRBMoM scheme, we define the additional parameters:

- t_i: The time interval between the ith multicast packet arrival and the $i+1$th multicast packet arrival.
- $G(t_i)$: The number of *movements* during t_i.
- $Q(t_i)$: The number of *movements* when AMA is in active state during t_i.
- $S(t_i)$: The number of *movements* when AMA is in idle state during t_i.

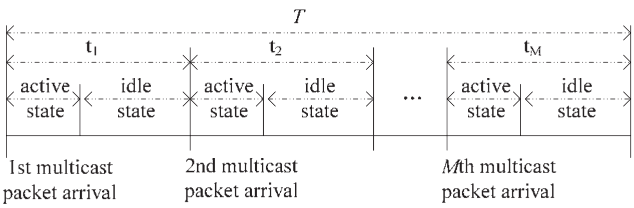

Fig. 5 The state transition diagram of AMA.

- T_r: The time threshold during which AMA has not received any multicast packet, it becomes idle.
- R_{active}: The service range of AMA in active state.
- R_{idle}: The service range of AMA in idle state.

The overhead of tree reconstruction in DRBMoM is the sum of the overhead of reconstruction in active state and that in idle state. Figure 5 is the state transition diagram for AMA.

The number of multicast packet arrival is

$$M = \lambda T \tag{18}$$

The number of *movements* during t_i is

$$G(t_i) = \frac{v}{\lambda} \tag{19}$$

The number of *movements* when AMA is in active state during t_i is

$$Q(t_i) = vT_r \tag{20}$$

From (19) and (20), we can obtain the number of *movements* when AMA is in idle state during t_i as follows:

$$S(t_i) = G(t_i) - Q(t_i) \tag{21}$$

When AMA is in idle state, the multicast packet arrival may cause tree reconstructing operation if the distance from a MH to its AMA (denoted as $Remaining(S(t_i))$) is bigger than R_{active}. The value of $Remaining(S(t_i))$ may be $0, 1, 2, \ldots R_{idle}$ with equal probability. For simplicity, we just compute the mean value of $Remaining(S(t_i))$.

$$Remaining(S(t_i)) = \left\lceil \frac{R_{idle}}{2} \right\rceil \tag{22}$$

Since the distance to AMA before the multicast packet arrival will influence the number of tree reconstructions in active state, such distance should be added to Q in order to get proper reconstruction times.

$$Q'(t_i) = \begin{cases} Q(t_i), \\ \quad \text{if } i=1 \text{ or } i>1 \text{ and } Remaining(S(t_{i-1}))>R_{active} \\ Q(t_i) + Remaining(S(t_{i-1})), \quad \text{otherwise} \end{cases} \tag{23}$$

In (23), if $Remaining(S(t_{i-1}))$ is bigger than R_{active}, the FA in the subnet where the MH resides should join the multicast tree when the multicast packet arrives. Then, we can obtain the number of reconstructions in active state during t_i.

$$\Pi_{active}(t_i) = F(Q'(t_i), R_{active}) + c(i) \tag{24}$$

$$c(i) = \begin{cases} 1, & \text{if } i>1 \text{ and } Remaining(S(t_{i-1}))>R_{active} \\ 0, & \text{otherwise} \end{cases} \tag{25}$$

Similarly, let $Remaining(Q(t_i))$ denote the distance to AMA before AMA is changed to idle state.

$$Remaining(Q(t_i)) = \left\lceil \frac{R_{active}}{2} \right\rceil \tag{26}$$

$$S'(t_i) = S(t_i) + Remaining(Q(t_i)) \tag{27}$$

From (1) and (27), the number of reconstructions in AMA's idle state during t_i can be obtained as follows:

$$\Pi_{idle}(t_i) = F(S'(t_i), R_{idle}) \tag{28}$$

From (24) and (28), we can get the function of the total number of reconstructions in the proposed scheme as follows, which can be worked out through Eqs. (9) and (15), too.

$$\Pi_{DRBMoM} = \sum_{i=1}^{M} (\Pi_{active}(t_i) + \Pi_{idle}(t_i)) \tag{29}$$

3.2 Delivery Overhead

The delivery path is divided into a tree path and a tunnel path. Because the delivery cost is mainly influenced by the path in tunnel, the tunnel path length is compared here just like [11]. Let $L_{RBMoM}(i)$ denote the tunnel path length at the ith multicast packet arrival in the RBMoM scheme. Thus we can get the total tunnel path length as follows.

$$L_{RBMoM} = \sum_{i=1}^{M} L_{RBMoM}(i) \tag{30}$$

Under the worst condition, the tunnel path length is R_{MHA} when every multicast packet arrives. Then, the maximal tunnel path length is

$$L_{RBMoM}(\max) = \sum_{i=1}^{M} R_{MHA} = MR_{MHA} \tag{31}$$

And the mean tunnel path length for each multicast packet is

$$\overline{L}_{RBMoM}(i) = \left\lceil \frac{R_{MHA}}{2} \right\rceil \tag{32}$$

Then we can get the mean tunnel path length as follows:

$$\overline{L}_{RBMoM} = \sum_{i=1}^{M} \overline{L}_{RBMoM}(i) = M\left\lceil \frac{R_{MHA}}{2} \right\rceil \tag{33}$$

In the DRBMoM scheme, because we just consider the low arrival rate of multicast packet, AMA is in its idle state when multicast packets arrive. Therefore, the maximal and mean tunnel path lengths are given as follows respectively:

$$L_{DRBMoM}(\max) = M \cdot R_{idle} \tag{34}$$

$$\overline{L}_{DRBMoM} = M\left\lceil \frac{R_{idle}}{2} \right\rceil \tag{35}$$

If multicast packet arrival rate is high, the delivery cost will be the same as that in the RBMoM scheme.

3.3 Group Management Overhead

DRBMoM behaves the same as RBMoM when sending the *Join* and the *Leave* message. The MH sends such message to notify the AMA (in DRBMoM) or the MHA (in RBMoM) its intention. So the number of the *Join* and *Leave* messages is equal. On the other hand, such kind of messages is usually delivered through unicast routing by certain members. If the members keep their status unchangeably, the number of such messages is negligible compared with the *Query* and *Report* message, which takes place more frequently and all of the members are concerned. Therefore, here we just analyze the group management overhead caused by delivering the *Query* and *Report* messages.

During AMA's active state, DRBMoM produces the same number of the *Query* and *Report* messages as RBMoM does since the multicast agent sends the *Query* message at the same interval. The difference appears when the AMA becomes idle, during which state the interval of the *Query* messages is prolonged. Here we assume the prolonged interval is $G_{interval}$ times of the initial one. In addition, the *Query* and *Report* message in AMA's idle state may cross more hops owning to its bigger service range.

Let Num_{MHA_qry} denote the total number of the *Query* messages sent out by the MHA in RBMoM. Since every member should send out a *Report* message as a response, the total number of *Report* messages is $Num_{MHA\_qry} * Num_{mem}$ for Num_{mem} members in the group on the average. We analyze the maximal delivery overhead for such messages by computing the maximal delivery paths. So the delivery overhead caused by the *Query* and *Report* messages in RBMoM is

$$Del\_cost(RBMoM) = Num_{MHA\_qry} * R_{MHA} + Num_{MHA\_qry} * Num_{mem} * R_{MHA} \quad (36)$$

where the former item is the overhead caused by *Query* message and the latter one is the overhead caused by *Report* message.

The overhead caused by delivering the *Query* and *Report* messages in DRBMoM is divided into two parts, one is in active state and the other is in idle state. Let P_{idle} denote the probability that the *Query* and *Report* message is sent during AMA's idle state, where DRBMoM just produces one $(G_{interval})th$ of the *Query* messages compared with RBMoM. So the delivery overhead caused by the *Query* and *Report* messages in DRBMoM is

$$\begin{aligned} Del\_Cost(DRBMoM) &= Num_{MHA\_qry} * (1 - P_{idle}) * R_{active} * (1 + Num_{mem}) \\ &\quad + Num_{MHA\_qry}/G_{interval} * P_{idle} * R_{idle} * (1 + Num_{mem}) \end{aligned} \quad (37)$$

where the former item is the overhead caused by the *Query* and *Report* messages in active state and the latter one is the overhead caused by the *Query* and *Report* messages in idle state.

4. Numerical Results

In this paper, we use the parameters in Tables 1 and 2 for performance analysis. In Table 2, we use two sets of parameters in our analysis to compare the overhead in different service range. The service range of AMA in active state is identical to that of MHA.

The whole time used to simulate the multicast routing is set to 1000 unit times. The whole simulation network is made up of 400 subnets, among which there are 20 or 40 multicast routers at the beginning. The handoff of mobile hosts happens ranging from every 1 unit time to every 10 unit times. That is, for the fast moving host, it just stays at a subnet for one unit time, and then moves out of the subnet; for the slowly moving host, it takes a longer period of time to stay at a subnet such as 10 unit times before it enters into a new subnet. The time interval of multicast packets' arrival is set to 200 unit times. A longer interval of multicast services is common in our daily lives. For example, the information of weather forecast is delivered to a certain interested mobile users at a very long interval. 10 unit times are used as time threshold, which means when AMA has not received any multicast packet during 10 unit times, it changes the state from active to idle. As we know, during such period, the handoff of mobile hosts will happen at least once; for some fast moving hosts, the handoff will happen even 10 times. Of course, the shorter the time threshold is, the more reconstruction overhead DRBMoM will save.

4.1 Network Model

We assume that there are 400 nodes (subnets) located on *x*-*y* coordinate system as shown in Fig. 6. The initial multicast nodes (routers) were selected randomly from these nodes. We can obtain the probability that the node is a multicast

Table 1 Parameters for analysis.

parameters	Values
T	1000(ticks)
v	10%,20%,……,100%(1/tick)
λ	0.005 (pkts/tick)
T_r	10(ticks)
W	20*20
U	20 or 40

Table 2 Parameters for analysis.

Set	R_{MHA}	R_{active}	R_{idle}
1	1	1	4
2	2	2	6

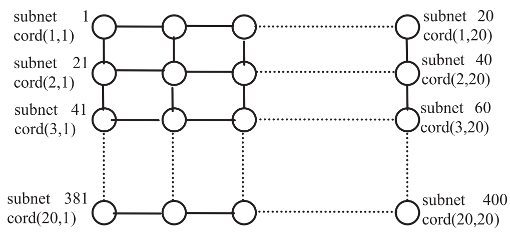

Fig. 6 Network topology.

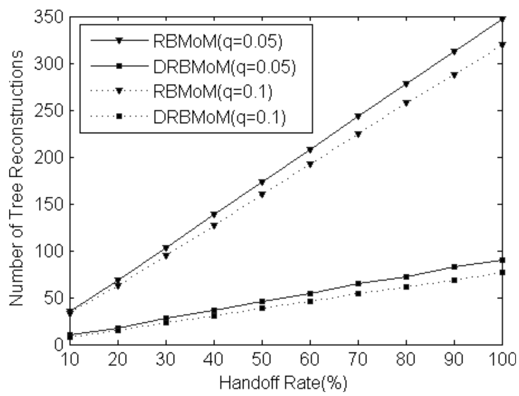

Fig. 7 Number of tree reconstructions when using set1 parameters.

router as follows:

$$q = \frac{U}{W} = \frac{U}{20 \times 20} \tag{38}$$

And $d(i) = 4$, so

$$P_{iB}^k = \begin{cases} \frac{1}{4}, & \text{if } i > 1 \\ 0, & \text{if } i = 1. \end{cases} \tag{39}$$

$$P_{iF}^k = \begin{cases} \frac{3}{4}, & \text{if } i > 1 \\ 1, & \text{if } i = 1. \end{cases} \tag{40}$$

4.2 Signaling Costs Evaluation

Figure 7 shows the number of tree reconstructions as a function of handoff rate of MH when using set 1 parameters. From Fig. 7, DRBMoM shows smaller number of tree reconstructions than the RBMoM protocol does. With the increase of the speed of MH, more reconstruction overhead is saved by DRBMoM. This is because the MH crosses over more subnets during AMA's idle state when it moves quickly. The larger the service range of AMA in idle state is, the lower the frequency of tree reconstruction will be. If we enhance the number of initial multicast nodes from 20 to 40, the number of reconstructions is also reduced because the probability that the FA of the subnet the MH moves to is a multicast router becomes larger.

Figure 8 shows the number of tree reconstructions as a function of handoff rate of MH when using set 2 parameters. We can get the same conclusion as that from Fig. 7 except that the number of reconstructions is reduced again.

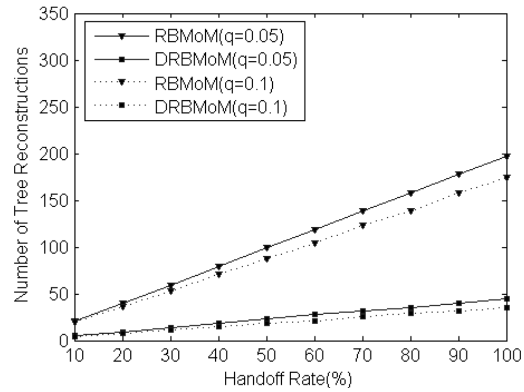

Fig. 8 Number of tree reconstructions when using set2 parameters.

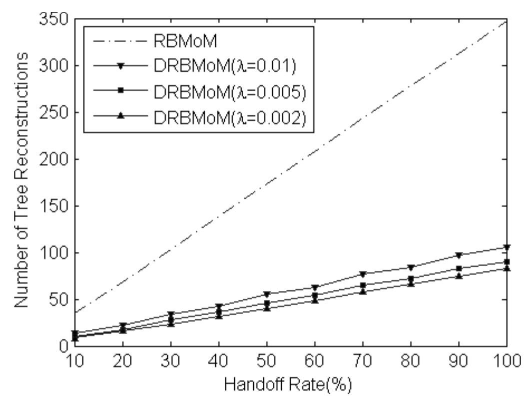

Fig. 9 Number of tree reconstructions when using set1 parameters and $q = 0.05$.

This is due to the fact that the service range of the multicast agent becomes larger.

In Fig. 9, we show the reconstruction overhead of RBMoM and DRBMoM using different λ as a function of handoff rate of MH. Because the service range of MHA is fixed, the number of reconstructions is unaltered when using different λ. But in the DRBMoM scheme, the number of reconstructions becomes larger as λ is increased. When λ is close to $\frac{v}{R_{active}}$, the reconstruction overhead in DRBMoM is also close to that in RBMoM. When λ is bigger than $\frac{v}{R_{active}}$ or $\frac{1}{T_r}$, the overhead in DRBMoM will be the same as that in RBMoM since AMA always remains active. The primary goal of DRBMoM is to lower the high tree reconstruction overhead when λ is low.

Figures 10 and 11 show the tunnel path length as a function of the handoff rate of MH when using the two sets of parameters. The tunnel path length in DRBMoM is slightly longer than that in RBMoM. This is mainly because the first multicast packet must be delivered to MHs when AMA is in idle state before it completes updating the state. Generally, the tunnel length is much longer in AMA's idle state than that in active state. But such little delivery cost can be compensated by the reconstruction cost reduced

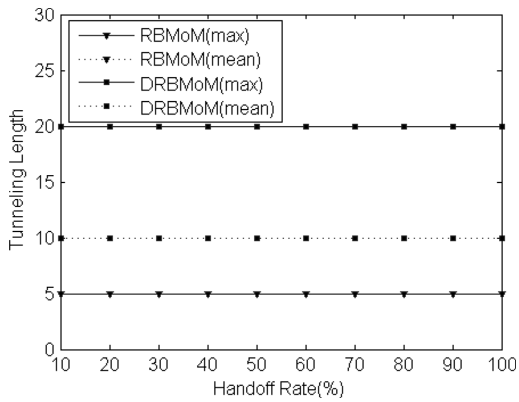

Fig. 10 Tunneling length when using set1 parameters.

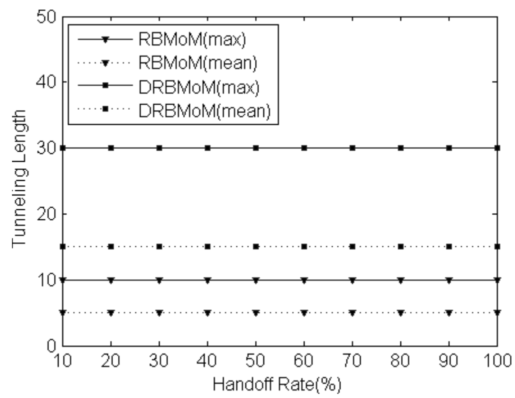

Fig. 11 Tunneling length when using set2 parameters.

by DRBMoM completely. DRBMoM cuts down the total signaling cost compared with RBMoM.

DRBMoM adopts a tradeoff strategy between multicast packets delivery and multicast tree reconstruction. Because the overhead of tree reconstruction mainly involves the control signaling exchange, which is different from multicast packets in terms of data size, sending frequency and buffer size, it is difficult to evaluate the tradeoff between the overhead of multicast packets delivery and multicast tree reconfiguration. However, if the changing trend of the overhead of multicast packets delivery and multicast tree reconfiguration is described, then such kind of tradeoff can be estimated through qualitative analysis. As shown in Figs. 12 and 13, when the service range in AMA's idle state is increased, more tree reconstructions can be avoided with the cost of longer packet delivery paths. If we change the ratio of R_{active} and R_{idle}, for example, enhance this ratio with a fixed value of R_{active}, the reverse conclusion can be made. Therefore, for the scenario that the multicast service is provided frequently, the smaller service range in AMA's idle state is preferred since a lot of packets arriving in such state can enjoy a shorter delivery path. Otherwise, if the interval of multicast services is very long, the bigger service range should be adopted to avoid unnecessary reconstructions.

Figure 14 shows the overhead of group management caused by delivering *Query* and *Report* messages as

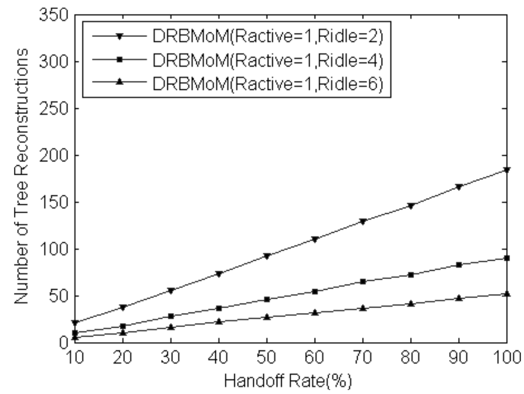

Fig. 12 Number of tree reconstructions when using different service range in idle state.

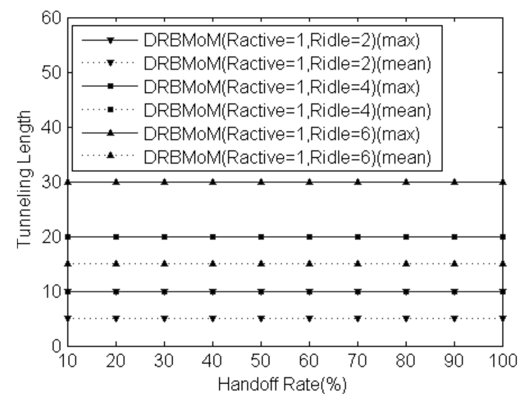

Fig. 13 Tunneling length when using different service range in idle state.

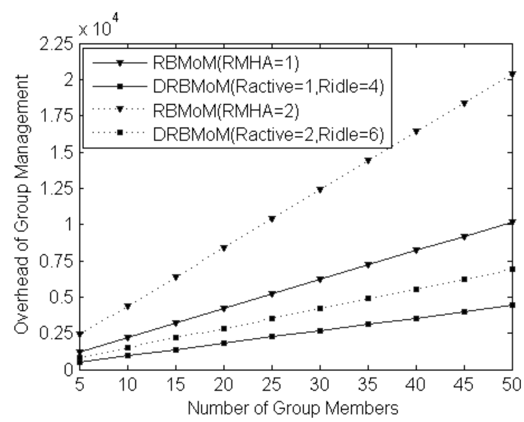

Fig. 14 Overhead of group management caused by delivering Query and Report messages.

a function of the number of group members. We assume the *Query* message is sent out every 5 unit times. The prolonged interval of *Membership Query* messages in idle state is set to 10 times of the initial one in active state. The probability that the *Query* and *Report* message is sent during AMA's idle state is approximately equal to the probability that the AMA is in idle state. As shown in Fig. 14, the adaptive group management mechanism in DRBMoM reduces the overhead of Membership *Query* and *Report* messages. This is because a lot of such messages are avoided in AMA's idle state during which no multicast service is provided. As the number of group members is increased, more delivery overhead can be saved since more such messages are avoided. If the service range in RBMoM and in DRBMoM is extended accordingly, the same result can be obtained.

5. Conclusion

This paper has proposed a new mobile multicast routing scheme DRBMoM, which employs the state characteristic of multicast agent to reduce system overhead. DRBMoM is capable of distinguishing active and idle multicast agent and does not reconstruct the multicast tree due to host mobility in AMA's idle state. When AMA starts to forward multicast packets again, it becomes active and the small service range provides near optimal routing path. Therefore, DRBMoM can minimize signaling cost by eliminating unnecessary join and prune operations and achieve near optimal multicast routing. In this paper, we also proposed an iterative algorithm to compute the overhead of tree reconstruction and packet delivery. Our analysis shows that the DRBMoM scheme can significantly reduce the tree reconstruction overhead at the cost of slightly larger delivery overhead, especially when the multicast packet arrival rate is low.

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