A Min-Max Hop-Count Based Self-discovering Method of a Bootstrap Router for the Bootstrap Mechanism in Multicast Routing

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Abstract. In this paper, a min-max hop-count based self-discovering method of a Bootstrap Router (BSR) for the bootstrap mechanism in multicast routing is proposed and its performance is evaluated. The key for the proposed method is that the BSR is selected as to become a position such as almost equal distances from the other routers by the min-max hop-count way. Especially, the proposed method can reduce the processing time efficiently to discover a Rendezvous Point which plays a central role of the data transmission. Simulation results show that the proposed method can reduce the processing time by average more than 43% compared with that of the conventional one.

Keywords: multicast, routing, protocol, bootstrap mechanism, bootstrap router, self-discovery.

1 Introduction

Recently, multicast can play an important role in delivering messages to many specific users of the Internet. Many multicast routing protocols have been studied and well surveyed in [1]–[4]. Among them, Protocol Independent Multicast – Sparse Mode (for short, PIM-SM) has been the center of focus in [5],[6]. Data transmission in the PIM-SM domain is performed on a shared tree. A shared tree is a distribution tree for one multicast group in the domain. Packets destined to a group are delivered on the shared tree, which is generated beforehand by a multicast routing algorithm [2]–[4].

The shared tree has a single router called a Rendezvous Point (RP) which plays a central role of the data transmission in PIM-SM [12]–[16]. All packets from a sender are first sent to the RP and the packets on the RP-rooted tree are delivered to all receivers of a multicast group. The methods to configure or discover the RP can mainly classify into two kinds of way: one is to select it by manual statically, e.g., static configuration and embedded-RP; the other is by some mechanism dynamically, e.g., Cisco's Auto-RP and Bootstrap Router [6].

In discovery of the RP on the shared tree in the PIM-SM domain, one of the important mechanisms is that of the "Bootstrap Mechanism" [7],[8]. The

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mechanism has its features of dynamic, self-configuring largely, and robust to a router failure. However, because the mechanism needs data flooding for all routers in the domain to find the RP, some traffic or congestion is prone to occur on the domain. The processing of the mechanism is also time-consuming. Besides, the role of the RP selection is played in a Bootstrap Router (BSR). Before discovering the RP, one of the routers is selected as the BSR firstly. As a result, some bordering routers in the domain can be selected as the BSR. Thus, since the distances between the BSR to the other routers may become longer, data transmission also takes much time.

In this paper, to overcome the mentioned-above problem, a min-max hop-count based self-discovering method of a BSR for the Bootstrap Mechanism in multicast routing is proposed and its performance is evaluated. The key for the proposed method is that the BSR is selected as to become a position such as almost equal distances from the other routers by the min-max hop-count way. Thus, especially, the proposed method can reduce the processing time efficiently to discover the BSR and the RP. The proposed method is characterized by a self-discovering method of the BSR. Simulation results show that the proposed method can reduce the processing time efficiently by compared with that of the conventional one.

The rest of this paper is organized as follows: Section 2 describes the overview of multicast routing, the PIM-SM, the bootstrap mechanism, and the hybrid one. Section 3 presents the proposed method. Section 4 evaluates the performance of the bootstrap mechanism, the hybrid one, and the proposed one by simulation. Section 5 discusses and compares the proposed method with the other methods. Section 6 summarizes and concludes this paper.

2 Preliminaries

In this section, an overview of the multicast routing, a multicast routing protocol in Protocol Independent Multicast – Sparse Mode (PIM-SM), a bootstrap mechanism, and a hybrid bootstrap one in PIM-SM are described.

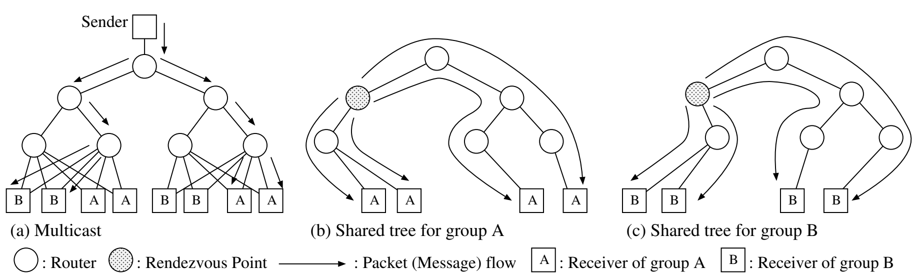

Fig. 1. Examples of multicast routing in PIM-SM

2.1 Overview of Multicast Routing

In the Internet, there are four kinds of data communication as follows: unicast, broadcast, anycast, and multicast. Especially, multicast has been brought to much public attention since efficient communication is needed for specific users in the Internet. Thus, many multicast routing protocols have been studied [2]–[4].

Multicast is to aim at sending packets efficiently for specific destinations (i.e., receivers) or a group of destinations. Fig. 1a shows an example of the multicast that some packets are sent to the specific groups on a shared tree. As shown in Figs. 1b and 1c, the packets toward the group A are delivered on a group-specific Rendezvous Point (RP)-rooted tree; the packets toward the group B are also delivered on a RP-rooted tree, which will be described detail in the following subsection.

To construct such a shared tree, there are also many multicast routing algorithms [2]–[4]. In one of the features of a multicast group in the algorithms, the receivers have their group addresses, which are assigned to Class D addresses from 224.0.0.0 to 239.255.255.255 in IPv4 [4] and, upper eight bits are all one in IPv6 [11].

2.2 PIM-SM

In this here, PIM-SM [5],[6] is described briefly and informally for simplicity. The join mechanism of PIM-SM is described in the following.

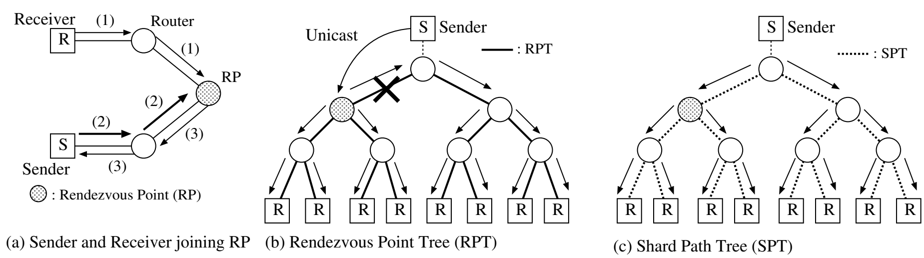

Fig. 2. An overview of PIM-SM

As shown in Fig. 2a, when a receiver joins a multicast group by sending an Internet Group Management Protocol (IGMP), its first-hop router (i.e., Designated Router) sends a PIM join message toward a Rendezvous Point (RP) in Fig. 2a(1). Then, the processing of this message by intermediate routers maintains status information for the group. From this information, a new branch of the distribution tree, i.e. a multicast tree, from the RP-rooted to the receivers is built. On the other hand, when a sender joins the multicast group, the sender sends a PIM register message with data packets encapsulated to the RP by unicast in Fig. 2a(2). After the RP is receiving the PIM register message from the sender, the RP sends a PIM join message toward the sender in Fig. 2a(3).

Note that the single router (i.e., RP) is selected in the PIM-SM domain and the RP-rooted tree called a Rendezvous Point Tree (RPT) is set up. The packets of the sender are firstly sent to the RP by unicast, the packets are secondly sent to the receivers on the RP-rooted tree as shown in Fig. 2b. If traffic or congestion has occurred on the RPT, it is switched over the tree with originated the sender (i.e., the shortest path from the sender to the receiver) called a Shared Path Tree (SPT) as shown in Fig. 2c.

2.3 Bootstrap Mechanism

In this here, an overview of the bootstrap mechanism [7],[8] is given in the following.

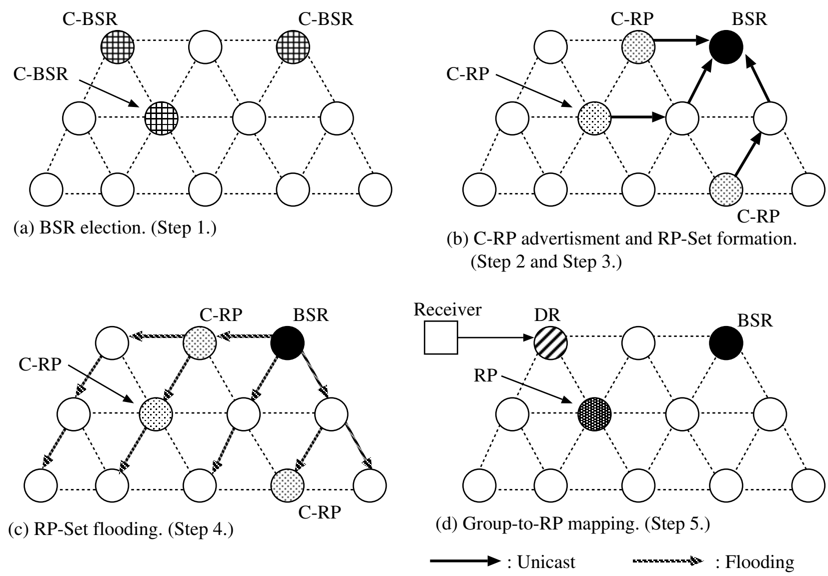

Fig. 3. Outline of bootstrap mechanism

Fig. 3 shows an outline of the bootstrap mechanism. A bootstrap mechanism is an algorithm which is to find a RP on a shared tree dynamically. Some of the PIM routers within a PIM domain are configured to be Candidate Bootstrap Routers (C-BSRs) for the domain as shown in Fig. 3a. In addition, some of the PIM routers in the PIM-SM domain are also as potential RPs as Candidate RPs (C-RPs) as shown in Fig. 3b. A PIM router may be configured as both C-BSR and C-RP. A C-BSR may be identical to a C-RP or may be different from the C-RP. One of the C-BSRs is elected as a Bootstrap Router (BSR). The BSR is an important role in the mechanism.

The procedures of the bootstrap mechanism [7],[8] are as follows:

Step 1. (BSR Election). Each C-BSR generates bootstrap messages (BSMs). Every BSM contains a BSR priority filed, a BSR address filed, and so on.

BSMs are flooded hop-by-hop throughout the domain. If a C-BSR hears about a higher-priority C-BSR than itself, then the C-BSR stops its sending of further BSMs for some period of time. A single remaining C-BSR becomes the elected BSR.

Step 2. (C-RP Advertisement). Each C-RP within a domain sends periodic C-RP-Advertisement (C-RP-Adv) messages to the elected BSR as shown in Fig. 3b. A C-RP-Adv message includes the priority of the advertising C-RP, group addresses, and so on.

Step 3. (RP-Set Formation). The BSR collects a set of C-RPs information (the RP-Set). To form the RP-Set, the BSR selects a subset of the C-RPs that it has received C-RP-Adv messages from each C-RP. Note that the RP-Set contains the following elements: multicast group range, RP priority, RP address, Hash mask length, and so on.

Step 4. (RP-Set Flooding). In future BSMs, the BSR includes the RP-Set information. BSMs are flooded through the domain, which ensures that the RP-Set rapidly reaches all the routers in the domain as shown in Fig. 3c.

Step 5. (Group-to-RP mapping). When a Designated Router (DR) receives an IGMP from a directly connected receiver for a group for which it has no state, the DR uses an algorithmic mapping to bind the group to one of the RPs in the RP-Set.

Note that the algorithmic mapping is used as the following hash function in this paper. The same function is used in all routers in the domain. This is guaranteed to select one RP in the RP-Set for a domain (i.e., a group address) even if the hash value is provided for any routers.

$$f = (n \cdot ((n \cdot (g \& m) + k) \text{ XOR } C(i)) + k) \bmod 2^{31}$$

where g is multicast address; m is a hash-mask, in case that IPv4 by RFC2362 or RFC4601, $m = 30$ is recommended; $C(i)$ is the IP address of the i-th RP in the RP-Set; n and k are constant, and $n = 1103515245, k = 12345$.

In the procedures of Step 1 and Step 4 mentioned above, the data flooding is performed to all routers within the domain. However, these processes may cause traffic in the network and they may take a lot of time.

2.4 Hybrid Bootstrap Mechanism

In this here, an overview of the hybrid mechanism [9],[10] is given in the following.

As described in Subsection 2.3, Steps 1 and 4 in Figs. 3a and 3c, respectively, make their flooding for all routers within the domain. However, the flooding may cause some traffic or congestion and it may take a lot of time in the processing.

The procedures from Step 1 to Step 3 in the hybrid method as shown in Figs. 4a and 4b are the same procedures from those in the conventional one as shown in Figs. 3a and 3b. However, in Step 4 as shown in Fig. 4c, to select one RP from C-RPs, the hybrid method is that the role of the RP selection is played in the BSR, not that the DR. Since the BSR only knows the RP-Set in Step 3 of Fig. 4b, the BSR can select the RP. Thus, BSR can also embed the information of the RP into the BSM in advance.

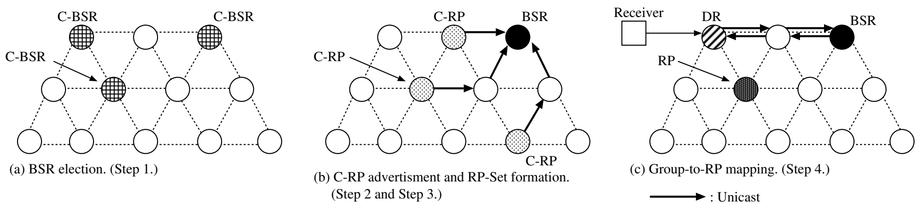

Fig. 4. Hybrid bootstrap mechanism

In this way, the hybrid method in Step 4 as shown in Fig. 4c is performed by unicast between the DR and the BSR as follows: the DR sends a query to the BSR; then, the BSR sends the BSM contained the RP-Set to the DR. Thus, the hybrid method does not need the flooding of BSM for all routers in Step 4 of Fig. 4c.

The procedures of the hybrid method are as follows:

Step 1. (BSR Election). The same as that in the previous Subsection 2.3.
Step 2. (C-RP Advertisement). The same as that in the previous Subsection 2.3.
Step 3. (RP-Set Formation). The same as that in the previous Subsection 2.3.
Step 4. (Group-to-RP mapping). When a Designated Router (DR) receives an IGMP from a directly connected receiver for a group for which it has no state, the DR sends a query to the BSR; then, the BSR sends the BSM contained the RP-Set information to the DR.

Note that, because the hybrid method does not need to inform the RP-Set by flooding in Step 4 as shown in Fig. 3c, the load of communication can thus reduce against the domain. In addition, the processing time can reduce.

3 Proposed Method

In this section, an overview of the proposed method and its procedures are described in the following.

3.1 Overview of Proposed Method

For the conventional bootstrap method and the hybrid one in the above-mentioned, a BSR is selected from C-BSRs in Step 1 of the both methods. Since the procedure of Step 1 (i.e., the BSR election) is based on the BSR priority, e.g., the IP address, in the BSM in each C-BSR as shown in Figs. 3a and 4a, there may happen to be selected a boundary router as the BSR in the domain. In this case, BSMs of the BSR in the procedure of Step 4 (i.e., RP-Set Flooding) are flooded to all routers in the domain as shown in Fig. 3c. However, since there are some routers which have a lot of hops to reach from the BSR, to inform the BSM for all routers may take a lot of times. So that the processing time may become longer. As a result, the performance can be decreased in both methods, respectively.

In the proposed min-max hop-count method in Step 1 when one BSR is selected from C-BSRs, the procedure is based on distances, i.e., the number of hops, but not such as IP addresses. Due to select the BSR by the number of hops, distances which are sending and receiving data between sources and destinations may become middle or short, but not long. Thus, the proposed method makes it possible to reduce the processing time of it rather than that of the conventional one. Note that it is assumed that the BSM in each C-BSR contains the information, i.e., distances between C-BSRs.

3.2 Procedures of Proposed Min-Max Hop-Count Method

Fig. 5 shows the proposed method of Step 1 in the mechanism. Steps 2 to 5 in the proposed method are as same as those in the conventional one.

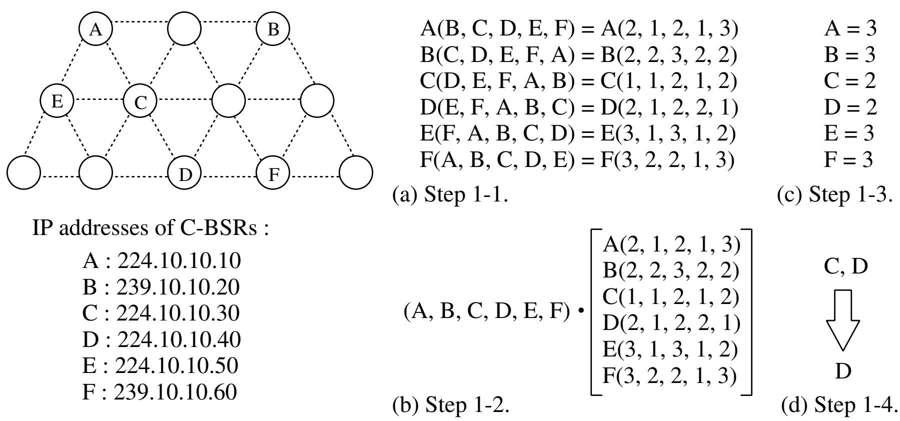

Fig. 5. Example of the proposed min-max hop-count method in bootstrap mechanism

The procedures from Step 1-1 to Step 1-4 in the proposed method are as follows:

Step 1. (BSR Election). Each C-BSR generates BSMs. Every BSM contains a BSR priority filed, a BSR address filed, and so on. BSMs are flooded hop-by-hop throughout the domain.

- **Step 1-1.** Each router finds the minimum number of hops between one to the others, respectively, as shown in Fig. 5a.
- **Step 1-2.** Each router sends the information obtained in Step 1-1 to all routers by each BSM as shown in Fig. 5b.
- **Step 1-3.** The maximum number of hops is selected among the number of hops in each router obtained in Step 1-2 as shown in Fig. 5c.

Step 1-4. The router which has the minimum number of hops from the results in Step 1-3 is selected. Note that, in the case that there are several routers with the same number of hops, the router which has the higher value of Class D in the IP address is selected as shown in Fig. 5d.

Step 2. (C-RP Advertisement). The same as that in the previous Subsection 2.3.

Step 3. (RP-Set Formation). The same as that in the previous Subsection 2.3.

Step 4. (RP-Set Flooding). The same as that in the previous Subsection 2.3.

Step 5. (Group-to-RP mapping). The same as that in the previous Subsection 2.3.

4 Evaluation

In this section, computer simulation was performed to verify the proposed method in the following.

We have conducted a simulation to compare performance of the bootstrap mechanism, the hybrid one, and the proposed one. The simulation was written in the C programming language and was compiled in Visual C++ 2008, and was running on a Windows XP SP3 with Pentium Dual Core 2.5 GHz CPU and 2048 MB RAM.

Simulation runs were made repeatedly until 95 percent confidence intervals for the sample means were acceptable, where a source (i.e., sender) and destinations (i.e., receivers) were randomly given on the four topologies assumed as shown in Fig. 6. The topologies were a mesh-type topology and, complete-, partial-, and incomplete-binary tree topologies.

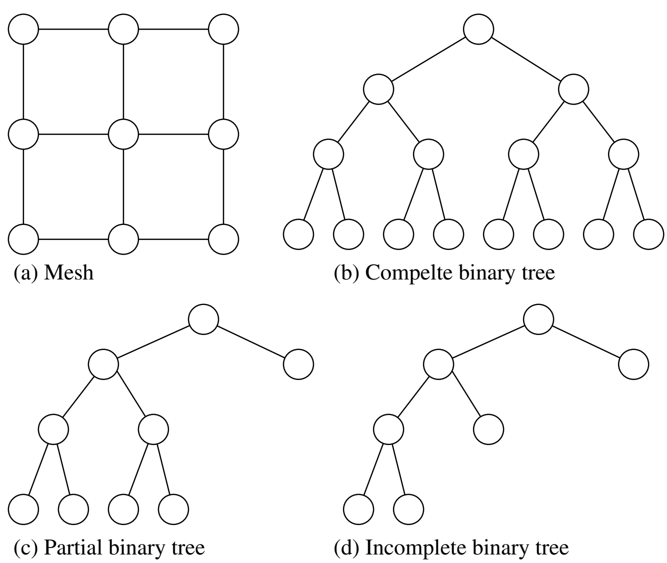

Fig. 6. Topologies used for simulations

Note that the IP addresses of Class D in the routers regarding as the nodes were also randomly given. To examine the scalability of the mechanism, the number of nodes used for a topology was that of 16, 49, 100, 144, 256, and 676, respectively, in the simulations. Also note that, to investigate the worst influence of the flooding, all routers were configured as C-BSRs and C-RPs.

In the bootstrap mechanism, the hybrid one, and the proposed one, the means of the processing time of them were measured from the start to the finish in the simulation in terms of the topologies. That is, the processing time is from Step 1 to Step 5 described in Subsection 2.3, from Step 1 to Step 4 described in Subsection 2.4, and from Step 1 to Step 5 in Section 3, respectively.

5 Discussion

Figs. 7 to 12 show the results of the simulations in the case that the number of nodes is 676, 256, 144, 100, 49, and 16, respectively. Table. 1 summarizes the reduction ratio of the hybrid method [9] to the conventional one [7] and that of the proposed one to the conventional one [7] in processing time. From Fig. 7 and Table. 1, in the case that the number of nodes is 676, the reduction ratio of the proposed method to the conventional one [7] is more than 70% about a mesh and a complete binary tree, and is more or less 7% about a partial binary tree and an incomplete binary tree. Furthermore, in uniform topologies such as a mesh and a complete binary tree in Figs. 8 to 12, the proposed method is also almost superior to the other methods.

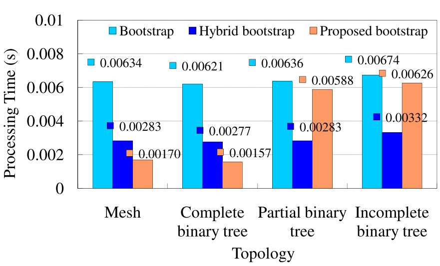

Fig. 7. Simulation Results on 676 nodes

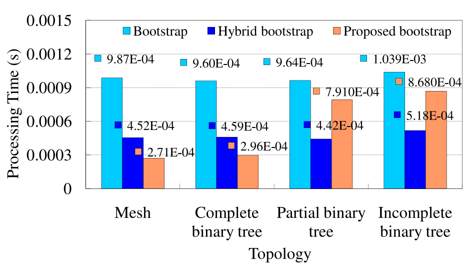

Fig. 8. Simulation Results on 256 nodes

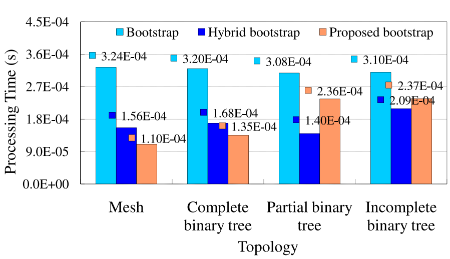

Fig. 9. Simulation Results on 144 nodes

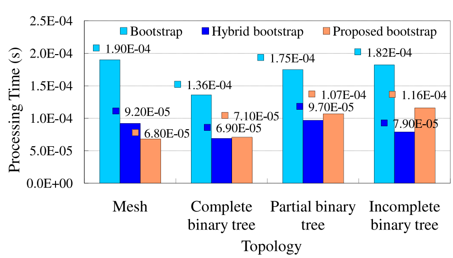

Fig. 10. Simulation Results on 100 nodes

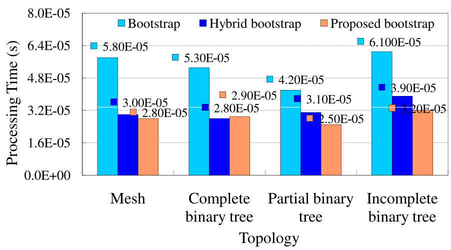

Fig. 11. Simulation Results on 49 nodes

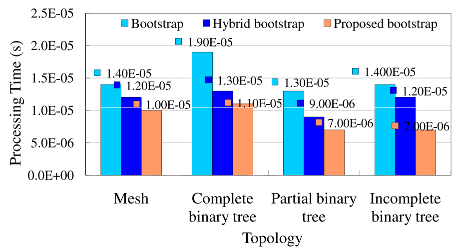

Fig. 12. Simulation Results on 16 nodes

Table 1. Comparison of the reduction ratio of [9] to [7] and that of the proposed method to [7] in processing time for four topologies on 676, 256, 144, 100, 49, and 16 nodes, respectively

Topology	Bootstrap [7]	Hybrid method [9] (#1)	Prop. method (#2)
Mesh (26 × 26)	100%	55.4%	73.3%
Complete binary tree	100%	55.5%	74.8%
Partial binary tree	100%	55.6%	7.6%
Incomplete binary tree	100%	50.8%	7.1%
Mesh (16 × 16)	100%	54.2%	72.5%
Complete binary tree	100%	52.2%	69.2%
Partial binary tree	100%	54.1%	17.9%
Incomplete binary tree	100%	50.1%	16.5%
Mesh (12 × 12)	100%	51.9%	66.0%
Complete binary tree	100%	47.5%	57.8%
Partial binary tree	100%	54.5%	23.4%
Incomplete binary tree	100%	32.6%	23.5%
Mesh (10 × 10)	100%	51.6%	64.2%
Complete binary tree	100%	49.3%	47.8%
Partial binary tree	100%	44.6%	38.9%
Incomplete binary tree	100%	56.6%	36.3%
Mesh (7 × 7)	100%	48.3%	51.7%
Complete binary tree	100%	47.2%	45.3%
Partial binary tree	100%	26.2%	40.5%
Incomplete binary tree	100%	36.1%	47.5%
Mesh (4 × 4)	100%	14.3%	28.6%
Complete binary tree	100%	31.6%	42.1%
Partial binary tree	100%	30.8%	46.2%
Incomplete binary tree	100%	14.3%	50.0%
ave.	–	44.4%	43.7%

#1: the reduction ratio (%) of the hybrid method [9] to [7] = $(1 - [9]/[7]) \times 100$;
#2: the reduction ratio (%) of the proposed method to [7] = $(1 - Prop./[7]) \times 100$.

However, from the reduction ratio as shown in Table. 1 in non-uniform topologies such as a partial binary tree and an incomplete binary tree, the performance of the proposed method is better than that of the conventional one, but worse than that of the hybrid one for the large number of nodes as shown in Figs. 7 to 10. This is because there may exist some nodes which take many hops from a BSR even if one node had been selected as to be the minimum hops from the BSR in the proposed method. On the other hand, the smaller the number of nodes becomes in the topologies, the shorter the processing time does as shown in Figs. 11 and 12. As a result, the reduction ratio of the proposed method has achieved better as compared with that of the other ones for the small number of nodes.

Thus, for the large number of nodes in uniform topologies, the processing time of the proposed method can reduce greatly as compared with that of the other methods. On the other hand, for the small number of nodes in uniform topologies and the large number of nodes in non-uniform ones, the processing time of the proposed method may affect the whole processing time as compared with that of the other methods because finding distances (i.e., the number of hops) between routers takes much time.

6 Conclusions

In this paper, a min-max hop-count based self-discovering method of a Bootstrap Router (BSR) for the bootstrap mechanism in multicast routing is proposed and its performance is evaluated. The key for the proposed method is that the BSR is selected as to become a position such as almost equal distances from the other routers by the min-max hop-count way. Especially, the proposed method can reduce the processing time efficiently to discover the BSR and a Rendezvous Point which plays a central role of the data transmission. Simulation results show that the proposed method can reduce the processing time effectively by average more than 43% compared with that of the original one.

Further research issues remain to be explored; these include running precise simulations on various topologies and developing an efficient self-management mechanism with fault tolerance to find the BSR, also applying the mechanism to a mobile environment.

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