MULTICAST IN MOBILE AD HOC NETWORKS

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Abstract: Multicast is a very efficient technology in one-to-many communication scenarios. With the popularity of mobile devices, and demanding group information exchange, multicast in mobile ad hoc networks attracts much research attention. This paper reviews the state-of-art multicast protocols and classifies them into two categories: tree-based and mesh-based. We review one classic protocol closely for each category and briefly describe others. Then some open problems were discussed such as scalability and reliability.

Keywords: ad hoc Networks, Multicast, MAODV, ODMRP

1. INTRODUCTION

Multicast is a one-to-many communication strategy, in which the source sends a copy of data to multiple members of a multicast group. The packet is duplicated only when necessary, that is, at the branch point. Thus the minimum numbers of copies per packet are used to disseminate the data to all receivers. Compared with unicast communication, multicasting saves much bandwidth and achieves high efficiency. In wired networks, multicast is a very well studied research topic. A myriad of papers and RFCs have been published in this area. However the emerging and popularity of wireless ad hoc networks brings new life and challenges to the multicast strategy. In ad hoc networks, mobile nodes are resource constrained, especially when mobile devices like PDAs and hand phones are internetworking. The constraints

Wang, Z., Liang, Y. and Wang, L., 2008, in IFIP International Federation for Information Processing, Volume 258; Computer and Computing Technologies in Agriculture, Vol. 1; Daoliang Li; (Boston: Springer), pp. 151–164.

include limited battery capacity, limited computation capability and storage. Also, due to nodal mobility, the underlying topology changes often, which introduces new challenges to the multicast problem. In this situation, how to establish a multicast underlying structure efficiently becomes an essential issue to the lifetime of a whole ad hoc network.

Other issues such as scalability and reliability are critical to the success of multicast applications in wireless ad hoc networks. Wireless transmission is more error-prone than wired counterparts. Thus, reliability is another important issue in multicasting here.

The rest of the paper is organized as follows. Section 2 discusses the multicast support in wired networks and challenges of deploying multicast in mobile ad hoc network environment. We survey existing multicast protocols in Section 3 followed by a comparison of protocols and other multicast issues in MANET. Finally, we conclude the paper in Section 5.

2. RELATED WORK

In this section, we discuss multicast protocols in wired network, followed by the challenges introduced by the mobility and characteristics of terminal nodes in ad hoc networks during the process of applying traditional multicast protocols directly.

2.1 Multicast support in wired network

In this section, some typical multicast protocols are briefly reviewed. The concept of multicast was proposed by Steve Deering in his dissertation in 1988. It was driven by the observation that much bandwidth could be saved if the data could be delivered to all receivers at one time instead of using multiple individual transmissions. Through the years, many research efforts focused on Internet multicast, and after a test in wide scale of "audiocast" in 1992, a multicast Internet (now called MBone) was setup for experiment use. A new type of IP address is reserved for multicast, and Internet Group Management Protocol (IGMP) was proposed to support dynamic joining and leaving of a group. The up-to-now multicast protocols could be classified into two categories: one category of multicast protocols works at the network layer, and the other works over the transport layer (but below application layer). The first category covers Distance Vector Multicast Routing Protocol (DVMRP) (S.E. Deering et al., 1990), Multicast Extension to OSPF (MOSPF) (J. Moy, 1994) and Protocol-Independent Multicast-Spare Mode (PIM-SM), Protocol-Independent Multicast-Dense Mode (PIM-DM) (S.E.

Deering et al.,1996). DVMRP is based on distance vector routing protocol, and uses reverse path multicasting algorithm to build a spanning tree for each multicast group. If a leaf router finds no nodes in its domain belonging to the group, it sends prune messages to the multicast source, which leads the leaf pruned from the multicast spanning tree. MOSPF is an extension of Open Shortest Path First (OSPF). It requires the information obtained by IGMP to build a multicast forwarding tree on demand for each multicast group. MOSPF, like DVMRP, is source-based multicast protocols. Instead PIM-SM is a core-based multicast protocol that maintains a rendezvous point. The rendezvous point is responsible for forwarding all packets for the multicast group. And each of the multicast domains selects a designated router, which handles multicast group messages in its domain. PIM-DM multicast protocol is very similar to DVMRP.

The second category of multicast protocols works over the transport layer. The classic protocols like Scalable Reliable Multicast (SRM) (S. Floyd et al., 1997) and Reliable Multicast Transport Protocol (RMTP) (S. Paul et al., 1997) fall into this category. SRM provides reliable multicast delivery service. It delegates the responsibility for recovery of packet loss to members in the multicast group. Through clever use of randomized timers, the numbers of feedbacks (replies) are effectively suppressed, and repair locality problem could be alleviated. RMTP makes use of logic tree structure to solve repair locality problem and refrain the feedback implosion problem. Specialized receivers located at the root of the sub-trees of the logic tree receive requests and initiate retransmission only to their own children in the tree. Note that this category multicast protocols does not require multicast support from router. Some of them impose some requirements on receivers instead.

2.2 Challenges of multicasting in mobile ad hoc network

Unlike wired networks, mobile ad hoc networks have no fixed underlying infrastructure. Nodes/terminals are free to move arbitrarily, thus the underlying topology may change randomly in an unpredictable manner (S. Corson et al., 1999). This makes the task of multicast group maintenance more difficult, and packet forwarding more challenging. Also, these mobile terminals/nodes are more resource-restricted compared to the counterparts in wired networks. These resources include, but are not limited to, bandwidth, energy (most cases terminals are run by battery instead of main), and link quality (wireless link are more error-prone than wired link). Thus one possibility is to require using multicast in order to save resources when multiple receivers exist. Another possibility is that careful design is required to consider in the sake of avoiding waste precious resources. For example, network-wired broadcast operations should be used less frequently in finding paths if it could not be avoided. How to balance between the efficiency and robustness is a big challenge for multicasting in mobile ad hoc network.

3. MULTICAST PROTOCOLS IN MOBILE AD HOC NETWORK

There are two approaches to categorize the existing multicast protocols in mobile ad hoc networks. One approach is to group together protocols that evolved from a similar chronological path. Multicast protocols in MANET evolved through three paths: extending existing multicast solution from wired network to MANET; extending existing MANET unicast protocols to support multicast; and proposing new multicast protocols. The (Figure 1) shows the relationship among varying protocols. It would be very interesting to review the protocols in this way. The other approach is to classify the protocols based on the structures the protocols used, tree-based or mesh-based. In this paper, we prefer surveying these literatures in this more natural and technical viewpoint.

Although there exist some protocols (e.g. hierarchical structure employed like (Y.J. Yi et al., 2000)) that do not fall into the following structure, the two very important classes of multicast routing protocols in mobile ad hoc network are reviewed in following subsections. Section 3.1 discusses the tree-based multicast protocols and Section 3.2 reviews the complicated mesh-based multicast protocols. We acknowledge that with hierarchical structure, multicast protocols are more scalable than without it.

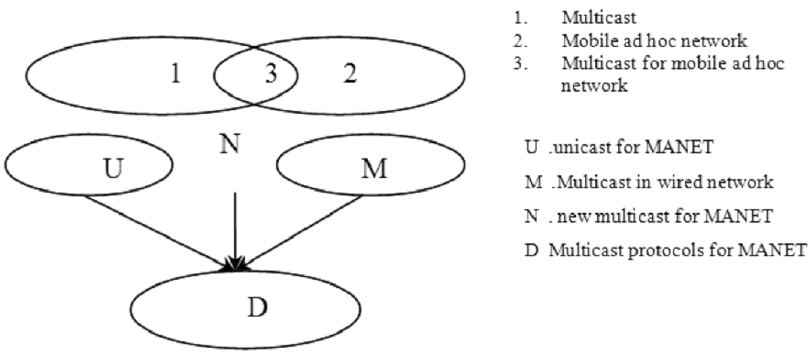

Figure 1. Evolution of multicast protocols in MANET

3.1 Tree-based multicast protocol

Large families of multicast protocols for ad hoc networks are based on a tree structure. One reason is that tree-based multicast protocols are well studied in wired network, thus more researchers tried to extend those feasible solutions to the mobile ad hoc environment. These sets of protocols usually establish a shared multicast delivery tree before multicasting packets in the group. The protocols are Multicast Operation of the ad hoc On-demand Distance Vector (MAODV) (E.M. Royer et al., 1999), ad hoc Multicast Routing Protocol Utilizing Increasing ID Numbers (AMRIS) (C.W. Wu et al., 1998) (C.W. Wu et al., 1999), On-Demand Associatively-Based Multicast Routing for ad hoc networks (ABAM) (C.K. Toh et al., 2000), Adaptive Demand-Driven Multicast Routing (ADMR) (J.G. Jetcheva et al., 2001) etc. AMRIS dynamically assigns each participant an id-number that reflects the "logic height" in the multicast delivery tree. A multicast tree starts to grow after receivers express interest in joining the multicast session. In ABARM, the concept of association stability (such as spatial, temporal, connection, and power stability of a node with its neighbor) is used to establish a multicast tree. Because the link quality and relations to neighbors are considered in an early stage, the tree structure tends to be very stable and does not require frequent reconfiguration in low mobility scenarios. ADMR creates a source-based forwarding tree when a multicast group starts. Receivers adapt to the traffic patterns of the multicast source application for efficiency and maintenance. Passive acknowledgements are used for efficient branch pruning instead of explicit pruning messages. Some other researchers published some tree-based multicast solutions instead of a full set of multicast protocols, such as (Sajama et al., 2003).

Some similarities are shared among these tree-based protocols. They work in two phases: tree establishment and tree maintenance. Tree establishment usually involves starting a multicast group and building a multicast forwarding tree. The phase of tree maintenance consists of adding a branch when a receiver requests to join the multicast group and pruning when no receivers exist in a tree branch. Instead of reviewing each protocol in detail, the classic protocol, MAODV, is reviewed closely on how it creates a multicast group, processes the join/leave request, and maintains the multicast tree.

MAODV is a naturally extension to ad hoc On-demand Distance Vector Routing (AODV) for providing multicast capabilities. Therefore, during the process of tree establishment, unicast is also used to disseminate some information, for example, Multicast Activation (MACT). For this functionality, each node maintains two tables pertaining to routing, and a third table called request table for optimization purposes. The first is route table, which is used to record the next hop for routes to other nodes. The second routing table that a node maintains is multicast route table. The following information is stored in each entry of a multicast route table:

Entry Multicast Rt {

IP_t ipGroup; //multicast addr

IP_t ipLeader;//leader addr

Seq_t seqNo; //group seq

int hopCnt; //to group leader

HopList nextHops;

Time_t Lifetime;

}

In MAODV, the first member of the multicast group becomes the group leader, and it remains the leader until it leaves the group. This leader takes responsibility of maintaining a multicast group sequence number and disseminating this number to the entire group through a proactive Group Hello Message. Members use the group hello message to update its request table and its distance to the group leader.

Once the group is setup, it is ready to accept join requests from others. When a source node broadcasts RREQ for a multicast group, it is expected to receive multiple replies. Only one of RREPs causes a branch to connect to the existing tree in order to avoid loops. The source node unicasts MACT to determine the next hop. The next hop propagates the MACT further until the node sending out the RREP if it is not a member of the multicast trees. Otherwise, it just updates its multicast route table when necessary. The multicast tree is created in this manner. (Figures 2, 3, and 4) show the process of multicast join operation.

During normal network operation, a multicast group member may decide to terminate its membership in the multicast group. As usual, leave operation leads multicast tree pruning. If the node is not a leaf node of the tree, it may revoke its membership status but may continue to serve as a router for the tree. Otherwise, if the node is a leaf node, it unicasts MACT messages with flag prune being set to next hop, thus it prunes itself from the tree.

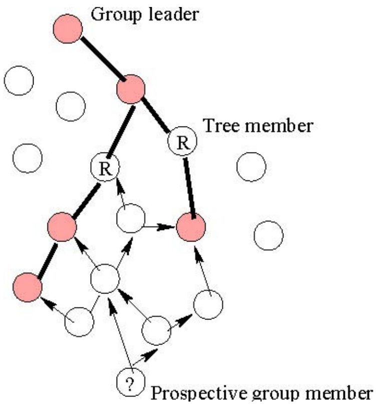

Figure 2. Route Request propagation

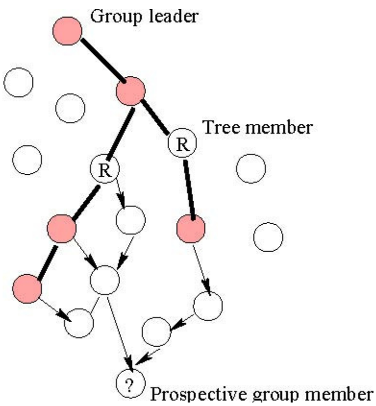

Figure 3. Route Reply sent back to source

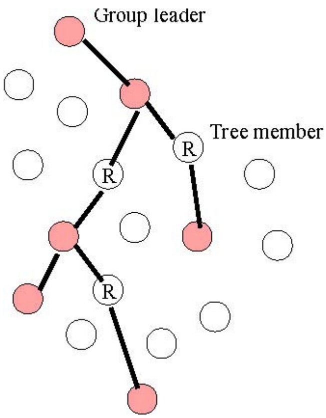

Figure 4. Tree branch growth

Multicast group tree may experience a break due to node mobility or dysfunction. In this situation, MAODV tries to repair the broken links. However, the cost of detecting link breakage is very expensive because it requires nodes to promiscuously listen to any neighbor's transmissions. The node downstream of the break point is responsible for repairing the broken link. Either it broadcasts RREQ and gets RREP soon, thus the link is fixed soon, or it has to act as a group leader if it is a multicast group member. If it is not a group member, the node unicasts MACT to the next hop until reaching a node that is a group member, which would become a group leader. Thus the network consists of two partitions, each one with a group leader.

If the network partition reconnects, a node eventually receives a group hello message with different group leader information. The node unicasts RREQ to each group leader to get permission of rebuilding by grafting a branch on the tree.

3.2 Mesh-based multicast protocol

Another class of multicast protocols in ad hoc network is mesh-based. Compared with tree-based counterparts, they are likely more robust because keeping multiple paths between sources and members in the multicast group. In the case that a link is broken, they may not necessarily initiate route discovery. Intuitively, they would outperform tree-based protocols in MANET environment where topologies are expected to change frequently. Typical existing mesh-based protocols are On Demand Multicast Routing Protocols (ODMRP) (S.J. Lee et al., 2002) (S.J. Lee et al., 1999), and Core-Assisted Mesh Protocol (CAMP) (J.J. Garcia-Luna-Aceves et al., 1999) (J.J. Garcia-Luna-Aceves et al., 1999).

In ODMRP, group membership and multicast routes are established and updated by the source "on demand". Similarly the protocol operation consists of a request phase and a reply phase for join. Sources flood a member advertisement packet to entire network with piggybacked payload when it has packets to send. This advertisement is called join query. A node (not necessarily be a receiver) receives a non-duplicate join query, it stores the upstream node ID in routing table and forwards the packet by flooding. When the join query reaches a multicast receiver, the receiver broadcasts a join reply to its neighbors. When a node receives a join reply, it checks if its own ID matches with the next hop of one of the entries. In the case of match, it marks itself a member of forwarding group, and broadcasts join reply. Thus the join reply is propagated by each forwarding group member until it reaches the multicast source. This process constructs (updates) the routes from source to receivers, and build a mesh of nodes. (Figure 5) shows the example of mesh.

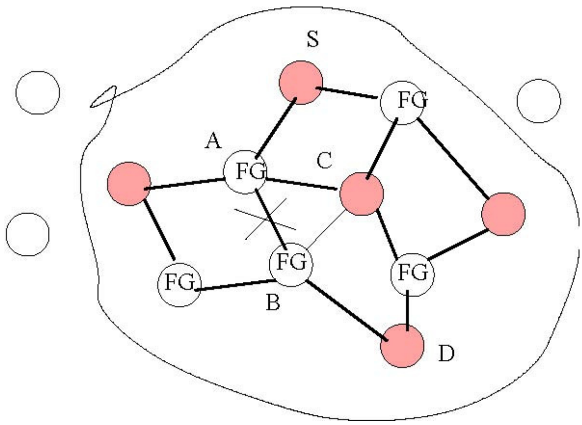

Figure 5. Example of mesh and the concept of forwarding group in ODMRP

ODMRP has several features worth of mentioning. The "on-demand" is source based, which means it does not require receivers to send leave explicitly when they are not interested in the group. It is different from MAODV and other multicast protocols. Secondly, the concept of forwarding group is very similar to the role of "forwarding nodes" in MAODV. Thirdly, the use of mesh configuration enables high connectivity thus its feature of robustness. For example, in (Figure 5) if the link between A and B is broken, the packet transmission from source S to receiver D is not affected because the redundant path S →A→C→B→D could be used instead.

S.J. Lee, et al. proposed some enhancements to ODMRP in (S.J. Lee et al., 2001) (S.J. Lee et al., 2002). The enhancements include adapting the refresh interval via mobility prediction, reliability, and elimination of route acquisition latency by flooding data instead of Join requests when the source does not know any multicast route. Another improved version of ODMRP is proposed in (H. Dhillon et al., 2005). It consolidates join queries in intermediate nodes, thus reducing the total number of control packet transmissions. Compared with ODMRP, simulation results show that it increases multicast efficiency and improves the packet delivery ratio.

CAMP is also a mesh-based multicast protocol. It borrows concepts from core-based tree (CBT), but unlike CBT where all traffic flows through the core node, the core nodes in CAMP are used to limit traffic flow through the core node. CAMP uses a receiver-initiated method for routers to join multicast groups. A node first determines the address of the group it is interested in. Then it uses this address to ask its attached router to join the multicast group. Upon receiving a host request to join a group, the router then determines whether to announce its membership in the group or to request being added to the group. Any router that is a regular member of a multicast group and receives the join request is free to transmit a join acknowledgment to the sending router. When the origin or a relay of a join request receives the first acknowledgement to its request, the router becomes part of the multicast group.

A router leaves a multicast group when it has no nodes that are members of the group and it has no neighbors for whom it is an anchor. It issues a quit notification to its neighbors, which can update their multicast routing tables.

In the established mesh, it contains all reverse shortest paths between a source and the recipients. A receiver node periodically reviews its packet cache in order to determine whether it is receiving data packets from neighbors, which are on the reverse shortest path to the source. Otherwise, a heartbeat message is sent to the successor in the reverse shortest path to the source. The heartbeat message triggers a push join message. If the successor is not a mesh member, the push join forces the specific successor and all the routers in the path to join the mesh. The requests only propagate to mesh members. To date, CAMP is the only multicast routing protocol based on the mesh topology and without using flooding of data or control packets.

The protocol CAMP requires the support of unicast and Domain Name Service (DNS). Additionally, the unicast routing protocol must provide correct distance to known destinations within a finite time. These requirements are difficult to meet in the current MANET environment.

CAMP is improved by unified multicasting through announcement (PUMA) in ad hoc networks from the same researchers in (R. Vaishampayan et al., 2004). Like its preceding work, "core-based mesh", this protocol also establishes and maintains a shared mesh for each multicast group. It is based on a novel idea of using simple multicast announcements to elect a core for the group, inform all routers of their distance and next-hops to the core join and leave the multicast group.

4. COMPARISON OF PROTOCOLS AND OTHER MULTICAST ISSUES IN MANET

Multicast technology was invented/developed at the early internetworking time when the bandwidth was a very precious resource. With the advances of wired technology and reduced costs, it is not an issue in wired networks. The situation of multicast residing in wireless ad hoc networks is very similar to that in wired networks of early stage. Due to the natural characteristics of MANET, multicasting is a very promising technology desired in the scenarios where multiple receivers exist at one time. In this section, we compare multiple multicast protocols, followed by a discussion of various open problems.

Table 1 shows the comparison of multicast protocols in MANET in terms of several evaluation metrics. From the table, we can see all of them could provide the mechanism of avoiding loops. Those protocols that evolved from unicast protocol in MANET usually depend on the support of unicast in the network. In contrast, the newly designed protocols often borrow some ideas from multicast protocols in wired network or others. For example, CAMP borrowed the concept of Core from CBT. ODMRP borrows the concept of the forwarding group from FGMP, and ABAM utilizes the concept of associativity from Associativity-Based Routing (ABR), a unicast protocol in MANET. Generally, the designs of tree-based protocols are not as complicated as mesh-based protocols. However, they are less robust than mesh-based protocols due to the connectivity of each node. This table also shows that all existing proposals have not been tested in large-scale networks. The largest network simulated consists of 100 nodes in AMRIS (C.W. Wu et al., 1999). From the survey and comparison, it is not difficult to summarize that on-demand is a desired property of all multicast protocols with the complement of periodical messages to keep structure or information updated.

Most active research of multicast in MANET is focused on the protocols itself, which mainly propose mechanisms of how to process join/leave request and how to establish the underlying packet forwarding structures. If we compare them with the peers in wired networks, it is interesting to find that no existing work matches to higher layer multicast protocols/

Table 1. Comparison of multicast protocols

Protocols	Underlying Structure	Loop Free	Dependence	Flood	Evolution	Simulation Size
MAODV	Tree	Yes	Unicast	Yes	From AODV	50 nodes
AMRIS	Tree	Yes	Unicast, beacon & broadcast	Yes	New protocol	100 nodes
ABAM	Tree	Yes	Beacon, scoped broadcast	No	From ABR	40 nodes
ADMR	Tree	Yes	No	Yes	From DSR	50 nodes
ODMRP	Mesh	Yes	No	Yes	New protocol	20 nodes
CAMP	Mesh	Yes	Unicast, DNS, etc	No	New protocol	30 nodes

frameworks (e.g. SRM, MFTP, etc) in wired networks. Maybe it is because so far no "killer" applications in MANET multicast scenario has driven the research toward this direction. Also, there are still many important topics of multicast in MANET that require further investigation, such as experiments, scalability, reliability and power consumption, etc.

Simulations could be used to evaluate the performance of proposed multicast protocols. However, further experiments with testbeds are still necessary. The largest ad hoc evaluation testbed (APE) consisted of up to 37 physical nodes (H. Lundgren et al., 2002). Also, no multicast protocol is supported in the testbed yet. To our best knowledge, none of the proposed multicast solutions perform experiments in a testbed. With recent advance in low-power supply, and reduced cost in mobile terminals (handsets, PDAs, laptops, etc), it is feasible to build a large-scale testbed and test multicast protocols in MANET.

The benefit of multicasting turns out to be tremendous only when a large number of receivers exist simultaneously. Therefore, scalability is one of the most important merits that should be provided by proposed multicast protocols. Although those published literatures claim the scalability of their proposals through simulations, further experiments in testbed are required to verify it. Scalability has two-fold meanings: one involves how large a multicast group could be processed, and the other one is how many multicast groups could be processed in the multicast group. A scalability proposed multicast protocol appears in (C. Gui et al., 2004). This paper studied the relationship of the protocol state management techniques and the performance of multicast provisioning. In order to address scalability and enhance performance, domain-based hierarchical and overlay-driven hierarchical routing are proposed. In domain-based hierarchical routing approach, large multicast group is divided into many sub-groups, and in each sub-group a node is selected as a sub-root and these sub-roots maintain the protocol states. The second approach is to use overlay multicast as the upper layer multicast protocol built upon low layer stateless small group multicast.

And reliability is also a very important issue of multicast in MANET. So far, few researchers emphasize this problem. The only paper is (J. Luo et al., 2003). The proposed router driven gossip in this article could achieve probabilistic reliability. Its main idea is based on a partial view for each group member. The spread of information is propelled mainly by a gossiper-push (each group member forwards multicast packets to a random subset of the group), but complemented by gossiper-pull (multicast packets piggyback negative acknowledgement of the forwarding group member). Three sessions are defined, join, leave and gossip. The dissemination of a leave indication relies on the gossip session.

The fourth important aspect that no literature mentioned is the power consumption problem for these proposed multicast protocols in MANET. Some multicast protocols rely on eavesdropping neighbors to detect link breakage while others periodically flood messages to refresh a multicast group. These are undesirable features in a MANET environment. Therefore how to minimize the power consumption and how much benefit could be achieved remain unanswered.

5. CONCLUSION

Multicasting can efficiently support many applications in mobile ad hoc networks. However, the characteristics of MANET, such as frequent topology changes and resource constraints bring many challenges to deploy multicast solutions. In this paper, we discuss the multicast protocols in MANET. The multicast protocols are classified into tree-based and mesh-based mechanisms. In each class of protocols, at least one of classic proposals is reviewed in detail. So far, the research for multicast in MANET is far from exhaustive. Some very important issues, such as scalability, reliability, and power consumption, are not yet investigated thoroughly. Also, existing multicast proposals are not convincing enough without running simulations in large-scale networks and performing experiments in a testbed.

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