several multicast ...

8.2 ISSUES IN DESIGNING A MULTICAST ROUTING PROTOCOL

Limited bandwidth availability, an error-prone shared broadcast channel, the mobility of nodes with limited energy resources, the hidden terminal problem [5], and limited security make the design of a multicast routing protocol for ad hoc networks a challenging one. There are several issues involved here which are discussed below.

- **Robustness:** Due to the mobility of the nodes, link failures are quite common in ad hoc wireless networks. Thus, data packets sent by the source may be dropped, which results in a low packet delivery ratio. Hence, a multicast routing protocol should be robust enough to sustain the mobility of the nodes and achieve a high packet delivery ratio.

- **Efficiency:** In an ad hoc network environment, where the bandwidth is scarce, the efficiency of the multicast protocol is very important. Multicast efficiency is defined as the ratio of the total number of data packets received by the receivers to the total number of (data and control) packets transmitted in the network.

- **Control overhead:** In order to keep track of the members in a multicast group, the exchange of control packets is required. This consumes a considerable amount of bandwidth. Since bandwidth is limited in ad hoc networks, the design of a multicast protocol should ensure that the total number of control packets transmitted for maintaining the multicast group is kept to a minimum.

- **Quality of service:** One of the important applications of ad hoc networks is in military/strategic applications. Hence, provisioning quality of service (QoS) is an issue in ad hoc multicast routing protocols. The main parameters which are taken into consideration for providing the required QoS are throughput, delay, delay jitter, and reliability.

- **Dependency on the unicast routing protocol:** If a multicast routing protocol needs the support of a particular routing protocol, then it is difficult

8.5 CLASSIFICATIONS OF MULTICAST ROUTING PROTOCOLS

Multicast routing protocols for ad hoc wireless networks can be broadly classified into two types: application-independent/generic multicast protocols and application-dependent multicast protocols (refer to Figure 8.4). While application-independent multicast protocols are used for conventional multicasting, application-dependent multicast protocols are meant only for specific applications for which they are designed. Application-independent multicast protocols can be classified along three different dimensions.

1. **Based on topology:** Current approaches used for ad hoc multicast routing protocols can be classified into two types based on the multicast topology: *tree-based* and *mesh-based*. In tree-based multicast routing protocols, there exists only a single path between a source-receiver pair, whereas in mesh-based multicast routing protocols, there may be more than one path between a source-receiver pair. Tree-based multicast protocols are more efficient compared to mesh-based multicast protocols, but mesh-based multicast protocols are robust due to the availability of multiple paths between the source and receiver. Tree-based multicast protocols can be further divided into two types: *source-tree-based* and *shared-tree-based*. In source-tree-based multicast protocols, the tree is rooted at the source, whereas in shared-tree-based multicast protocols, a single tree is shared by all the sources within the multicast group and is rooted at a node referred to as the *core node*. The source-tree-based multicast protocols perform better than the shared-tree-based protocols at heavy loads because of efficient traffic distribution. But the latter type of protocols are more scalable. The main problem in a shared-tree-based multicast protocol is that it heavily depends on the core node, and hence, a single point failure at the core node affects the performance of the multicast protocol.

2. **Based on initialization of the multicast session:** The multicast group formation can be initiated by the source as well as by the receivers. In a multicast protocol, if the group formation is initiated only by the source node, then

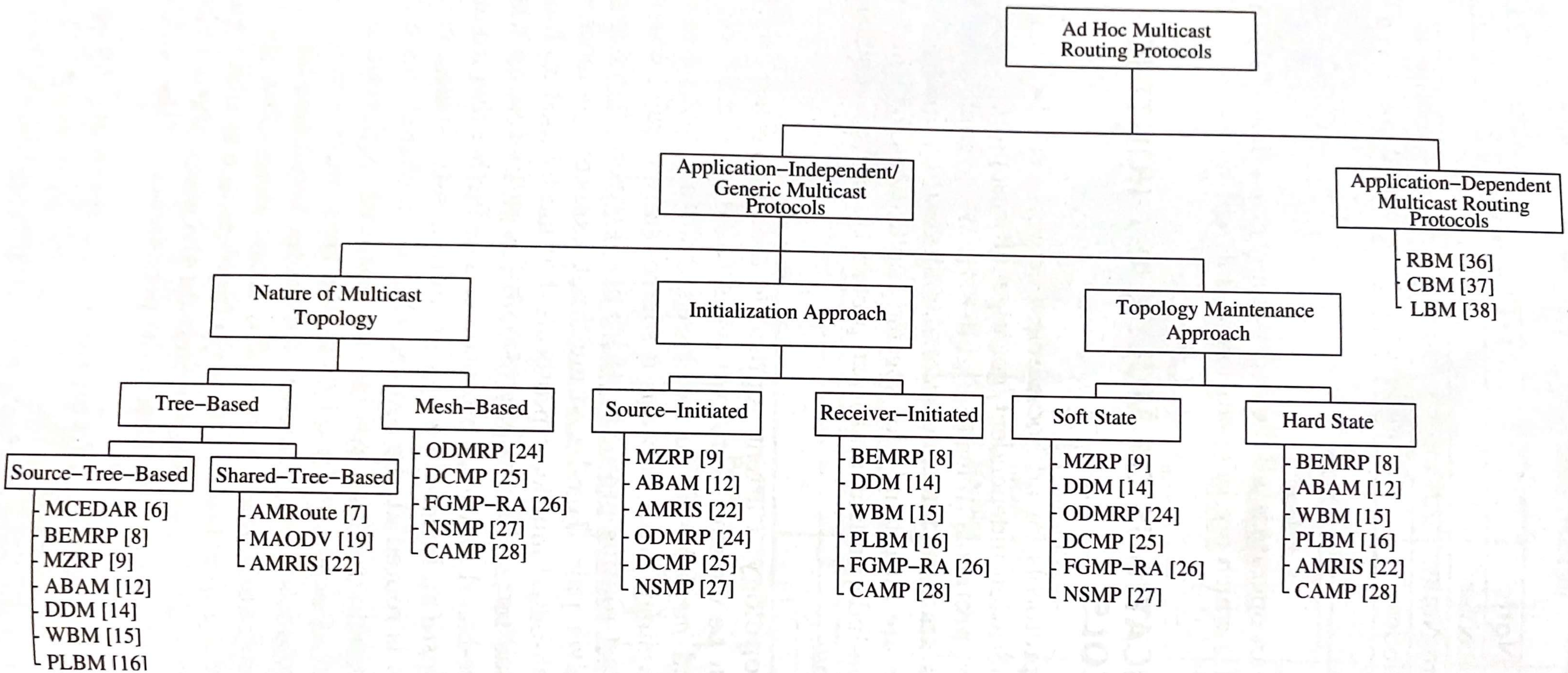

Figure 8.4. Classifications of multicast routing protocols.

it is called a *source-initiated* multicast routing protocol, and if it is initiated by the receivers of the multicast group, then it is called a *receiver-initiated* multicast routing protocol. Some multicast protocols do not distinguish between source and receiver for initialization of the multicast group. We call these *source-or-receiver-initiated* multicast routing protocols.

3. **Based on the topology maintenance mechanism:** Maintenance of the multicast topology can be done either by the *soft state approach* or by the *hard state approach*. In the soft state approach, control packets are flooded periodically to refresh the route, which leads to a high packet delivery ratio at the cost of more control overhead, whereas in the hard state approach, the control packets are transmitted (to maintain the routes) only when a link breaks, resulting in lower control overhead, but at the cost of a low packet delivery ratio.

8.6 TREE-BASED MULTICAST ROUTING PROTOCOLS

Tree-based multicasting is a well-established concept used in several wired multicast protocols to achieve high multicast efficiency. In tree-based multicast protocols, there is only one path between a source-receiver pair. The main drawback of these protocols is that they are not robust enough to operate in highly mobile environments. Tree-based multicast protocols can be classified into two types: source-tree-based multicast routing protocols and shared-tree-based multicast routing protocols (refer to Figure 8.4). In a source-tree-based protocol, a single multicast tree is maintained per source, whereas in a shared-tree-based protocol, a single tree is shared by all the sources in the multicast group. Shared-tree-based multicast protocols are more scalable compared to source-tree-based multicast protocols. By scalability, we mean the ability of the protocol to work well without any degradation in performance when the number of sources in a multicast session or the number of multicast sessions is increased. In source-tree-based multicast routing protocols, an increase in the number of sources gives rise to a proportional increase in the number of source-trees. This results in a significant increase in bandwidth consumption in the already-bandwidth-constrained network. But in a shared-tree-based multicast protocol, this increase in bandwidth usage is not as high as in source-tree-based protocols because, even when the number of sources for multicast sessions increases, the number of trees remains the same. Another factor that affects the scalability of source-tree-based protocols is the memory requirement. When the multicast group size is large with a large number of multicast sources, in a source-tree-based multicast protocol, the state information that is maintained per source per group consumes a large amount of memory at the nodes. But in a shared-tree-based multicast protocol, since the state information is maintained per group, the additional memory required when the number of sources increases is not very high. Hence shared-tree-based multicast protocols are more scalable compared to source-tree-based multicast protocols. The rest of this section describes some of the existing tree-based multicast routing protocols for ad hoc wireless networks.

8.6.1 Bandwidth-Efficient Multicast Routing Protocol

Ad hoc networks operate in a highly bandwidth-scarce environment, and hence bandwidth efficiency is one of the key design criteria for multicast protocols. Bandwidth efficient multicast routing protocol (BEMRP) [8] tries to find the nearest forwarding node, rather than the shortest path between source and receiver. Hence, it reduces the number of data packet transmissions. To maintain the multicast tree, it uses the hard state approach, that is, to rejoin the multicast group, a node transmits the required control packets only after the link breaks. Thus, it avoids periodic transmission of control packets and hence bandwidth is saved. To remove unwanted forwarding nodes, route optimization is done, which helps in further reducing the number of data packet transmissions. The multicast tree initialization phase and the tree maintenance phase are discussed in the following sections.

Tree Initialization Phase

In BEMRP, the multicast tree construction is initiated by the receivers. When a receiver wants to join the group, it initiates flooding of *Join* control packets. The existing members of the multicast tree, on receiving these packets, respond with *Reply* packets. When many such *Reply* packets reach the requesting node, it chooses one of them and sends a *Reserve* packet on the path taken by the chosen *Reply* packet. When a new receiver R3 (Figure 8.5) wants to join the multicast group, it floods the *Join* control packet. The nodes S, I1, and R2 of the multicast tree may receive more than one *Join* control packet. After waiting for a specific time, each of these tree nodes chooses one *Join* packet with the smallest hop count traversed. It sends back a *Reply* packet along the reverse path which the selected *Join* packet had traversed. When tree node I1 receives *Join* packets from the previous nodes I9 and I2, it sends a *Reply* packet to receiver R3 through node I2. The receiver may receive more than one *Reply* packet. In this case, it selects the *Reply* packet which has the lowest hop count, and sends a *Reserve* packet along the reverse path that the selected *Reply* packet had traversed. Here, in Figure 8.5, receiver R3 receives *Reply* packets from source S, receiver R2, and intermediate node I1. Since the *Reply* packet sent by intermediate node I1 has the lowest hop count (which is 3), it sends a *Reserve* packet to node I3, and thus joins the multicast group.

Tree Maintenance Phase

To reduce the control overhead, in BEMRP, tree reconfiguration is done only when a link break is detected. There are two schemes to recover from link failures.

1. Broadcast-multicast scheme: In this scheme, the upstream node is responsible for finding a new route to the previous downstream node. This is shown in Figure 8.6. When receiver R3 moves from A to B, it gets isolated from the remaining part of the tree. The upstream node I3 now floods broadcast-multicast packets (with limited TTL). After receiving this packet, receiver R3 sends a *Reserve* packet and joins the group again.

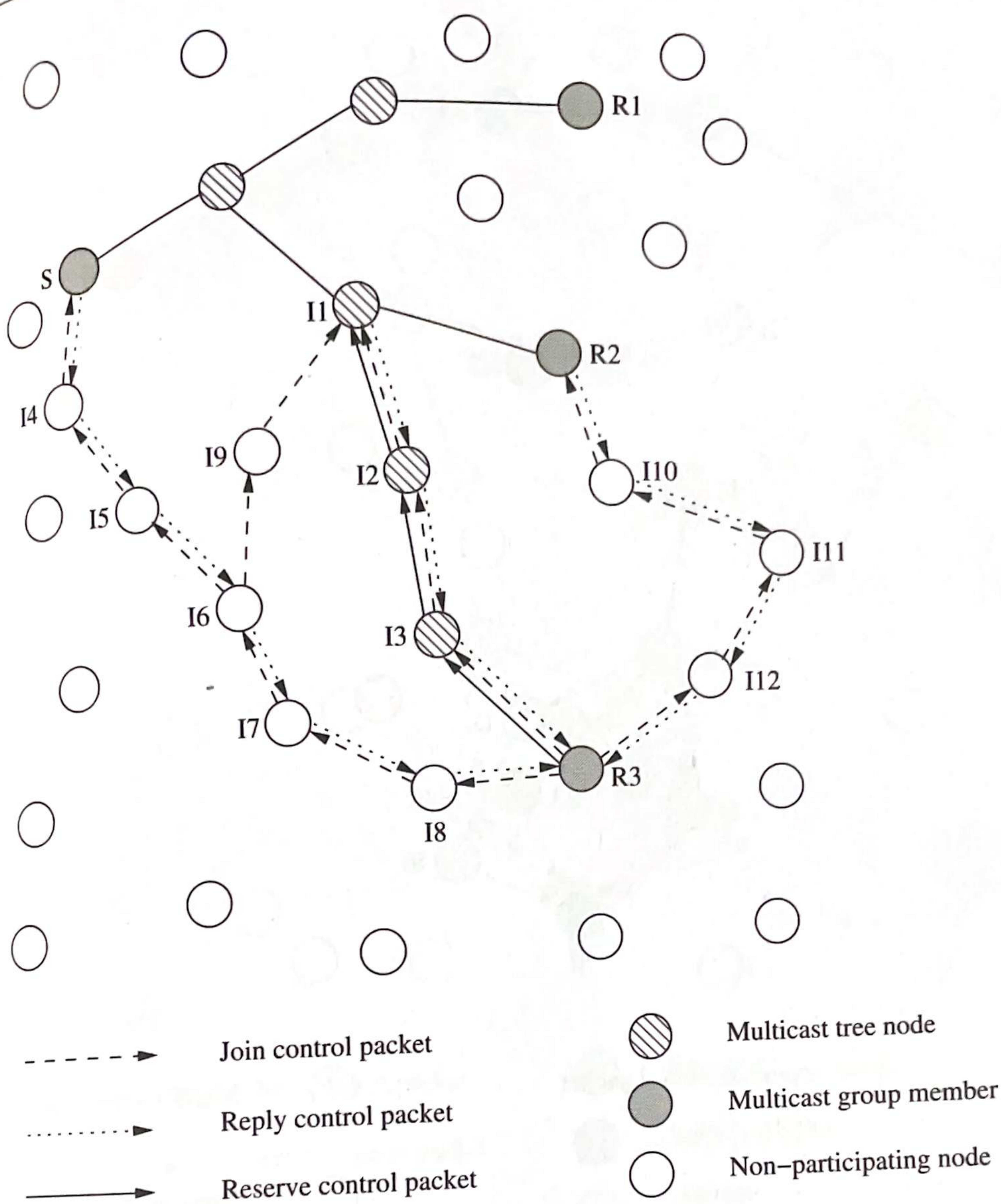

Figure 8.5. Multicast tree initialization in BEMRP.

2. Local rejoin scheme: In this scheme, the downstream node of the broken link tries to rejoin the multicast group by means of limited flooding of the *Join* packets. In Figure 8.7, when the link between receiver R3 and its upstream node I3 fails (due to movement of node R3), then R3 floods the *Join* control packet with a certain TTL value (depending on the topology, this value can be tuned). When tree nodes receive the *Join* control packet, they send back the *Reply* packet. After receiving the *Reply* packet, the downstream node R3 rejoins the group by sending a *Reserve* packet to the new upstream node I4.

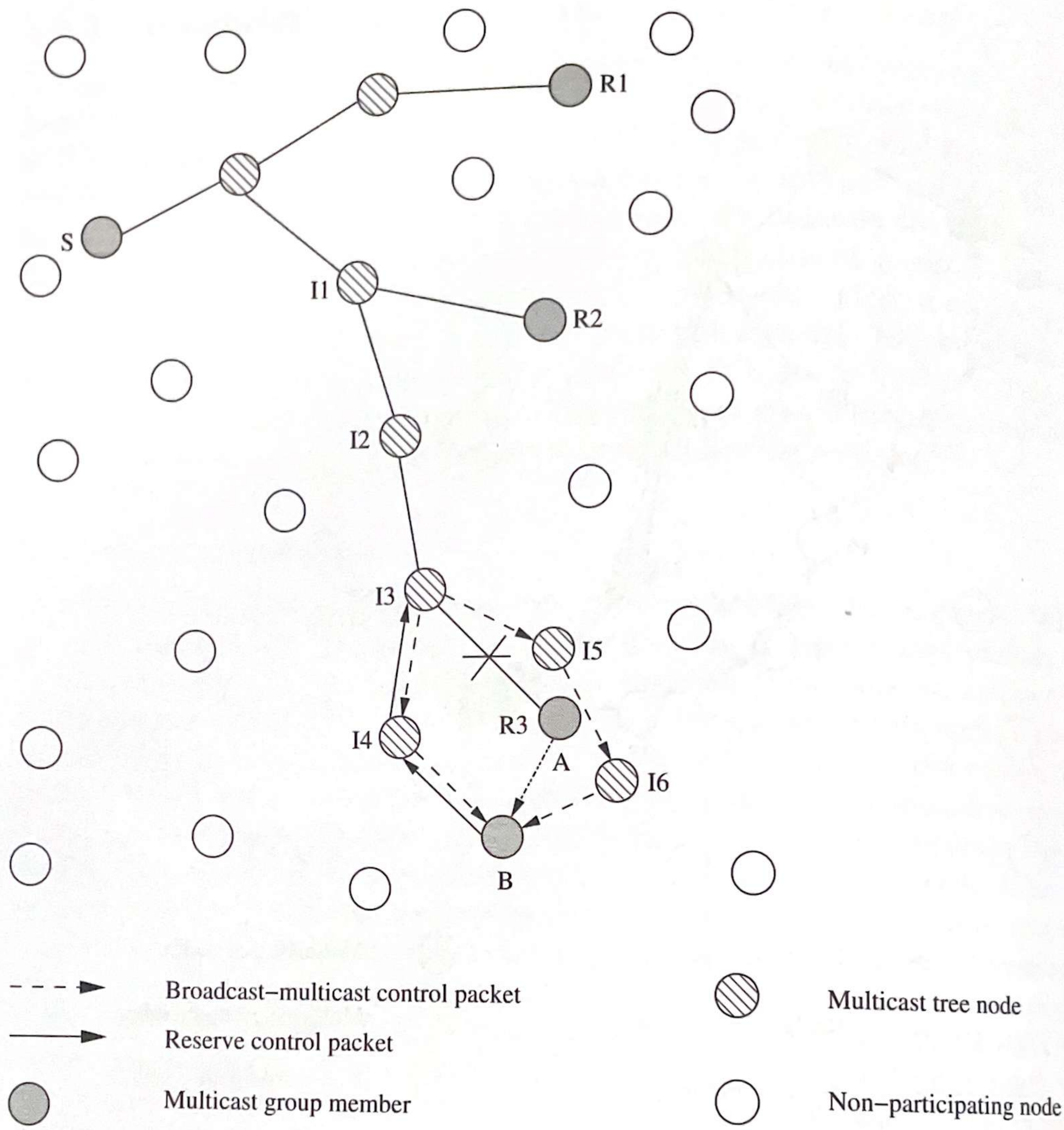

Figure 8.6. Multicast tree maintenance in broadcast-multicast scheme.

Route Optimization Phase

When a tree node or a receiver node comes within the transmission range of other tree nodes, then unwanted tree nodes are pruned by sending the *Quit* message. In Figure 8.8, when receiver R3 comes within the transmission range of the intermediate node I2, it will receive a multicast packet from node I2 earlier than from node I5. When node R3 receives a multicast packet from node I2, it sends a *Reserve* packet to node I2 to set up a new route directly to node I2, and sends a *Quit* packet to node I5. Since node R3 is no more its downstream node, node I5 sends a *Quit* packet to node I4, node I4 sends a *Quit* packet to node I3, and node I3 in turn sends a *Quit* packet to node I2. Thus unnecessary forwarding nodes are pruned. This mechanism helps to reduce the number of data packet transmissions.

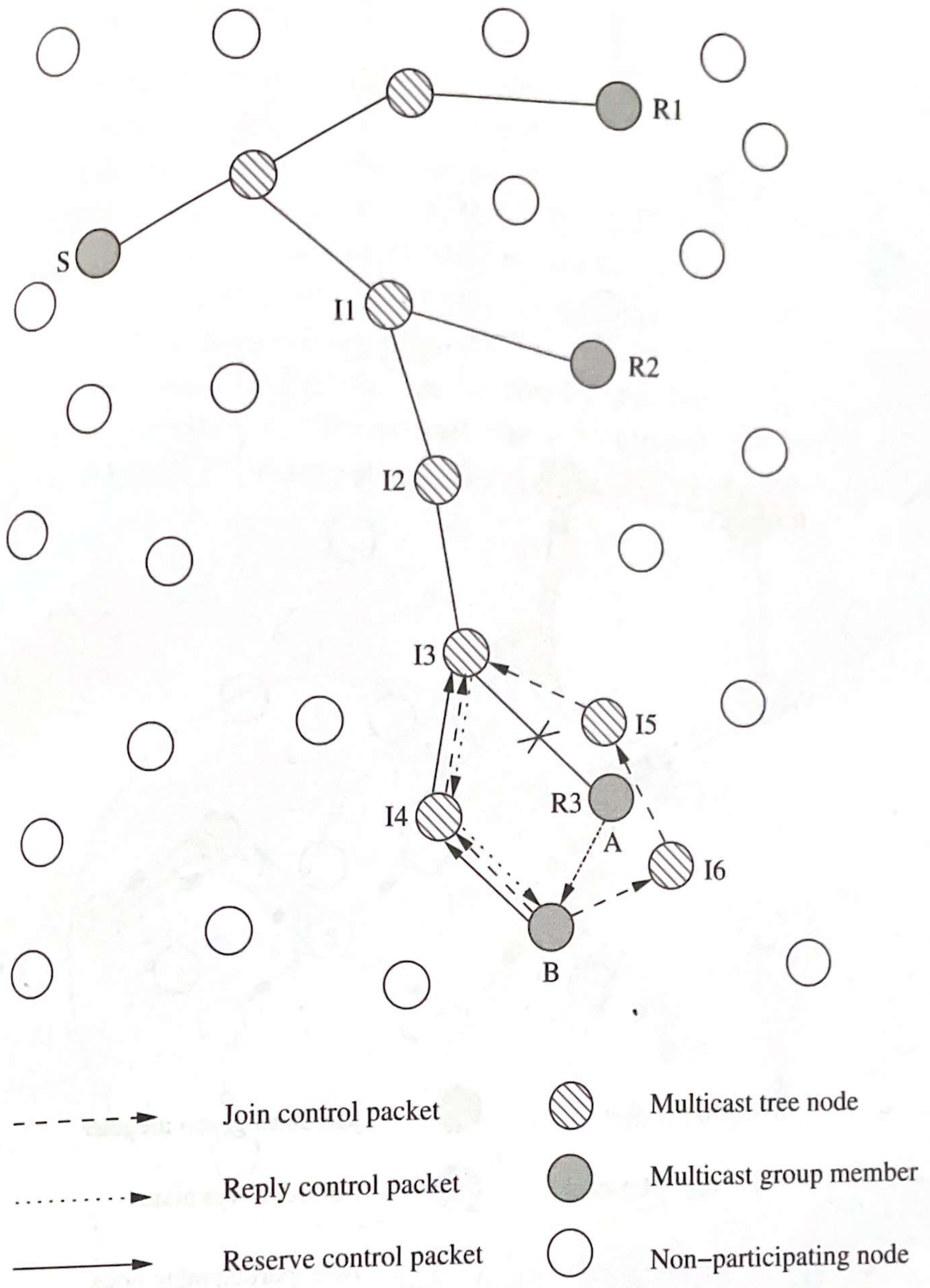

Figure 8.7. Multicast tree maintenance in local rejoin scheme.

Advantages and Disadvantages

The main advantage of this multicast protocol is that it saves bandwidth due to the reduction in the number of data packet transmissions and the hard state approach being adopted for tree maintenance. Since a node joins the multicast group through its nearest forwarding node, the distance between source and receiver increases. This increase in distance increases the probability of path breaks, which in turn gives rise to an increase in delay and reduction in the packet delivery ratio. Also, since the protocol uses the hard state approach for route repair, a considerable amount of time is spent by the node in reconnecting to the multicast session, which adds to the delay in packet delivery.

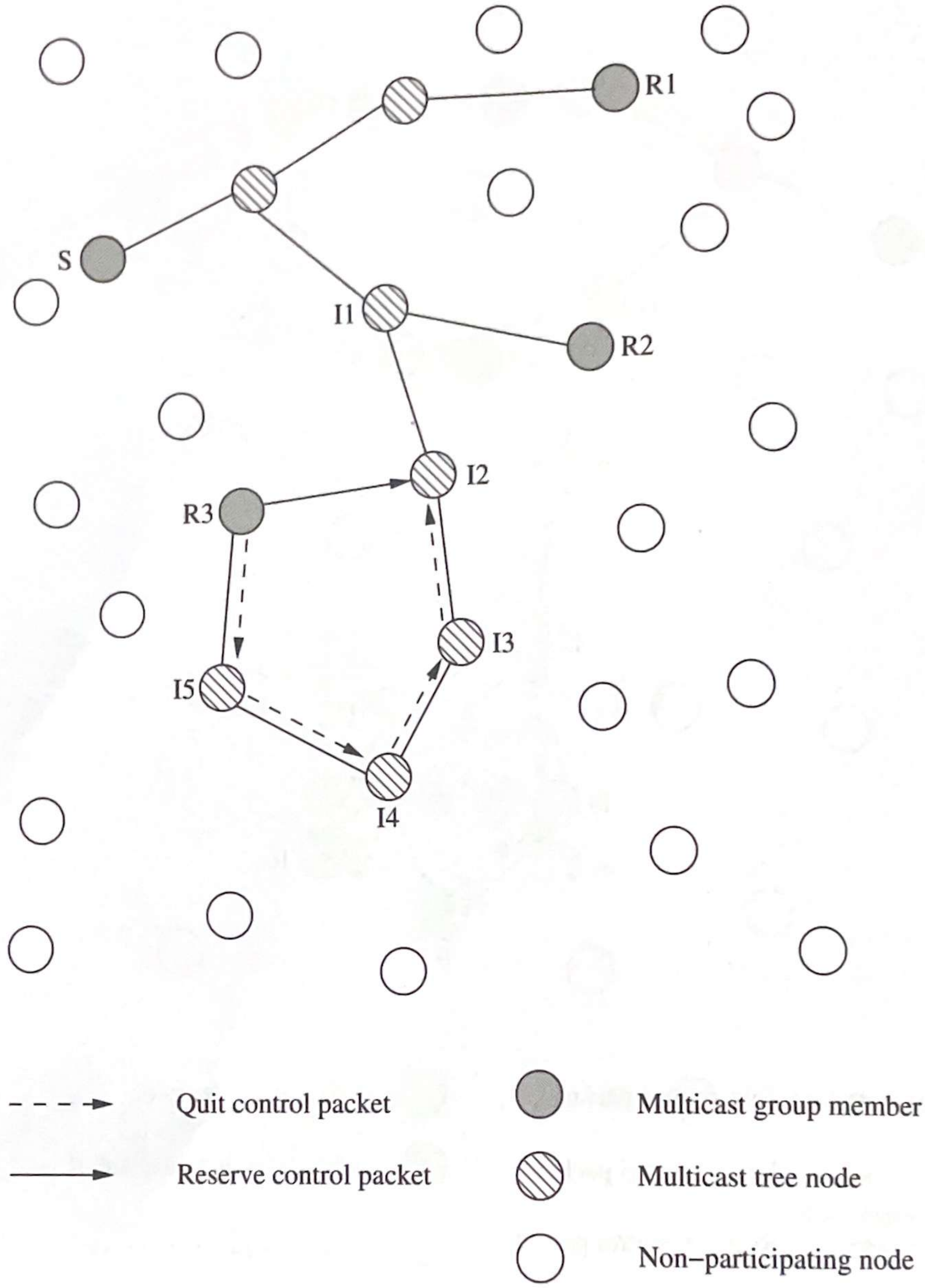

Figure 8.8. Multicast tree optimization in BEMRP.

8.6.2 Multicast Routing Protocol Based on Zone Routing

In multicast zone routing protocol (MZRP) [9], the flooding of control packets by each node which searches for members of the multicast group is controlled by using the *zone routing mechanism* [10]. In zone routing, each node is associated with a routing zone. For routing, a pro-active approach is used inside the zone (the node maintains the topology inside the zone, using a *table-driven* routing protocol), whereas a reactive approach is used across zones. In a nutshell, it attempts to combine the best of both on-demand and table-driven routing approaches.

Tree Initialization Phase

To create a multicast delivery tree over the network, the source initiates a two-stage process. In the first stage, the source tries to form the tree inside the zone, and then in the second stage it extends the tree to the entire network. In Figure 8.9, to create the tree, initially source S sends a TREE-CREATE control packet to nodes within its zone through unicast routing as it is aware of the topology within its zone, then node R1, which is interested in joining the group, replies with a TREE-CREATE-ACK packet and forms the route (for the sake of clarity, routing zones of nodes have been represented as circular regions in the figure; however, they need not always take the shape of circles). To extend the tree outside the zone, source S sends a TREE-PROPAGATE packet to all the border nodes of the zone. When node B

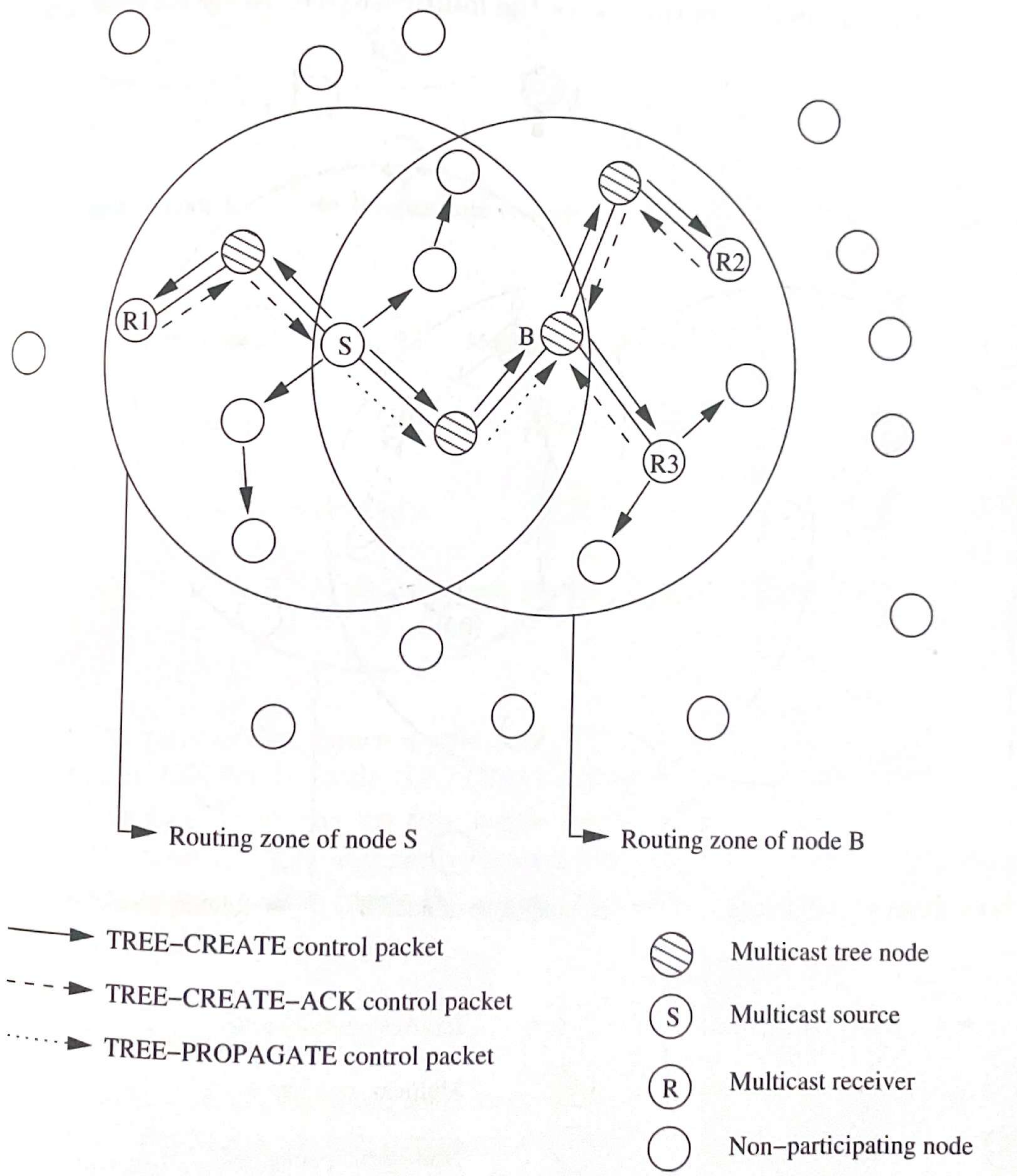

Figure 8.9. Multicast tree initialization in MZRP.

(which is at the border of the zone of node S) receives the TREE-PROPAGATE packet, it sends a TREE-CREATE packet to each of its zone nodes. Thus receivers R2 and R3 receive the TREE-CREATE packets and join the multicast session by sending TREE-CREATE-ACK packets.

Tree Maintenance Phase

Once the multicast tree is created, the source node periodically transmits TREE-REFRESH packets down the tree to refresh the multicast tree. If any tree node does not receive a TREE-REFRESH packet within a specific time period, it removes the corresponding stale multicast route entry. When a link in the multicast tree breaks, downstream nodes are responsible for detecting link breaks and rejoining the multicast group. Due to movement of the intermediate node I (Figure 8.10), receiver R2 gets isolated from the rest of the multicast tree. Node R2 first unicasts a

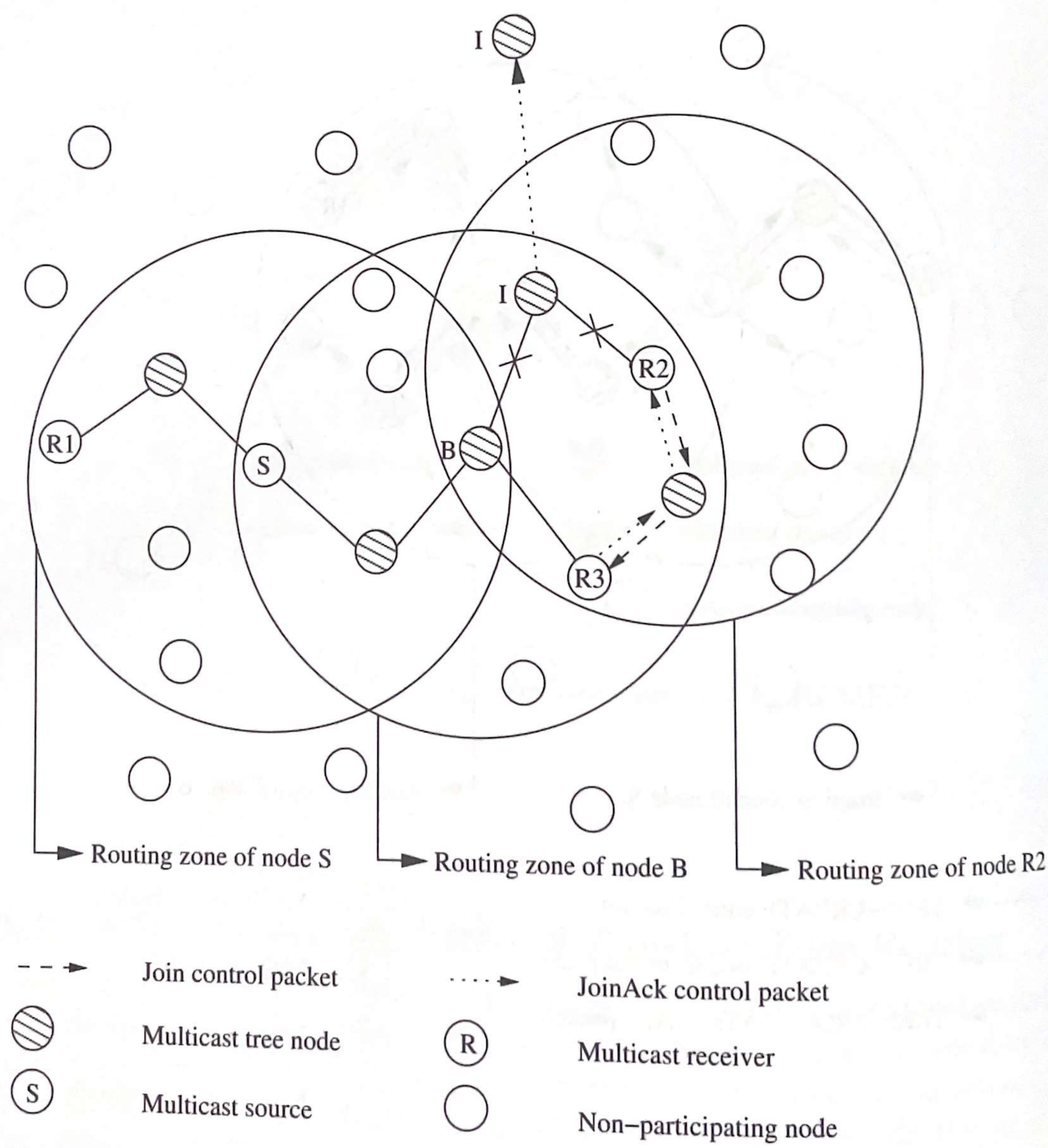

Figure 8.10. Multicast tree maintenance in MZRP.

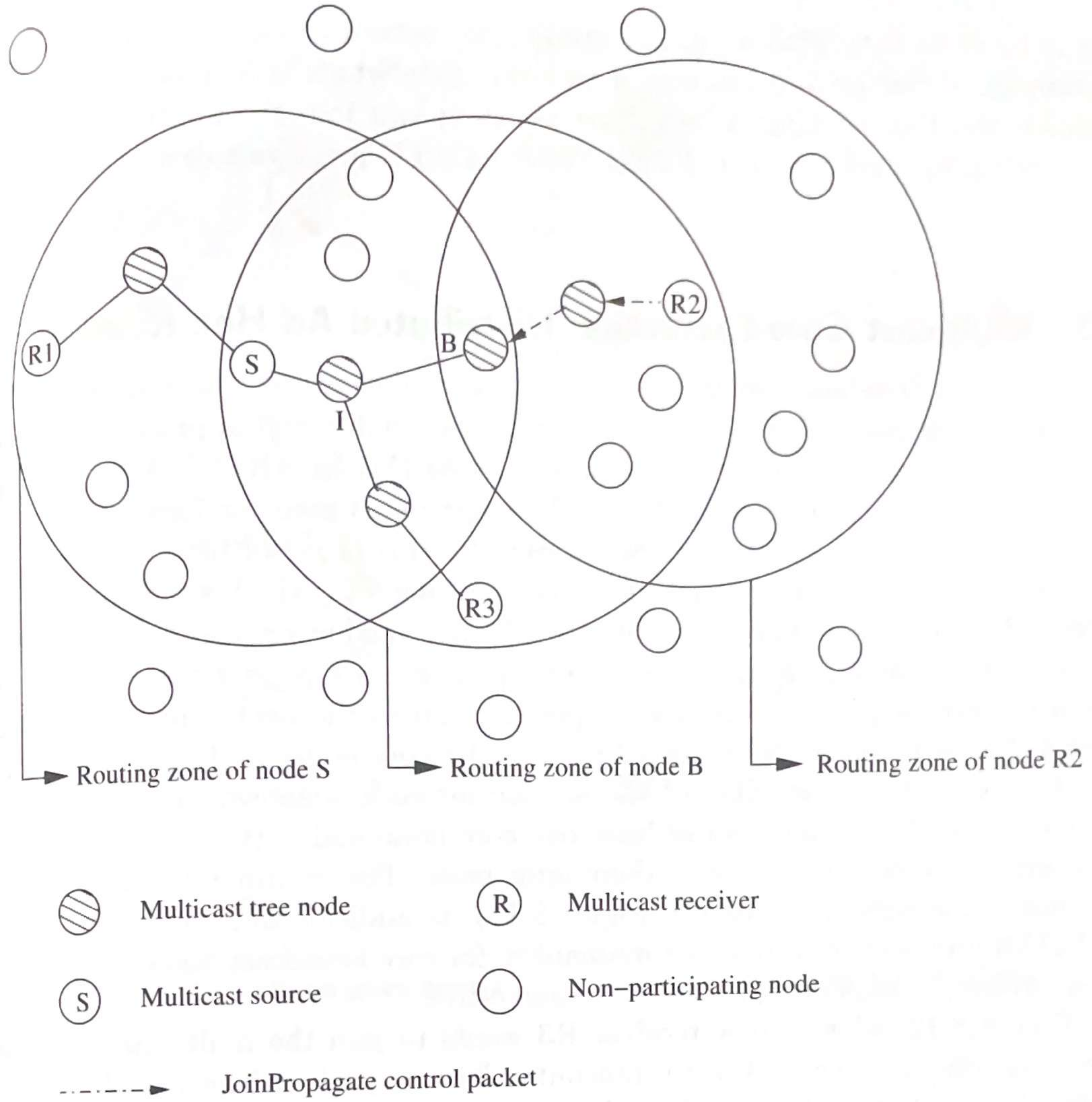

Figure 8.11. Multicast tree maintenance in MZRP.

Join packet to all zone nodes. Since a tree node R3 is already in the zone, it replies back by sending a *JoinAck* to node R2. Thus receiver R2 again joins the multicast group. It may be that there are no tree nodes in the zone of receiver R2. In this case, receiver R2 does not get any reply from zone nodes, it sends *JoinPropagate* control packets to border nodes (node B), and it joins the tree through intermediate node I (see Figure 8.11).

Advantages and Disadvantages

MZRP has reduced control overhead as it runs over ZRP. The fact that the unicast and multicast routing protocols can exchange information with each other is another advantage of MZRP. MZRP is important as it shows the efficacy of the zone-based approach to multicast routing. The size of the zone is very important in MZRP. The size should be neither too large nor too small. The optimum value for the zone radius is likely to vary with multicast group size, network load conditions, etc. A disadvantage of this protocol is that a receiver node which is located far off from the source needs to wait for a long time before it can join the multicast session, because the propagation of the TREE-PROPAGATE message takes considerable time.

8.7 MESH-BASED MULTICAST ROUTING PROTOCOLS

In ad hoc wireless networks, wireless links break due to the mobility of the nodes. In the case of multicast routing protocols, the path between a source and receiver, which consists of multiple wireless hops, suffers very much due to link breaks. Multicast routing protocols which provide multiple paths between a source-receiver pair are classified as mesh-based multicast routing protocols. The presence of multiple paths adds to the robustness of the mesh-based protocols at the cost of multicast efficiency. In this section, some of the existing mesh-based multicast routing protocols are described in detail.

8.7.1 On-Demand Multicast Routing Protocol

In the on-demand multicast routing protocol (ODMRP) [24], a mesh is formed by a set of nodes called forwarding nodes which are responsible for forwarding data packets between a source-receiver pair. These forwarding nodes maintain the *message-cache* which is used to detect duplicate data packets and duplicate *JoinReq* control packets.

Mesh Initialization Phase

In the mesh initialization phase, a multicast mesh is formed between the sources and the receivers. To create the mesh, each source in the multicast group floods the *JoinReq* control packet periodically. Upon reception of the *JoinReq* control packet from a source, potential receivers can send *JoinReply* through the reverse shortest path. The route between a source and receiver is established after the source receives the *JoinReply* packet. This is illustrated in Figure 8.30. For initializing the mesh, sources S1 and S2 in the multicast group flood the *JoinReq* control packets. The nodes that receive a *JoinReq* control packet store the upstream node identification number (ID) and broadcast the packet again. When receivers R1, R2, and R3 receive the *JoinReq* control packet, each node sends a *JoinReply* control packet along the reverse path to the source. Here in Figure 8.30, receiver R2 receives *JoinReq* control packets from sources S1 and S2 through paths S1-I2-I3-R2 and S2-I6-I4-I5-R2, respectively. The *JoinReply* packet contains the source ID and the corresponding next node ID (the upstream node through which it received the *JoinReq* packet). When node I2 receives the *JoinReply* control packet from receiver R1, it sets a forwarding flag and becomes the forwarding node for that particular multicast group. After waiting for a specified time, it composes a new *JoinReply* packet and forwards it. The format of the *JoinReply* packet sent by the node R2 is shown in Table 8.2. In this way, subsequent forwarding of *JoinReply* packets by the intermediate nodes along the reverse path to the source establishes the route.

Table 8.2. Format of *JoinReply* packet sent by receiver R2

Source ID	Next Node ID
$S1$	$I3$
$S2$	$I5$

Mesh Maintenance Phase

In this phase, attempts are made to maintain the multicast mesh topology formed with sources, forwarding nodes, and receivers. To some extent, the multicast mesh

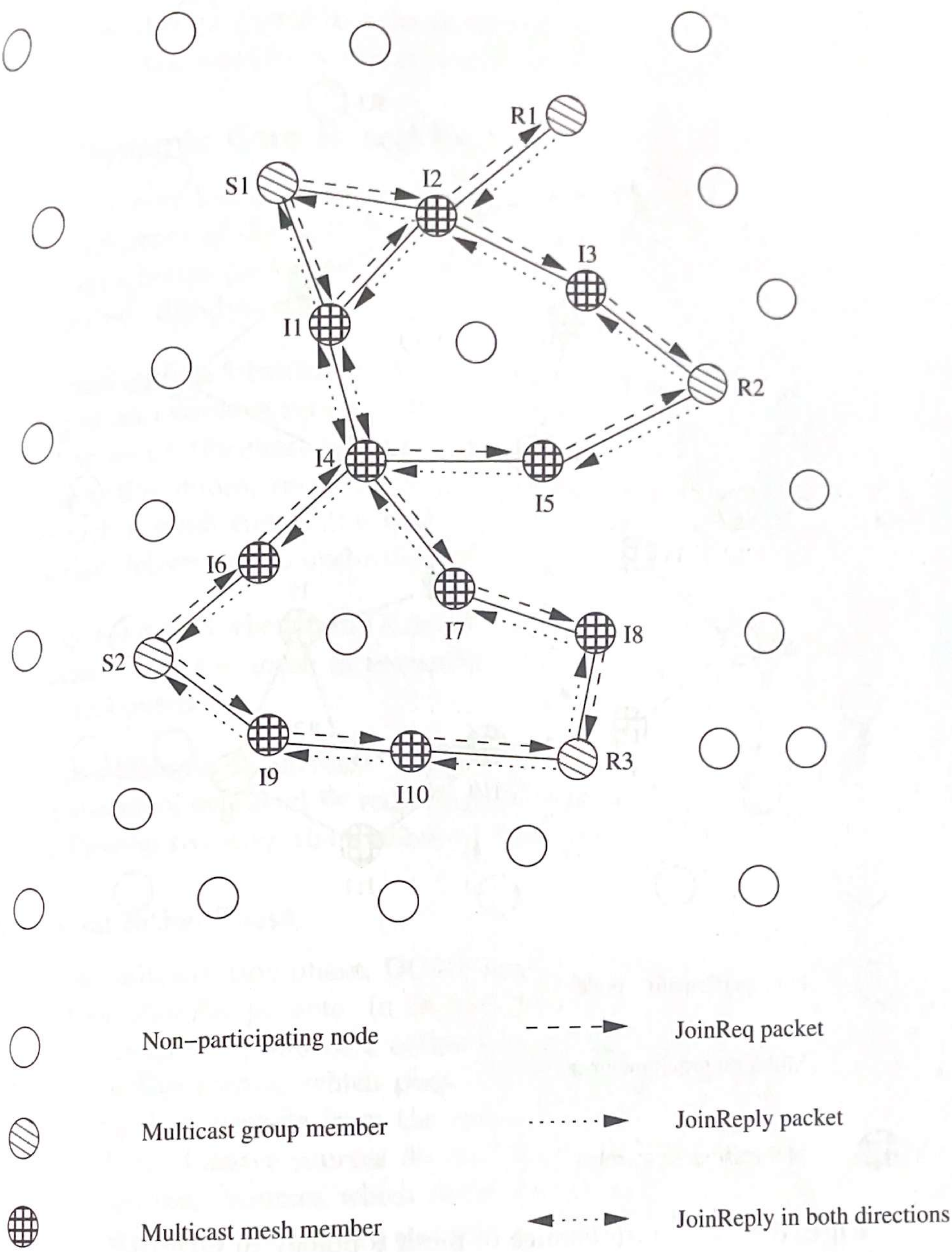

Figure 8.30. Mesh topology in ODMRP.

protects the session from being affected by mobility of nodes. For example, due to movement of the receiver R3 (from A to B), when the route S2-I9-I10-R3 breaks (Figure 8.31), R3 can still receive data packets through route S2-I6-I4-I7-I8-R3 and this contributes to the high packet delivery ratio. ODMRP uses a soft state approach to maintain the mesh, that is, to refresh the routes between the source and the receiver, the source periodically floods the *JoinReq* control packet. In Figure 8.31, when receiver R3 receives a new *JoinReq* control packet from node I11 (sent

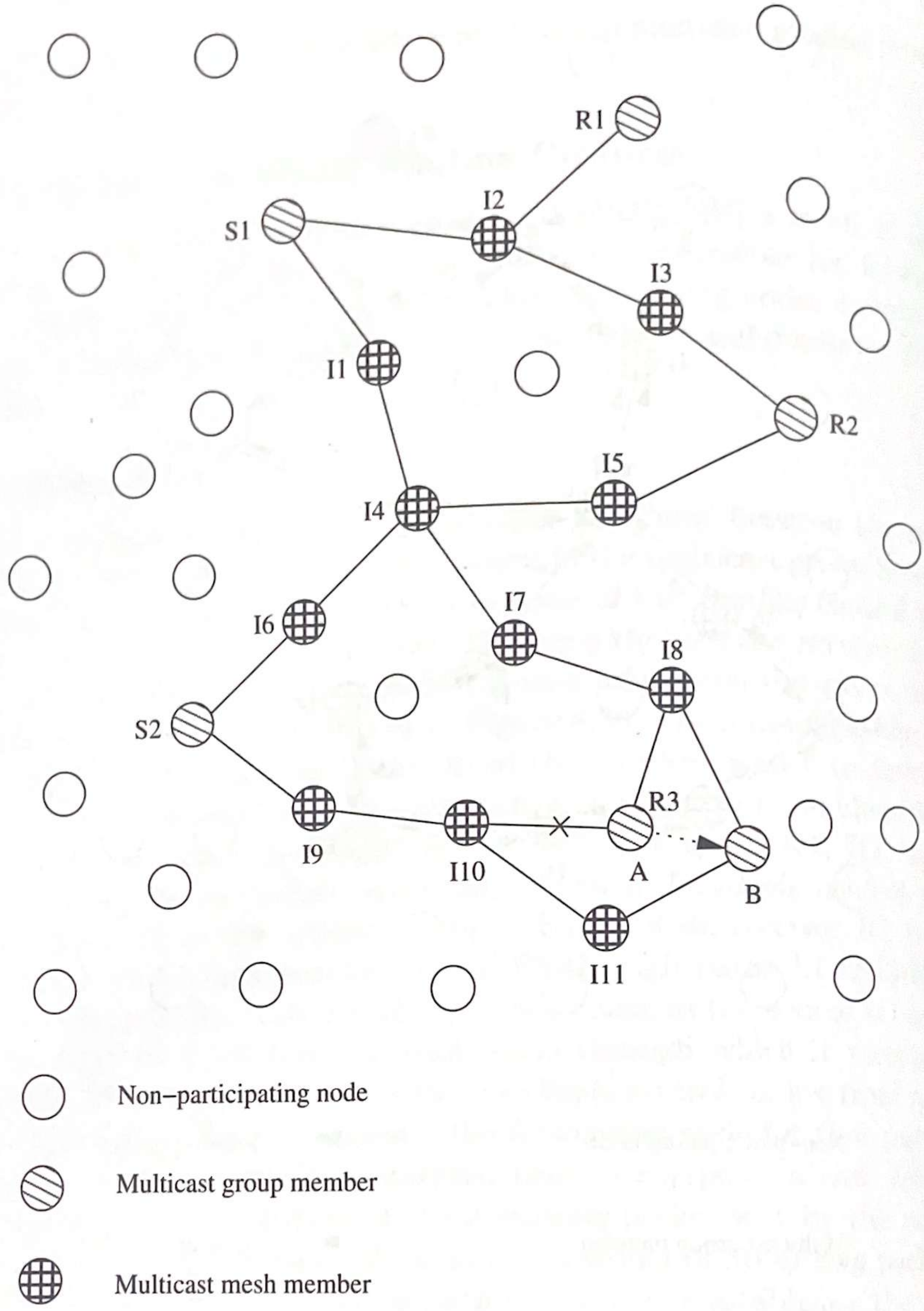

Figure 8.31. Maintenance of mesh topology in ODMRP.

by the source S2), it sends a *JoinReply* on this new shortest path R3-I11-I10-I9-S2, thereby maintaining the mesh structure.

Advantages and Disadvantages

Since ODMRP uses the soft state approach for maintaining the mesh, it exhibits robustness. But this robustness is at the expense of high control overhead. Another disadvantage is that the same data packet (from source S2 to receiver R3) propagates through more than one path to a destination node, resulting in an increased number of data packet transmissions, thereby reducing the multicast efficiency.

8.7.2 Dynamic Core-Based Multicast Routing Protocol

The dynamic core-based multicast routing protocol (DCMP) [25] attempts to improve the efficiency of the ODMRP multicast protocol by reducing control overhead and providing better packet delivery ratio. Mesh-based protocols, such as ODMRP, suffer from two disadvantages:

1. Excessive data forwarding: Too many nodes become forwarding nodes, resulting in an excessive number of retransmissions of data packets. In ODMRP, all nodes on the shortest path between each source and each receiver become forwarding nodes, resulting in too many forwarding nodes. (The advantage of such a mesh containing many forwarding nodes is, of course, the superior packet delivery ratio and robustness under mobility.)

2. High control overhead: In ODMRP, each source periodically floods its *JoinReq* packets and the mesh is reconstructed periodically. This leads to a heavy control overhead.

DCMP attempts to increase the packet delivery ratio and at the same time reduce the control overhead by reducing the number of sources which flood *JoinReq* packets, thereby reducing the number of forwarding nodes.

Mesh Initialization Phase

In the mesh initialization phase, DCMP attempts to reduce the number of sources flooding their *JoinReq* packets. In DCMP, there are three kinds of sources: passive sources, active sources, and core active sources. Each passive source is associated with a core active source, which plays the role of a proxy for the passive source, by forwarding data packets from the *passive* source, over the mesh created by its *JoinReq* packets. Passive sources do not flood *JoinReq* packets, unlike active and core active sources. Sources which flood *JoinReq* packets on their behalf as well as on the behalf of some passive source are called core active sources. The mesh establishment protocol is similar to that in ODMRP. Data packets of the active sources and core active sources are sent over the mesh created by themselves, while a passive source forwards the packet to its proxy core active node, which in turn sends it over its mesh. The control overhead is reduced, as compared to ODMRP, because there are a fewer number of sources which flood their *JoinReq* packets, and thus the number of forwarding nodes is also fewer. To allow the mesh to have enough forwarding nodes for robust operation, the number of passive sources has to be limited: This is done in DCMP by limiting the maximum number of passive sources a single core active source can serve (this maximum number is called *MaxPassSize*). To ensure that the packet delivery ratio is not reduced because of the fact that the average passive source-to-receiver distance is likely to be higher (because it is reusing the mesh created by its proxy core active node), the maximum hop distance between a passive source and its proxy core active node is also limited (this maximum hop distance is called *MaxHop*).

The example in Figure 8.32 shows mesh construction in DCMP, with the *MaxHop* and *MaxPassSize* parameters set to two. There are four sources in the multicast group, S1, S2, S3, and S4 and two receivers labeled R. Since S3 and S4 are at a hop distance of two from each other (which is equal to *MaxHop*), S3 goes passive and uses a proxy in the core active node S4. No other set of sources is within a hop distance of two from each other, so eventually S1 and S2 are the active sources, S3 is a passive source, and S4 is a core active source. The mesh consists of all the shortest paths between the sources S1, S2, and S3 and the two receivers R. Thus,

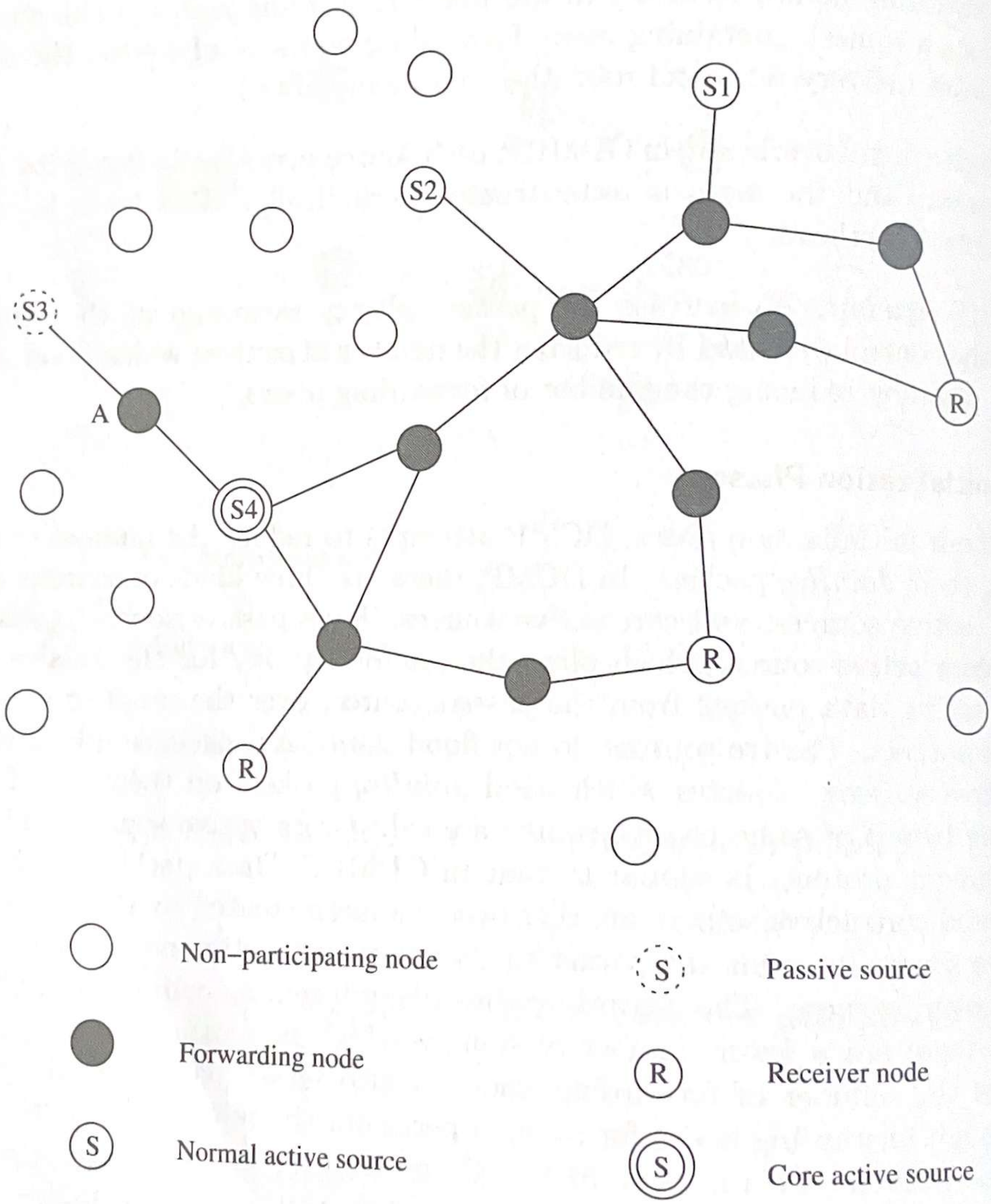

Figure 8.32. Construction of mesh in DCMP. *Reproduced with permission from [25], © ACM, 2002.*

the number of forwarding nodes is reduced, as compared to ODMRP, without much reduction in robustness and packet delivery ratio.

Mesh Maintenance Phase

DCMP's mesh maintenance is soft state, similar to that of ODMRP. Thus, the mesh is reconstructed periodically and forwarding nodes that are no longer part of the mesh, cancel their forwarding status after a timeout period. In the example shown in Figure 8.33, source S3 has moved away from its core active node S4, with the hop distance between them increasing to three (which is greater than the *MaxHop* parameter=2). Thus, S3 goes active, and begins flooding periodically with its own

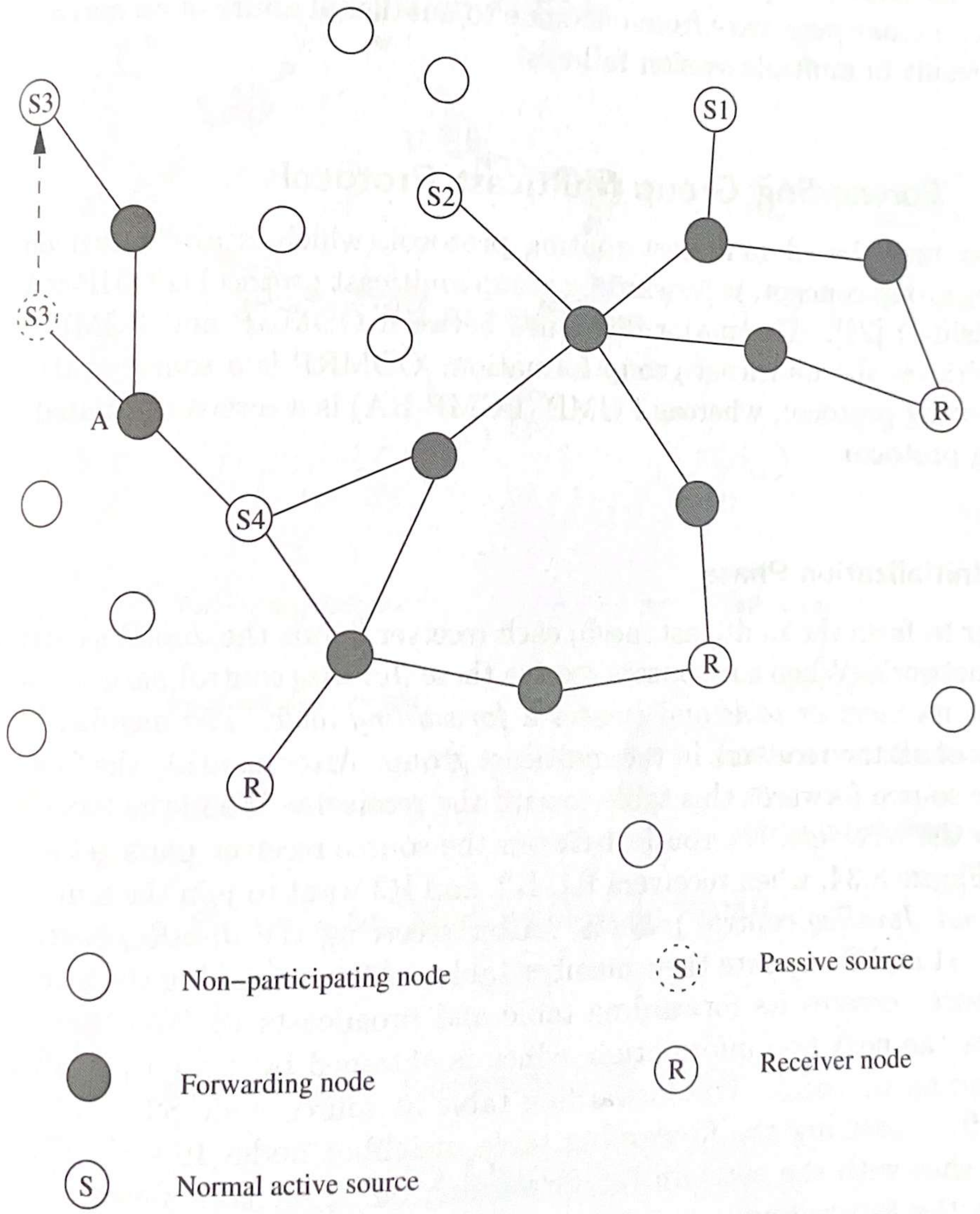

Figure 8.33. Maintenance of mesh topology in DCMP. *Reproduced with permission from [25], © ACM, 2002.*

JoinReq packets. Therefore, more nodes attain forwarding status and are grafted onto the mesh.

Advantages and Disadvantages

The primary advantage of DCMP is its scalability due to decreased control overhead and its superior packet delivery ratio. The performance improvement of DCMP over ODMRP increases with the number of sources in the multicast group (though they start performing on par beyond a certain number of sources, when almost all nodes are part of the mesh). One of the drawbacks of DCMP is that the parameters associated with it, *MaxPassSize* and *MaxHop*, are likely to depend on the network load conditions, group size, and number of sources, and optimal values of these parameters may even vary from one node to another. Failure of an active core node might result in multiple session failures.