Module 3

MULTICAST ROUTING IN AD HOC WIRELESS NETWORKS

Ad hoc wireless networks find applications in civilian operations (collaborative and distributed computing), emergency search-and-rescue, law enforcement, and warfare situations, where setting up and maintaining a communication infrastructure may be difficult or costly. In all these applications, communication and coordination among a given set of nodes are necessary.

Multicast routing protocols play an important role in ad hoc wireless networks to provide this communication. It is always advantageous to use multicast rather than multiple unicast, especially in the ad hoc environment, where bandwidth comes at a premium.

Conventional wired network Internet protocol (IP) multicast routing protocols, such as DVMRP [1], MOSPF [2], CBT [3], and PIM [4], do not perform well in ad hoc networks because of the dynamic nature of the network topology.

In a wired network, the basic approach adopted for multicasting consists of establishing a routing tree for a group of routing nodes that constitute the multicast session. Once the routing tree (or the spanning tree, which is an acyclic connected subgraph containing all the nodes in the tree) is established, a packet sent to all nodes in the tree traverses each node and each link in the tree only once. Such a multicast structure is not appropriate for ad hoc networks because the tree could easily break due to the highly dynamic topology.

Multicast tree structures are not stable and need to be reconstructed continuously as connectivity changes. Maintaining a routing tree for the purpose of multicasting packets, when the underlying topology keeps changing frequently, can incur substantial control traffic.

Therefore, multicast protocols used in static wired networks are not suitable for ad hoc wireless networks.

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:**
- **Efficiency**
- **Control overhead:**
- **Quality of service**
- **Dependency on the unicast routing protocol**
- **Resource management**

OPERATION OF MULTICAST ROUTING PROTOCOLS

Based on the type of operation, multicast protocols for ad hoc wireless networks are broadly classified into two types: *source-initiated* protocols and *receiver initiated* protocols.

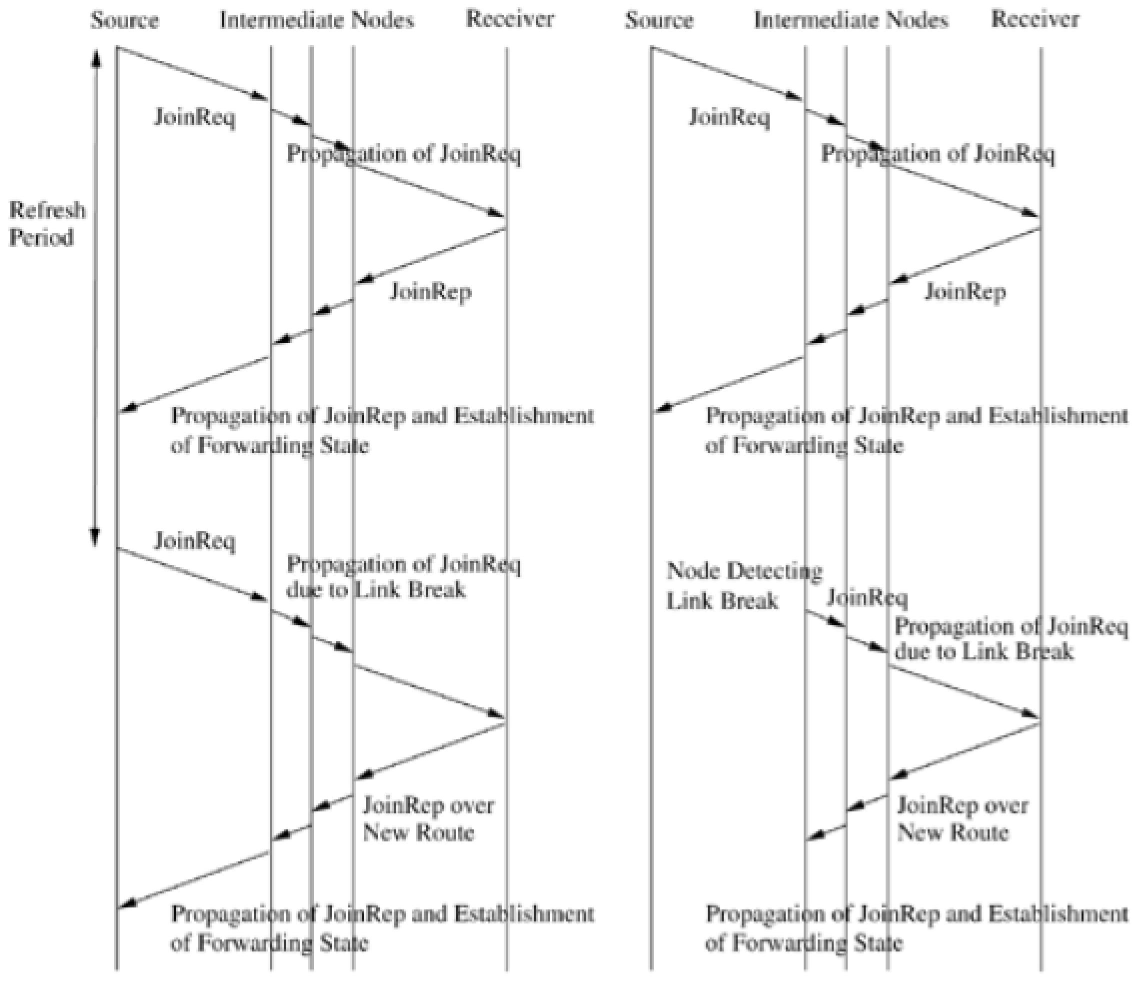
Source-Initiated Protocols

Shows the events as they occur in a source-initiated protocol that uses a soft state maintenance approach. In the soft state maintenance approach, the multicast tree or mesh is periodically updated by means of control packets.

In such protocols, the source(s) of the multicast group periodically floods *JoinRequest* (*JoinReq*) packet throughout the network. This *JoinReq* packet is propagated by other nodes in the network, and it eventually reaches all the receivers of the group. Receivers of the multicast group express their wish to receive packets for the group by responding with a *JoinReply* (*JoinRep*) packet, which is propagated along the reverse path of that followed by the*JoinReq* packet.

This *JoinRep* packet establishes forwarding states (forwarding state refers to the information regarding the multicast group maintained at nodes in the multicast tree or mesh, which aids the nodes in forwarding multicast packets to the appropriate next-hop neighbor nodes) in the intermediate nodes (either in the tree or mesh), and finally reaches the source. Thus, this is a two-pass protocol for establishing the tree (or mesh). There is no explicit procedure for route repair. In soft state protocols, the source periodically (once every *refresh period*) initiates the above procedure.

In Figure 8.1 (b), the operation of a hard state source-initiated protocol is shown. It is similar to that of a soft state source-initiated protocol, except that there is an explicit route repair procedure that is initiated when a link break (in the tree or mesh) is detected. The route repair procedure shown in Figure 8.1 (b) is a simple solution: The upstream node which detects that one of its downstream nodes has moved away, initiates a tree construction procedure (similar to the one initiated by the source). Different protocols adopt different strategies for route repair. Some protocols choose to have the downstream node search for its former parent (in the tree or mesh) by means of limited flooding, while others impose this responsibility on the upstream node.

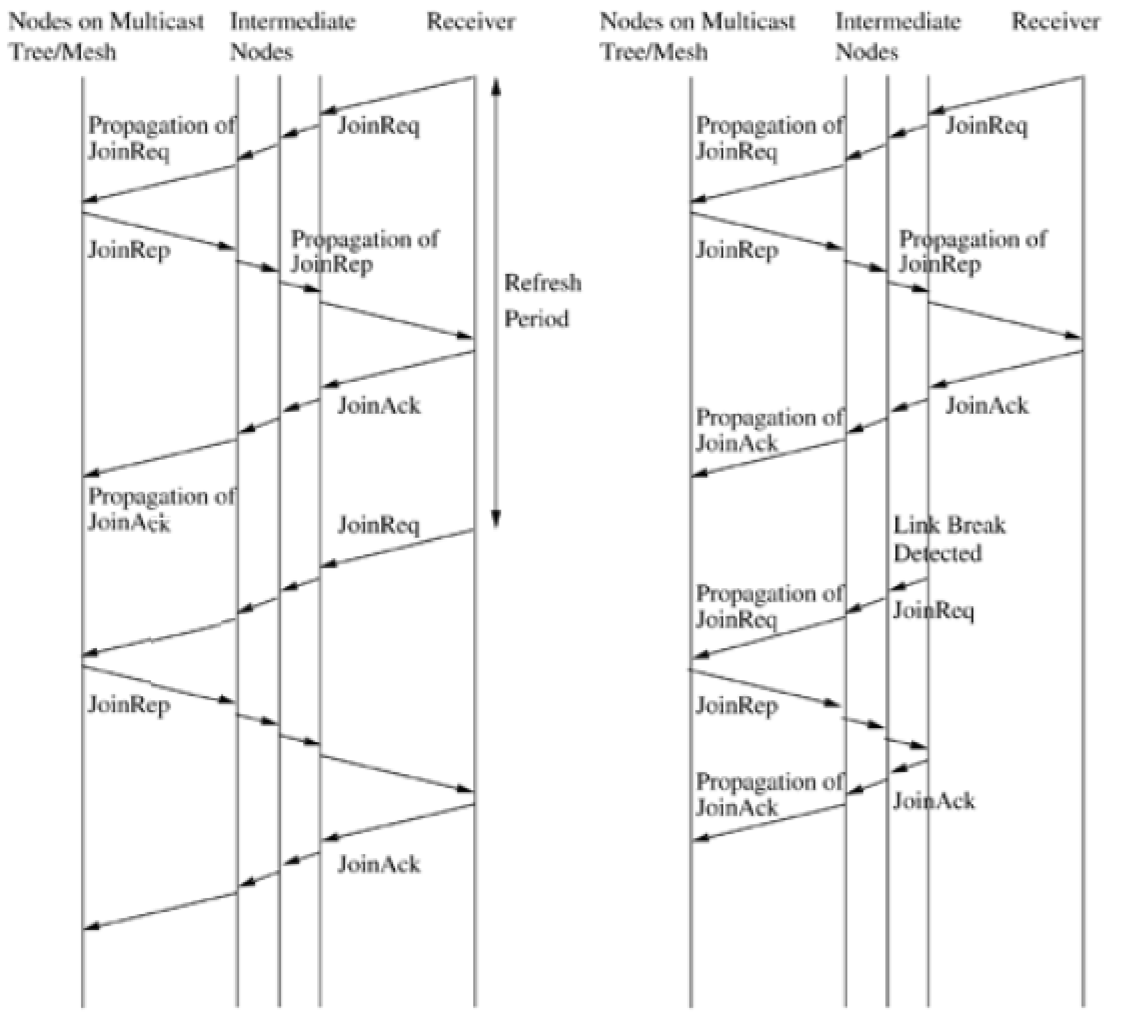


(a) Source–Initiated, Soft State Multicast Protocols (b) Source–Initiated, Hard State Multicast Protocols

Receiver-Initiated Protocols

In the receiver-initiated multicasting protocols, the receiver uses flooding to search for paths to the sources of the multicast groups to which it belongs. The soft state variant is illustrated in Figure 8.2 (a). The tree (or mesh) construction is a three-phase process. First, the receiver floods a *JoinReq* packet, which is propagated by the other nodes. Usually, the sources of the multicast group and/or nodes which are already part of the multicast tree (or mesh), are allowed to respond to the *JoinReq* packet with a *JoinRep* packet, indicating that they would be able to send data packets for that multicast group. The receiver chooses the *JoinRep* with the smallest hop count (or some other criterion) and sends a*JoinAcknowledgment* (*JoinAck*) packet along the reverse path (taken by the *JoinRep*). Route maintenance is accomplished by the periodic initiation of this procedure by the receiver.

In Figure 8.2 (b), the hard state variant is illustrated. The initial tree- (or mesh-) joining phase is the same as that in the corresponding soft state protocol. The route repair mechanism comes into play when a link break is detected: The responsibility to restore the multicast topology can be ascribed to either the downstream or to the upstream node. In Figure 8.2 (b), the downstream node searches for a route to the multicast tree (or mesh) through a procedure similar to the initial topology construction procedure.



(a) Receiver–Initiated, Soft State Multicast Protocols (b) Receiver–Initiated, Hard State Multicast Protocols

AN ARCHITECTURE REFERENCE MODEL FOR MULTICAST ROUTING PROTOCOLS

A reference model for understanding the architecture of multicast routing protocols is presented. This will aid the reader in understanding the different modules in the implementation of multicast routing protocols for ad hoc wireless networks. There are three layers in the network protocol stack concerned with multicasting in ad hoc wireless networks

1. **Medium access control (MAC) layer**
   Important services provided by this layer to the ones above are transmission and reception of packets.

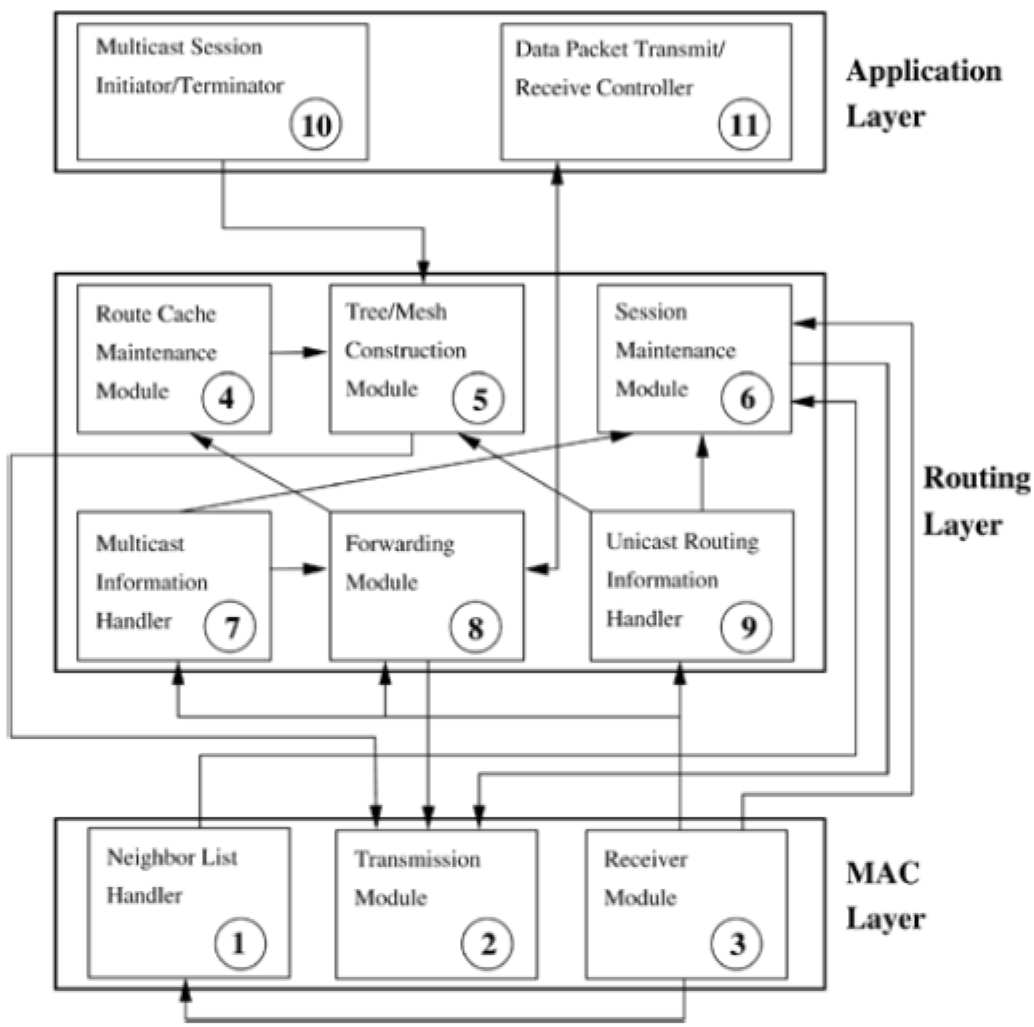
Apart from these functions, three other important functions are performed by this layer that are particularly important in wireless multicast: detecting all the neighbors (nodes at a hop distance of 1), observing link characteristics, and performing broadcast transmission/reception. Corresponding to these services, the MAC layer can be thought of as consisting of three principal modules:

   Transmission module:
   Receiver module.
   Neighbor list handler:
2. **Routing layer:**
   This layer is responsible for forming and maintaining the unicast session/multicast group.
   Unicast routing information handler
   Multicast information handler
   Forwarding module:
   Tree/mesh construction module
   Session maintenance module
   Route cache maintenance module
3. **Application layer:**
   This layer utilizes the services of the routing layer to satisfy the multicast requirements of applications. It primarily consists of two modules:
   1. Data packet transmit/receive controller
   2. Multicast session initiator/terminator

The interactions between these modules can be understood by

Considering some actions

1. *Joining a group*
2. *Data packet propagation*
3. *Route repair*



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 below Figure).

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**

   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.

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 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.

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.*

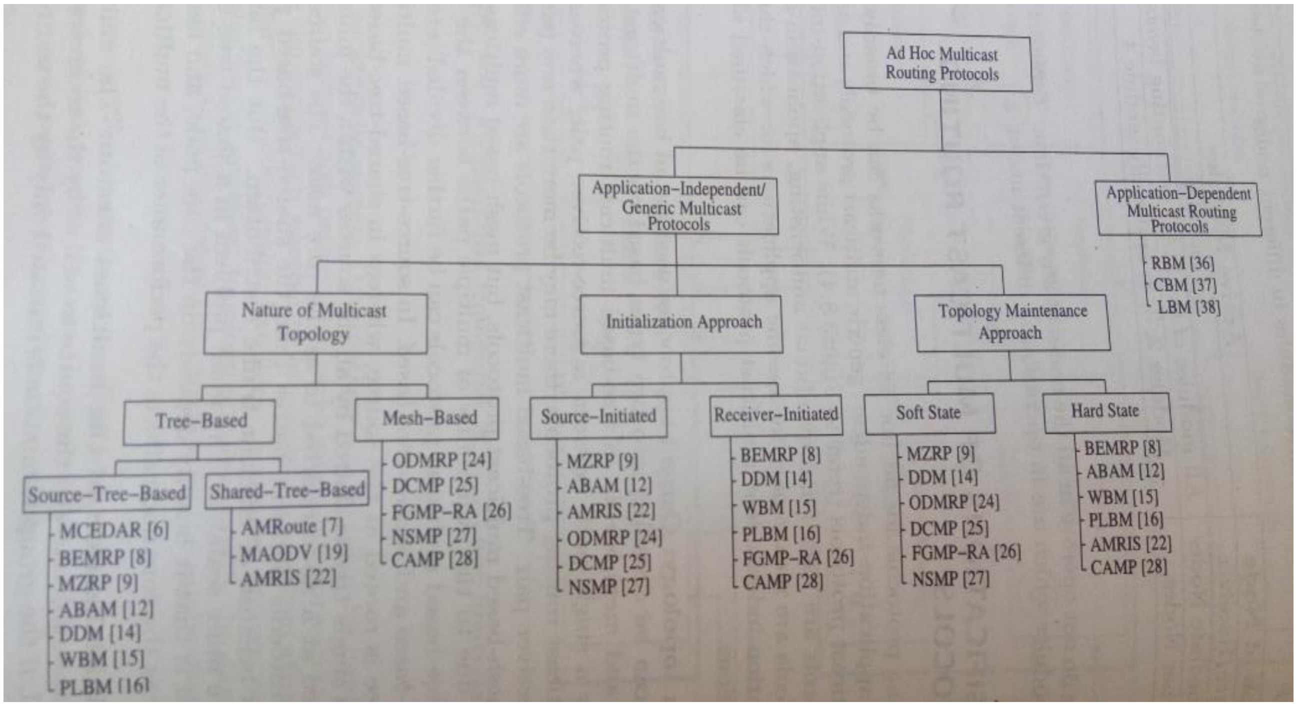


Figure: Classification of routing protocols

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

In a source-tree-based protocol, a single multicast tree is maintained per source, whereas in a sharedtree- 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. The rest of this section describes some of the existing tree-based multicast routing protocols for ad hoc wireless networks.

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 hosen*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.

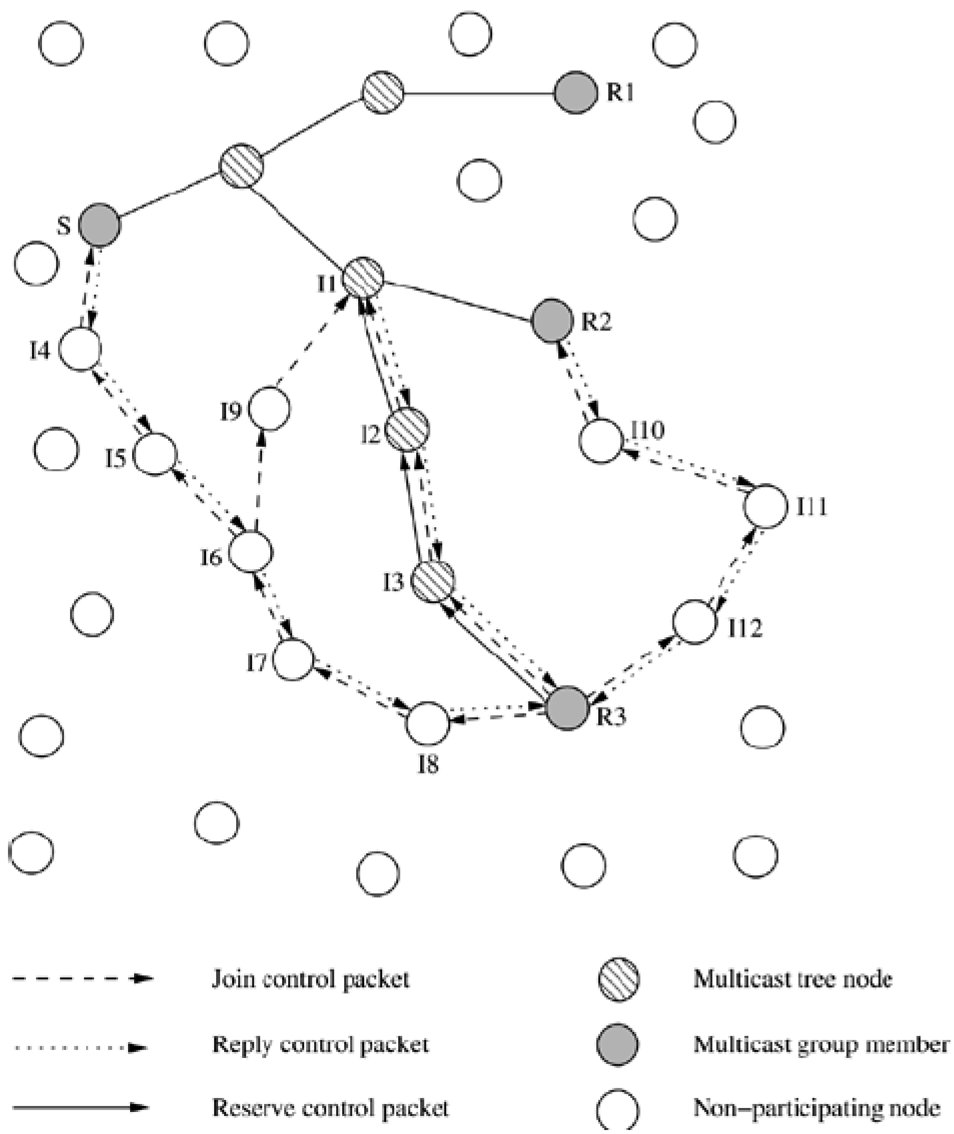


Figure 8.5. Multicast tree initialization in BEMRP

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

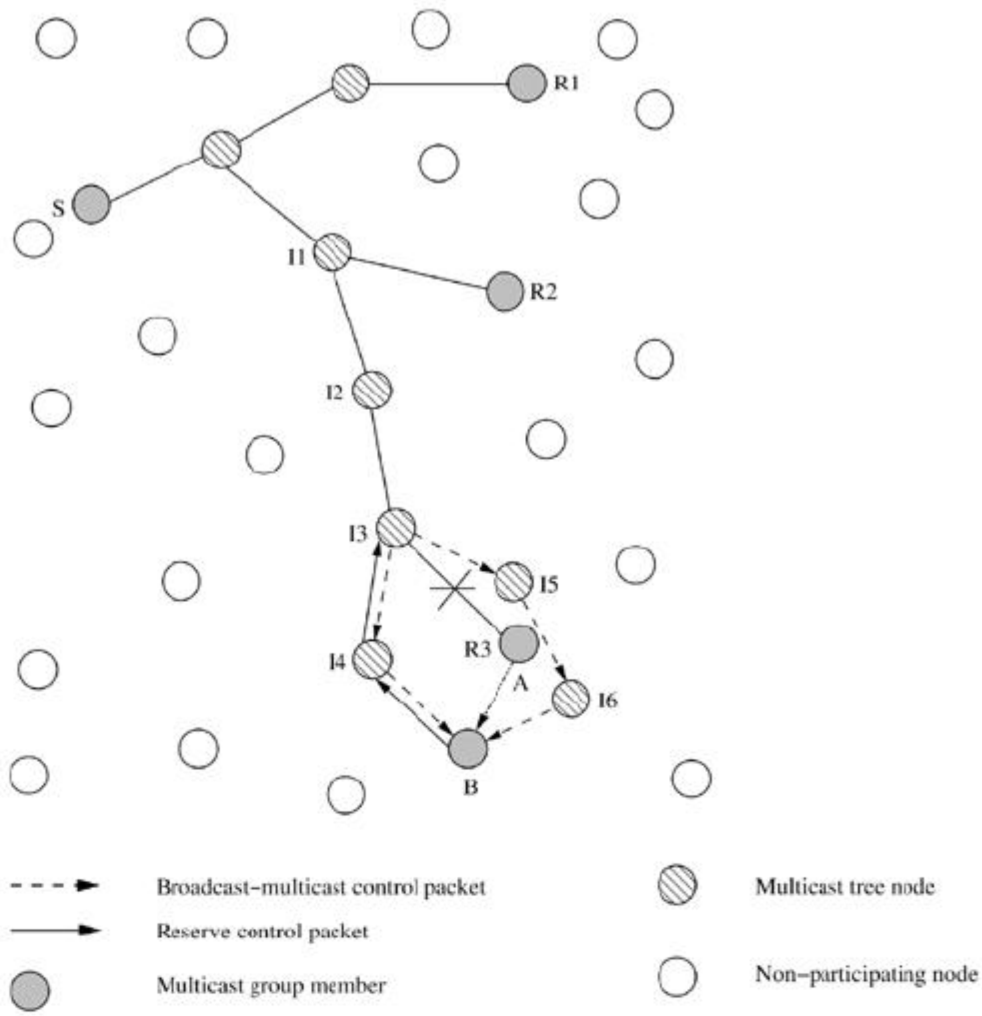


Figure 8.6. Multicast tree maintenance in broadcast-multicast scheme.

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.

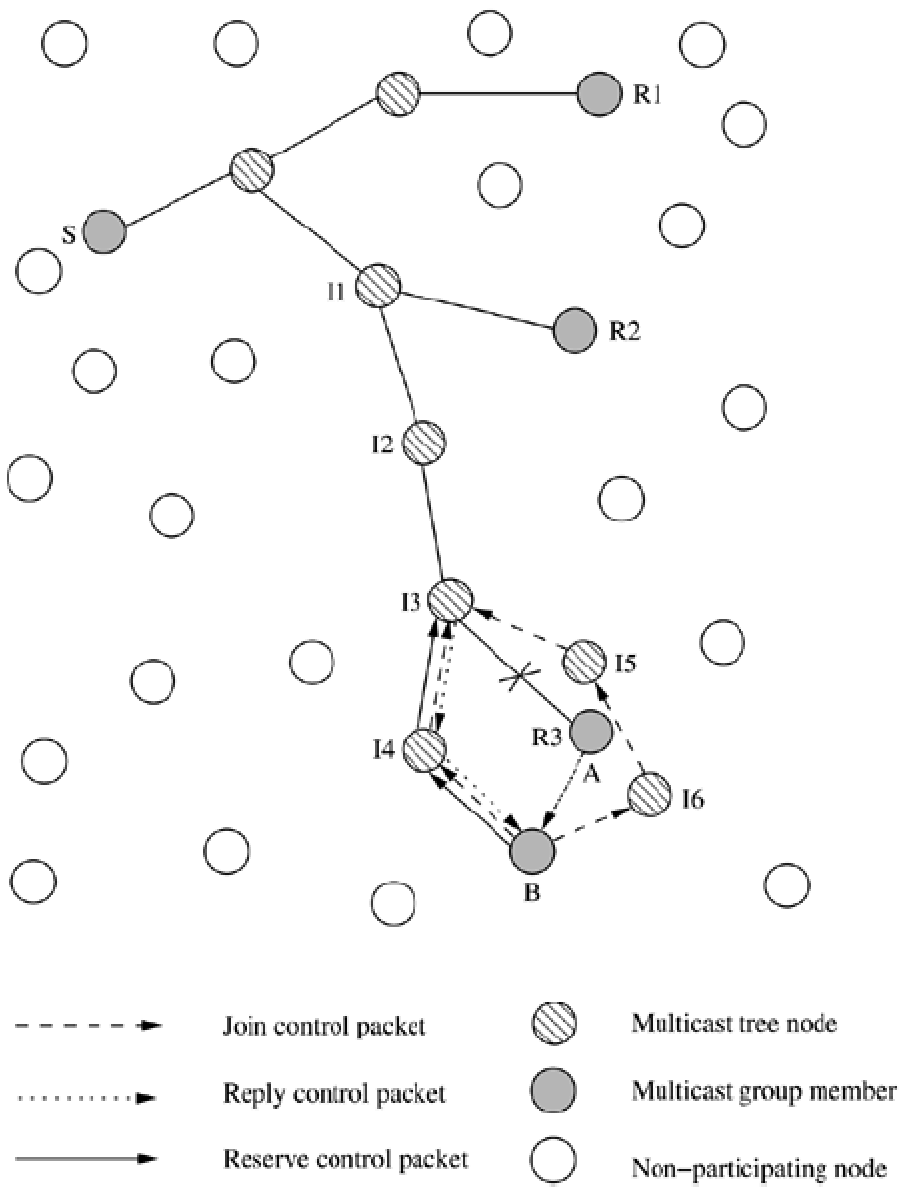


Figure 8.7. Multicast tree maintenance in local rejoin scheme.

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.

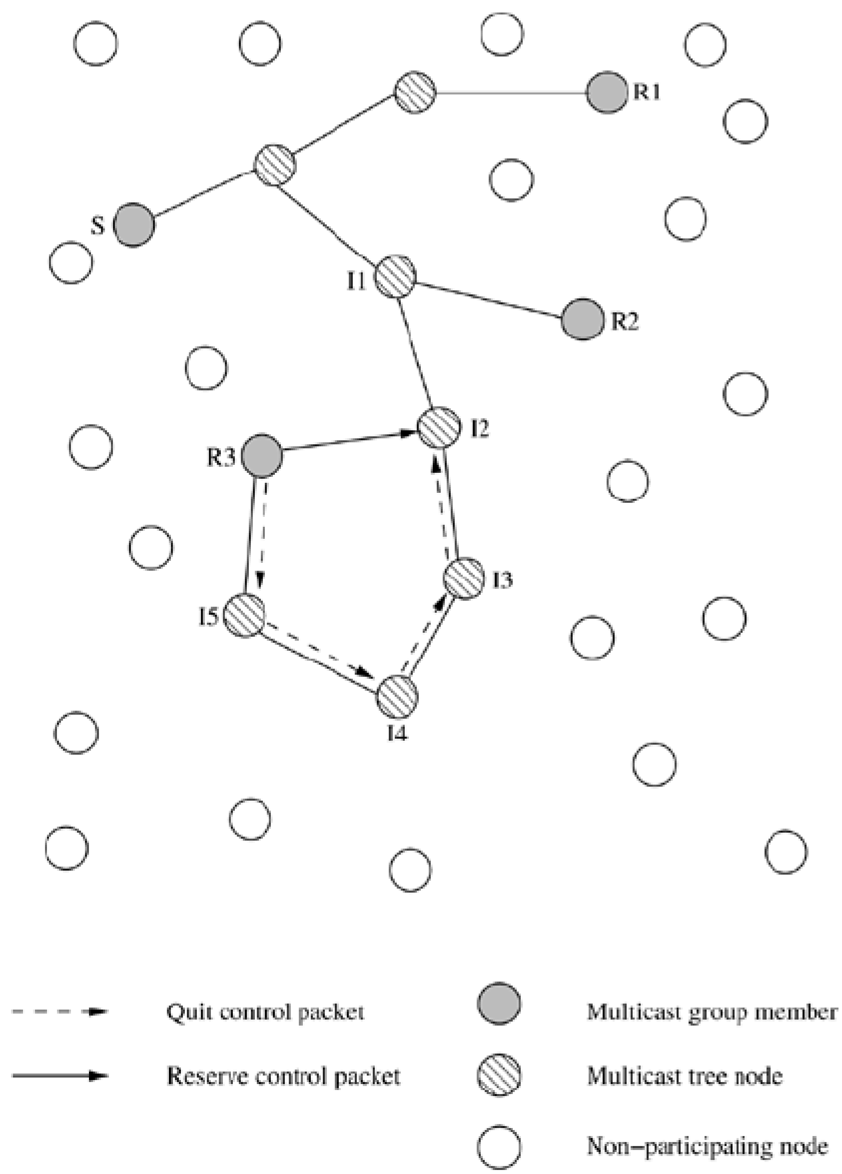


Figure 8.8. Multicast tree optimization in BEMRP.

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.

Multicast Routing Protocol Based on Zone Routing(MZRP)

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.*

In zone routing, each node is associated with a routing zone. For routing, a pro-ctive approach is used inside the zone (the node maintains the topology inside the zone, using a *tabledriven* routing protocol), whereas a reactive approach is used across zones.

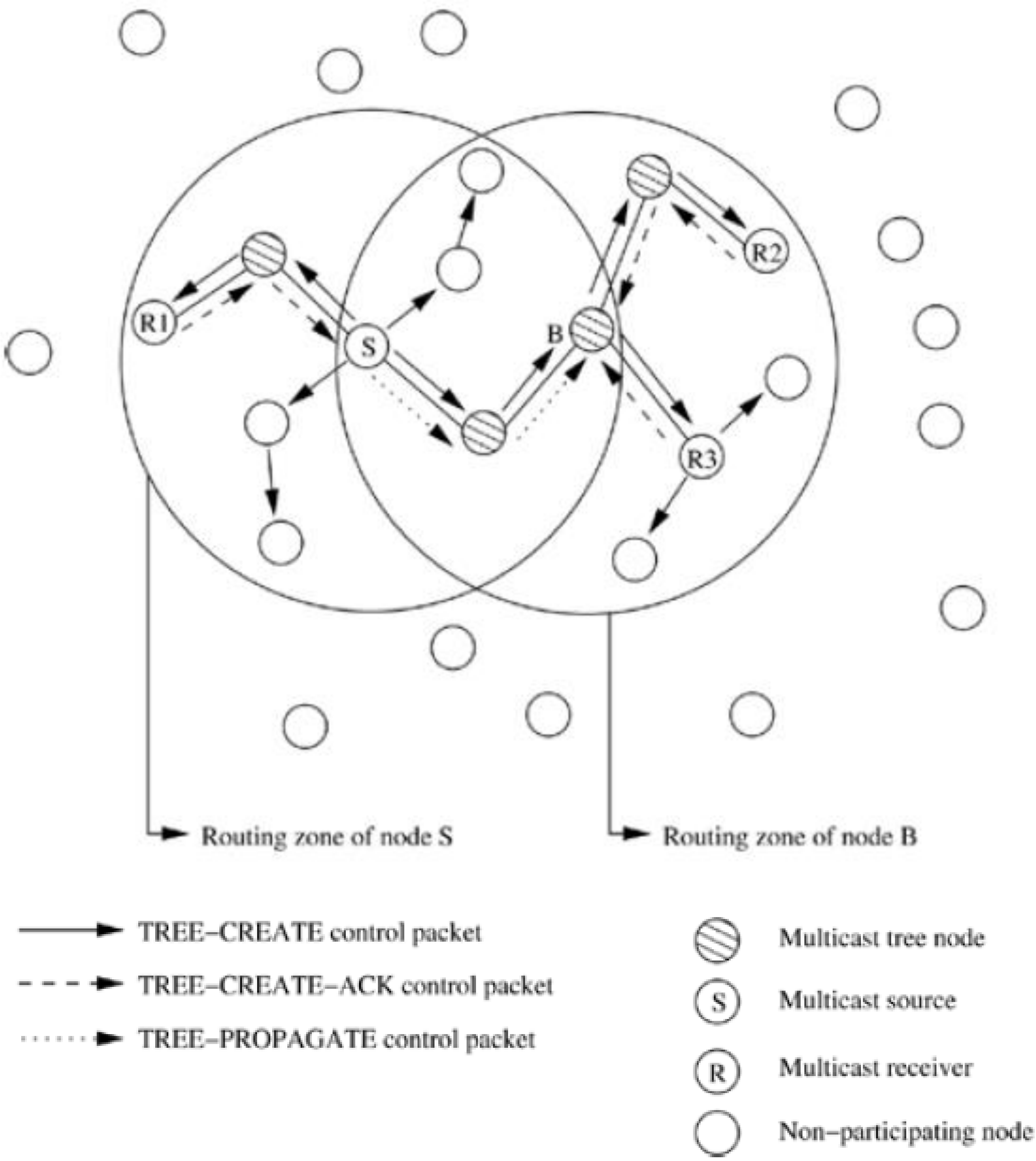
In a nutshell, it attempts to combine the best of both on-demand and table- riven routing approaches.

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.

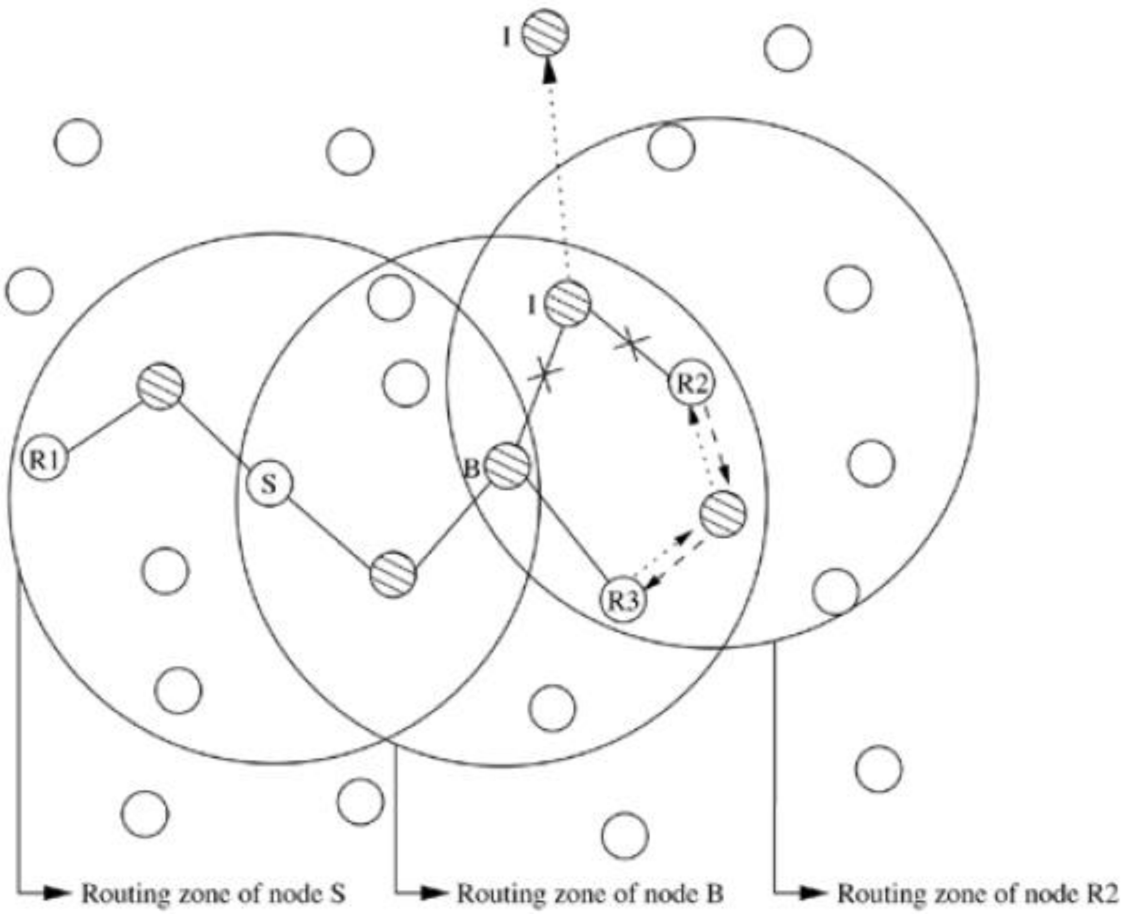
To extend the tree outside the zone, source S sends a TREE-PROPAGATE packet to all the border nodes of the zone. When node B (which is at the border of the zone of node S) receives the TREE-PROPAGATE packet, it sends a TREE-CREATE packet to each of its zone nodes. Thus receivers R2 and R3 receive the 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 TREEREFRESH 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 *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.



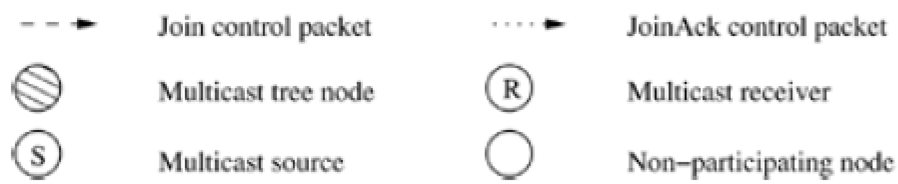
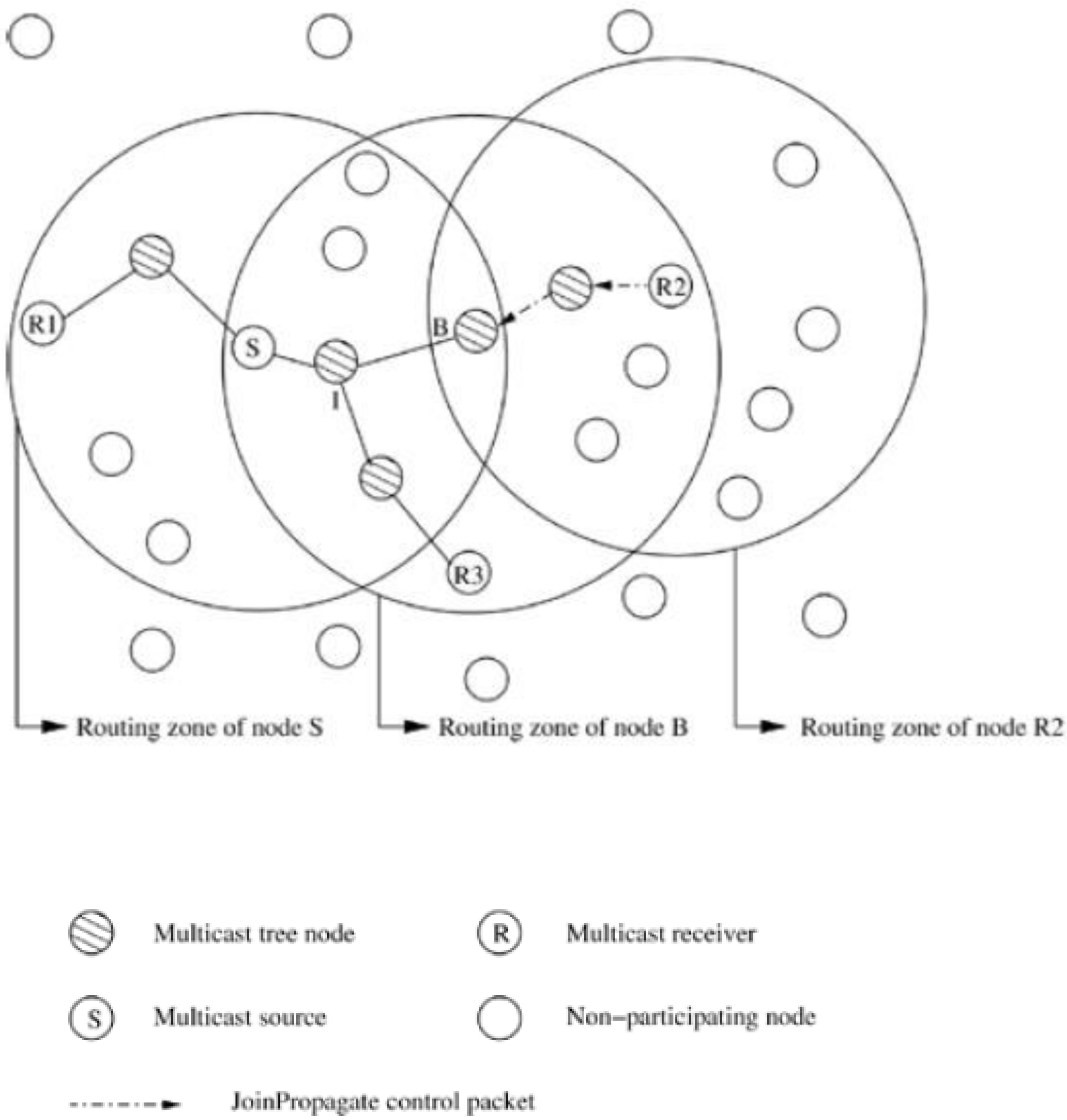


Figure 8.10. Multicast tree maintenance in MZRP

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 TREEPROPAGATE message takes considerable time.