A Comprehensive Survey of Multicast Routing Protocols for Mobile Ad Hoc Networks

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Abstract

MANETs are considered to be an important network type in the near future. Nodes in MANETs are often collaborative for a particular task and have limited power. Multicasting can efficiently support data transmissions and thus is very suitable for MANETs. There have been a number of multicast routing protocols which are classified into two types: tree-based protocols and mesh-based protocols. We investigate these protocols and point out the associated advantages and disadvantages. We then have deep discussions and insightful suggestions of the design of an excellent multicast routing protocol.

Keywords: Mobile Ad Hoc Networks, Multicast Routing Protocols, Tree-Based Protocols, Mesh-Based Protocols

1 Introduction

A mobile ad hoc network (MANET) is a collection of autonomous mobile nodes that communicate with each other over wireless links. The topology of an ad hoc network is highly dynamic due to the arbitrary movement of each node.

In recent years, a number of multicast protocols for ad hoc networks have been proposed. Based on the routing structure, they can broadly be classified into two categories: tree-based protocols and mesh-based protocols. In tree-based protocols, there exists a single path between any sender-receiver pair. Tree-based protocols have the advantage of high multicast efficiency (which is defined as the ratio of the total number of data packets received by all receivers to the total number of data packets transmitted or retransmitted by senders or intermediate nodes). However, tree-based protocols are not robust against frequent topology changes and the packet delivery ratio (which is defined as the ratio of the number of data packets delivered to all receivers to the number of data packets supposed to be received by all receivers) drops at high mobility. Mesh-based protocols provide redundant routes for maintaining connectivity to group members. The low packet delivery ratio problem caused by link failures is alleviated due to redundant routes. Mesh-based protocols are robust to node mobility. However, redundant routes cause low multicast efficiency.

In this paper, we conduct a comprehensive survey of current multicast routing protocols for ad hoc networks. [1] is the first paper to present the performance comparison study of ad hoc multicast routing protocols. [2] introduces multicast protocols and discusses some ongoing directions. [3] does similar work to ours. Compared with these works, we include some newly proposed protocols, have a further comparison of protocols and discuss the associated advantages and disadvantages in more detail.

The remainder of this paper is organized as follows. In Section 2, we explain terminology and provide background information. Section 3 and Section 4 introduce tree-based protocols and mesh-based protocols, respectively. We discuss what features an excellent multicast routing protocol should have and point out directions for designing a multicast routing protocol in Section 5. Finally, Section 6 concludes the paper.

2 Preliminaries

A multicast group is composed of senders and receivers. For connecting senders and receivers, each protocol constructs either a tree or a mesh as the routing structure. There are some nodes called forwarding nodes in the routing structure that are not interested in multicast packets but act as routers to forward them to receivers. Group members (senders and receivers) and forwarding nodes are also called tree or mesh nodes depending on the routing structure. In the routing structure, a node is an upstream (downstream) node of another node if it is closer to (farther away) the root of the tree. If the two nodes belong to the same link, the upstream (downstream) node is also called the parent (child) of the other node.

Generally, a sender initially floods a join message to all nodes in the network. Interested nodes reply to the sender via the reverse path. After all reply messages arrive at the sender, a multicast tree rooted at the sender is formed. This kind of tree construction is called a *sender-tree-based* one. A multicast group usually has several senders and thus it costs high for each sender to build its own tree. Some protocols select a single sender to build a multicast tree that is shared with other senders. This kind of tree construction is called a *shared-tree-based* one and the selected sender is called the group leader (or core node). Other senders first transmit data packets to the group leader and the group leader then relays the packets downward the shared tree to all receivers. The kind of initialization of tree construction by one or more senders is called a *sender-initiated* scheme. The *receiver-initiated* scheme requires receivers to initiate the tree construction, and it is often used for the shared-tree structure.

Due to node mobility, the routing structure requires reconfiguration. If a broken link is repaired by periodic flood packets issued by a sender (or the group leader), this kind of protocol is called a *soft-state* one. Periodic flood packets also help new members join the group. If a link failure is repaired by a node on the link, this kind of protocol is called a *hard-state* one. Since no periodic flood packets are issued in hard-state protocols, new members usually join the group by using expanded ring searches (i.e., iteratively expand the flood range). A group member usually leaves the group by sending a message to inform its parent of its departure. In addition to link failures, node mobility may cause partition of the routing structure. Partition must be merged for successfully delivering data packets to all group members.

Sender-tree-based protocols incur higher control overhead than shared-tree-based ones because each sender builds its own tree. Shared-tree-based protocols have two main drawbacks: single point of failure of the group leader and sub-optimal multicast paths. Moreover, the group leader may locate in a bad position which further decreases multicast efficiency and increases packet latency. The mesh structure is robust against topology changes, but multicast efficiency is reduced. In soft-state protocols, a new member cannot join a group as soon as it wishes and hence it may miss interested packets for a while.

3 Tree-based Multicast Routing Protocols

3.1 MAODV: Multicast Operation of the Ad-hoc On-Demand Distance Vector Routing Protocol

MAODV [4] is a shared-tree-based protocol that is an extension of AODV [5] to support multicast routing. With the unicast route information of AODV, MAODV constructs the shared tree more efficiently and has low control overhead. In MAODV, the group leader is the first node joining the group and announces its existence by Group Hello message flooding. An interested node P sends a join message toward the group leader. Any tree node of the group sends a reply message back to P. P only answers an MACT message to the reply message with minimum hop count to the originator. Then a new branch to the shared tree is set up (see Figure. 1).

Each node will broadcast a Hello message to its neighbors if it does not send any packet within a period of time. The lack of a Hello message indicates that the link between a node and its neighbor is broken. Then the node locally floods a join message towards the group leader. Only those tree nodes which are closer to the group leader and have fresher paths to the group leader respond to this join message.

The shared tree may be partitioned due to node mobility and hence two or more group leaders may co-exist. When this happens, a group member Q whose group leader has a lower IP address than any other group leader will inform its group leader to stop the leader's role. Q then sends a message to ask the group leader with the highest IP address to be the new group leader of the final merged tree.

Advantages: With the unicast route information, the multicast tree can be constructed more quickly and efficiently.

Disadvantages: The group leader continues flooding Group Hello messages even if no sender for the group exists.

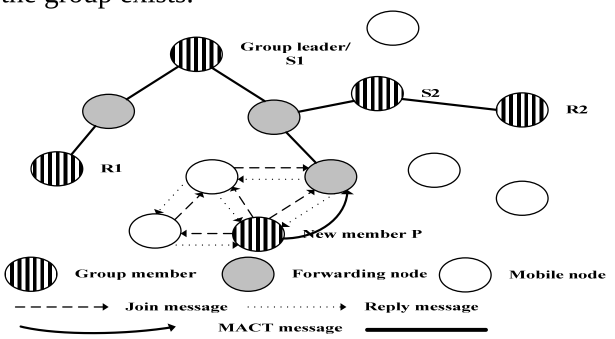

Figure 1. The joining procedure in MAODV.

3.2 AMRIS: Ad Hoc Multicast Routing Protocol Utilizing Increasing Id-numbers

AMRIS [6] is an on-demand shared-tree-based protocol which dynamically assigns every node in a multicast session an id-number. The multicast tree is rooted at a special node called Sid and the id-numbers of surrounding nodes increase in numerical value as they radiate from the Sid. These id-numbers help nodes know which neighbors are closer to the Sid and this reduces the cost to repair link failures.

Sid initially floods a NEW-SESSION message associated with its id-number through the network. Each node receiving the NEW-SESSION message generates its own id-number by computing a value that is larger than and not consecutive to the received one. Then the node places its own id-number and routing metrics before rebroadcasting the message. Each node sends a periodic beacon for exchanging information (like its own id-number) with its neighbors. When a new node P wants to join the session, it sends a join message to one of its potential parent nodes (i.e., those neighboring nodes having smaller id-numbers) Q. If Q is a tree node, it replies a message to P; otherwise, Q forwards this join message to one of its own potential parent nodes. This process is repeated until a tree node is found (see Figure. 2). If no reply message returns to P, a localized broadcast is used.

When a link between two nodes breaks, the node with larger id-number P invokes the repairing procedure. The repairing procedure is similar to the joining one, but P tries its potential parent nodes one by one until it can rejoin the session.

Advantages: 1. The concept of increasing id-numbers is useful for constructing and maintaining a multicast tree. 2. It may incur very low overhead for a node to join or rejoin the session if it chooses a potential parent node which happens to be a tree node.

Disadvantages: 1. Joining and rejoining of a node may take long time and waste much bandwidth since each node tries potential parent nodes arbitrarily. 2. The usage of periodic beacons consumes bandwidth.

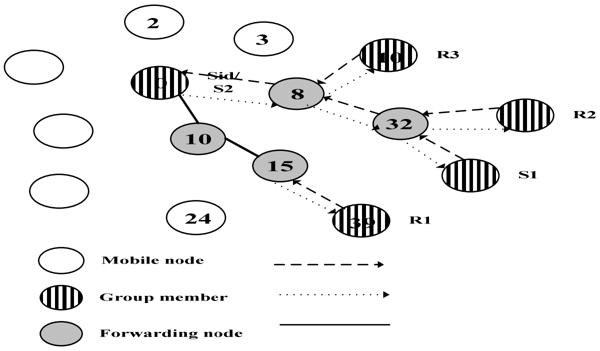

Figure 2. The joining procedure in AMRIS.

3.3 BEMRP: Bandwidth-Efficient Multicast Routing Protocol

BEMRP [7] is a sender-tree-based protocol which emphasizes on high multicast efficiency. BEMRP requires each new member to set up a branch with the fewest new forwarding nodes being added to the multicast tree. A route optimization process is also introduced to detect and remove unnecessary forwarding nodes

When a new node P wishes to join a group, it globally floods a join message into the network. Only tree nodes respond to the join message and will reply the one along the shortest path to P. P then selects the shortest path to connect to the tree node. In order to enhance multicast efficiency, BEMRP requires a tree node to changes to a new parent Q if it receives a multicast packet from Q and Q is closer to the sender than its parent (the route optimization process, see Figure. 3).

BEMRP proposes two link-repairing schemes: local-flooding and local-rejoin schemes. In the former scheme, when the upstream node of a broken link receives a multicast packet, it creates a special multicast-route-recovery packet which contains the original multicast packet, and floods it locally. When the downstream node of the broken link gets the multicast-route-recovery packet, it replies a message back to reconnect to the tree. The latter scheme requires the downstream node Q of a broken link to find a new path to any tree node in the upstream direction by using a local flood.

Advantages: 1. It achieves higher multicast efficiency. 2. The path optimization process eliminates redundant paths gradually that leads to higher efficiency and lower packet transfer delay. 3. It incurs low control overhead at low mobility.

Disadvantages: 1. Joining and rejoining of a node take long time and consume high bandwidth. 2. The failure of a shared link affects several receivers.

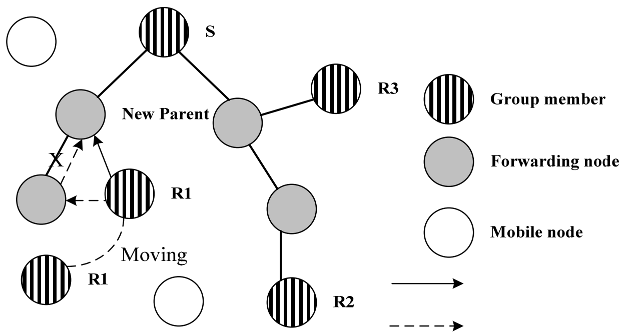

Figure 3. The route optimization process in BEMRP.

3.4 ADMR: Adaptive Demand-Driven Multicast Routing

ADMR [8] is an on-demand sender-tree-based protocol which adapts its behavior based on the application data sending pattern. It does not require periodic floods of control packets, periodic neighbor sensing, or periodic routing table exchanges. The application layer behavior allows efficient detection of link breaks and expiration of routing state. ADMR temporarily switches to the flooding of each data packet if high mobility is detected.

A multicast tree is created when a group sender originates a multicast packet for the first time. Interested nodes reply to the sender's packet to join the group. Each multicast packet includes the inter-packet time which is the average packet arrival time from the sender's application layer. The inter-packet time lets tree nodes predict when the next multicast packet will arrive and hence no periodic control messages are required for tree maintenance. If the application layer does not originate new packets as expected, the routing layer of the sender will issue special keep-alive packets to maintain the multicast tree. The sender occasionally uses network floods of data packets for finding new members.

A new member P globally floods a solicitation message to join a group. Upon a receipt of this message, a tree node unicasts the message toward the sender. The sender either chooses to advance the time for the network flood or unicast a packet to P as a reply. Each tree node maintains a disconnection timer which is based on the inter-packet time value contained in the last received packet, plus a time proportional to the node's hop count to the sender. If the timer expires, a node Q floods a hop-limited reconnect message and transmits a repair one to prevent its downstream nodes from executing their own repair procedures (see Figure. 4). Upstream nodes of Q will unicast the message toward the sender when receiving the reconnect message. The sender responds a message to help Q reconnect to the tree.

Advantages: 1. It utilizes the application data sending pattern to avoid periodic control messages. 2. It can adapt to the change of mobility.

Disadvantages: 1. The joining and rejoining processes waste bandwidth and take time. 2. The occasional flooding of multicast packets is an overhead.

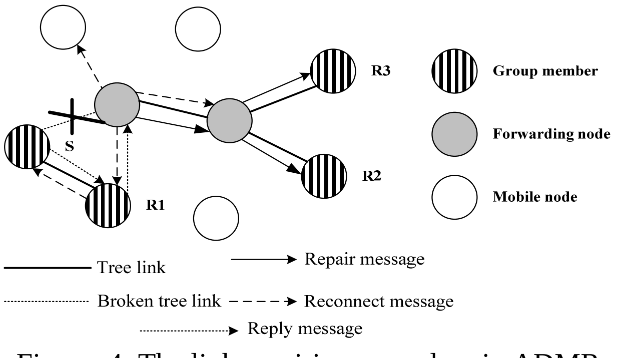

Figure. 4: The link repairing procedure in ADMR.

3.5 DDM: The Differential Destination Multicast Protocol

DDM [9] is a sender-tree-based protocol that is designed for small group. DDM has no any multicast routing structure. It encodes the addresses of group members in each packet header and transmits the packets using the underlying unicast routing protocol. When a node P is interested in a multicast session, it unicasts a join message toward the sender of the session. The sender adds P into its member list (ML) and unicasts an ACK message back to P. DDM has two operation modes: stateless mode and soft-state mode. In stateless mode, the sender includes a list of all receivers' addresses in each multicast packet. According to the address list and the unicast routing table, each node receiving the packet determines the next hop for forwarding the packet to some receivers, and will partition the address list to distinct parts for each chosen next hop. For example, in Figure. 5, the sender S delegates A to forward the packet to R1 and R2. A then sends the packet to R1 and forwards it to E.

In order to reduce the packet size, DDM can operate in soft-state mode. Each node in soft-state mode records the set of receivers for which it has been the forwarder. Each multicast packet only describes the change of the address list since the last forwarding by a special DDM block in the packet header. For instance, if R4 moves to another place and loses connection to R3, the DDM block in the packet header describes that R4 is removed. Then B knows that it only has to forward the packet to R3.

Advantages: 1. No storage overhead is required for group members when DDM operates in stateless mode. 2. No control overhead is incurred on the multicast routing structure.

Disadvantages: 1. It has to rely on underlying unicast routing protocols. 2. It is not mentioned how a receiver knows who the sender is. 3. It requires a specific packet header and this increases complexity.

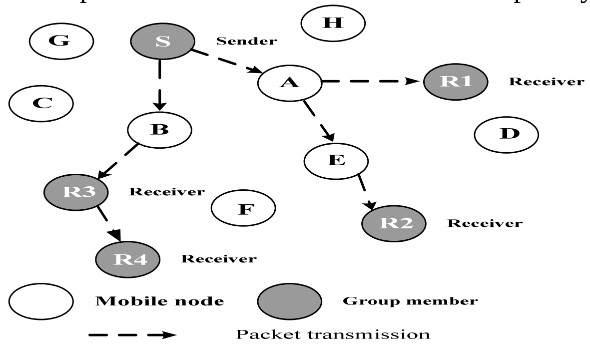

Figure. 5: Packet transmission in DDM.

3.6 MCEDAR: Multicast Core-Extraction Distributed Ad Hoc Routing

MCEDAR [10] is a multicast extension to the CEDAR [11] architecture which provides the robustness of mesh structures and the efficiency of tree structures. MCEDAR uses a mesh as the underlying infrastructure, but the data forwarding occurs only on a sender-rooted tree. MCEDAR is particularly suitable for situations where multiple groups coexist in a MANET.

At first, MCEDAR partitions the network into disjoint clusters. Each node exchanges a special beacon with its one hop neighbors to decide that it becomes a dominator or chooses a neighbor as its dominator. A dominator and those neighbors that have chosen it as a dominator form a cluster. A dominator then becomes a core node and issues a message to nearby core nodes for building virtual links between them. All the core nodes form a core graph.

When a node intends to join a group, it delegates its dominating core node P to join the appropriate mgraph instead of itself. An mgraph is a subgraph of the core graph and is composed of those core nodes belonging to the same group. P joins the mgraph by broadcasting a join message which contains a joinID. Only those members with smaller joinIDs reply an ACK message to P (see Figure. 6). Other nodes receiving the join message forward it to their nearby core nodes. An intermediate node Q only accepts at most R ACK messages where R is a robustness factor. Q then puts the nodes from which it receives the ACK message into its parent set and the nodes to which it forwards the ACK message into its child set.

When a node has less than R/2 parents, it periodically issues new join messages to get more parents. When a data packet arrives at an mgraph member, the member only forwards the packet to those nearby member core nodes that it knows.

Advantages: 1. The underlying mesh structure is robust to high mobility. 2. When multiple groups coexist, the core graph can work as a backbone and hence reduces the total control overhead for these groups.

Disadvantages: 1. High control overhead is incurred on the partitioning procedure. 2. Since the data forwarding tree is built among core nodes (not actual group members), it has non-optimal paths. 3. If a node leaves its dominating core node and attaches to another core node, it may miss interested packets. 4. The failure of a core node affects those nodes that delegate it to join the group.

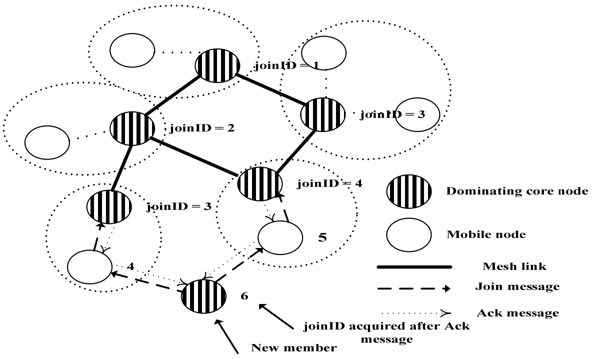

Figure. 6: The joining procedure in MCEDAR.

4 Mesh-based Multicast Routing Protocols

4.1 ODMRP: On-Demand Multicast Routing Protocol

ODMRP [12] provides richer connectivity among group members and builds a mesh for providing a high data delivery ratio even at high mobility. It introduces a “forwarding group” concept to construct the mesh and a mobility prediction scheme to refresh the mesh only necessarily.

The first sender floods a join message with data payload piggybacked. The join message is periodically flooded to the entire network to refresh the membership information and update the multicast paths. An interested node will respond to the join message. Note that the multicast paths built by this sender are shared with other senders. In other words, the forwarding node will forward the multicast packets from not only this sender but other senders in the same group (see Figure. 7).

Due to the high overhead incurred by flooding of join messages, a mobility prediction scheme is proposed to find the most stable path between a sender-receiver pair. The purpose is to flood join messages only when the paths indeed have to be refreshed. A formula based on the information provided by GPS (Global Positioning System) is used to predict the link expiration time between two connected nodes. A receiver sends the reply message back to the sender via the path having the maximum link expiration time.

Advantages: 1. It proposes an effective “forwarding group” concept. 2. The offering of shortest paths reduces data delivery latency. 3. The mobility prediction scheme lowers control overhead at mobility.

Disadvantages: 1. It suffers from excessive flooding when there is a large number of senders. 2. The duplicate transmissions waste bandwidth at low mobility.

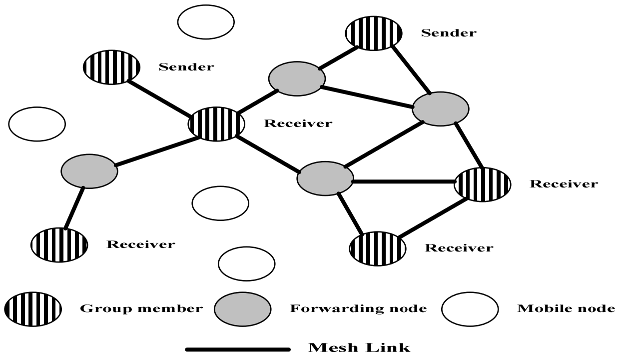

Figure. 7: The multicast mesh in ODMRP.

4.2 DCMP: A Dynamic Core Based Multicast Routing Protocol

DCMP [13] aims at mitigating the high control overhead problem in ODMRP. DCMP dynamically classifies the senders into different categories and only a portion of senders need issue control messages. In DCMP, senders are classified into three categories: active senders, core senders, and passive senders. Active senders flood join messages at regular intervals. Core senders are those active senders which also act as the core node for one or more passive senders. A passive sender does not flood join messages, but depends on a nearby core sender to forward its data packets. The mesh is created and refreshed by the join messages issued by active senders and core senders.

All senders are initially active senders. When a sender S has packets to send, it floods a join message. Upon receiving this message, an active sender P delegates S to be its core node if P is close to S and has smaller ID than S. Afterwards, the multicast packets sent by S will be forwarded to P first and P relays them through the mesh (see Figure. 8).

Advantages: It has a high packet delivery ratio with less control overhead.

Disadvantages: 1. For passive senders, the paths between them and receivers are sub-optimal. 2. The failure of a core node affects several passive senders. 3. An active sender with higher ID may not have any chance to be a passive sender (unfairness).

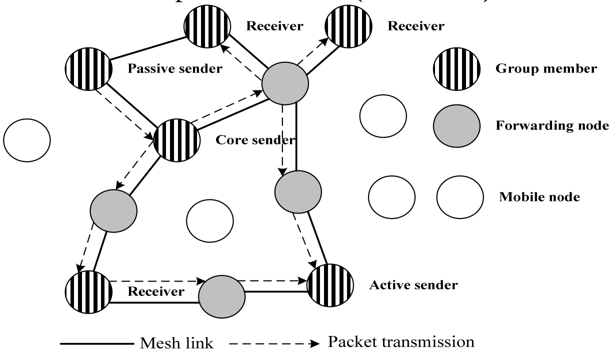

Figure. 8: Packet transmission path for a passive sender in DCMP.

4.3 ACMRP: Adaptive Core Multicast Routing Protocol

ACMRP [14] presents an adaptive core mechanism in which the core node adapts to the network and group status. In general mesh-based protocols, the mesh provides too rich connectivity and results in high delivery cost. Hence, ACMRP forces only one core node to take responsibility of the mesh creation and maintenance in a group. The adaptive core mechanism also handles any core failure caused by link failures, node failures, or network partitions.

A new core node of a group emerges when the first sender has multicast packets to send. The core node floods join messages and each node stores this message into its local cache. Interested members reply a JREP message to the core node. Forwarding nodes are those nodes who have received a JREP message. If a sender only desires to send packets (it’s not interested in packets from other senders), it sends an EJREP message back to the core node. Those nodes receiving this EJREP message only forward data packets from this sender (see Figure. 9). If a new sender wishes to send a packet but has not connected to the mesh, it encapsulates the packet toward the core node. The first forwarding node strips the encapsulated packet and sends the original packet through the mesh.

ACMRP proposes a novel mechanism to reelect a new core node which is located nearby all members regularly. The core node periodically floods a query message with TTL set to acquire the group membership information and lifetime of its neighboring nodes. The core node will select the node that has the minimum total hop count of routes toward group members among neighboring nodes as the new core node.

Advantages: 1. It incurs low control overhead. 2. The proposed adaptive core mechanism enhances overall performance.

Disadvantages: 1. Every node must have the ability to encapsulate and decapsulate data packets. 2. A node not interested in a group may be the core node for the group.

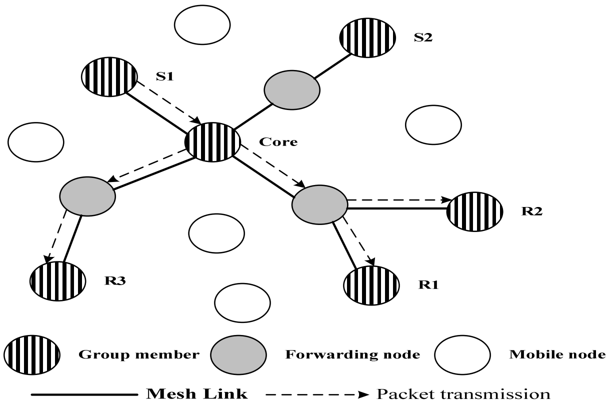

Figure. 9: Sender S1's packet transmission path in ACMRP.

4.4 MANSI: Multicast Protocol for Ad Hoc Networks with Swarm Intelligence

MANSI [15] relies on only one core node to build and maintain the mesh and applies swarm intelligence to tackle metrics like load balancing and energy conservation. Swarm intelligence refers to complex behaviors that arise from very simple individual behaviors and interactions. Although each individual has little intelligence and simply follows basic rules using local information obtained from the environment, globally optimized behaviors emerge when they work collectively as a group. MANSI utilizes this characteristic to lower the total cost in the multicast session.

The sender that first starts sending data takes the role of the core node and informs all nodes in the network of its existence. Reply messages transmitted by interested nodes construct the mesh. Each forwarding node is associated with a height which is identical to the highest ID of the members that use it to connect to the core node. After the mesh creation, MANSI adopts the swarm intelligence metaphor to allow nodes to learn better connections that yield lower forwarding cost. Each member P except the core node periodically deploys a small packet, called FORWARD ANT, which opportunistically explores better paths toward the core (see Figure. 10).

A FORWARD ANT stops and turns into a BACKWARD ANT when it encounters a forwarding node whose height is higher than the ID of P. A BACKWARD ANT will travel back to P via the reverse path. When the BACKWARD ANT arrives at each intermediate node, it estimates the cost of having the current node to join the forwarding set via the forwarding node it previously found. The estimated cost, as well as a pheromone amount, is updated on the node's local data structure. The pheromone amounts are then used by subsequent FORWARD ANTs that arrive at this node to make a decision which node they will travel to next.

MANSI also incorporates a mobility-adaptive mechanism. Each node keeps track of the normalized link failure frequency (nlff) which reflects the dynamic condition of the surrounding area. If the nlff exceeds the threshold, the node will add another entry for the second best next hop into its join messages. Then the additional path to the core node increases the reliability of MANSI.

Advantages: 1. The swarm intelligence makes MANSI applicable to different performance metrics. 2. It utilizes a mobility-adaptive mechanism to adapt to the degree of mobility.

Disadvantages: 1. Implementation complexity is high. 2. Swarm intelligence may be not useful at high mobility.

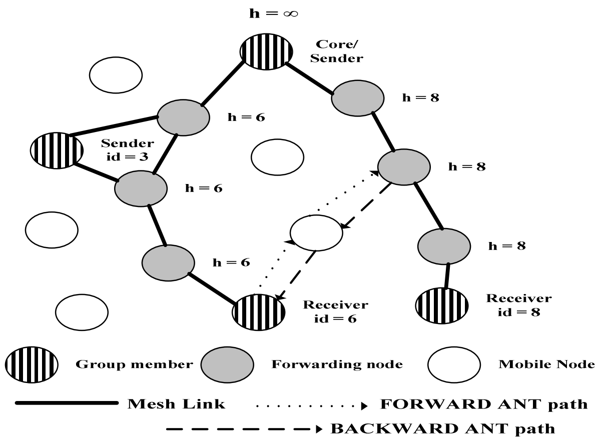

Figure. 10: The ANT exploring process in MANSI.

4.5 NSMP: Neighbor Supporting Ad Hoc Multicast Routing Protocol

NSMP [16] utilizes the node locality concept to lower the overhead of mesh maintenance. For initial path establishment or network partition repair, NSMP occasionally floods control messages through the network. For routine path maintenance, NSMP uses local path recovery which is restricted only to mesh nodes and neighbor nodes for a group.

The initial mesh creation is the same with that in MANSI. Those nodes (except mesh nodes) that detect reply messages become neighbor nodes, and neighbor nodes do not forward multicast packets. After the mesh creation phase (see Figure. 11), all senders transmit LOCAL_REQ messages to maintain the mesh at regular interval. Only mesh nodes and neighbor nodes forward the LOCAL_REQ messages. In order to balance the routing efficiency and path robustness, a receiver receiving several LOCAL_REQ messages replies a message to the sender via the path with largest weighted path length.

Since only mesh nodes and neighbor nodes accept LOCAL_REQ messages, the network partition may not be repaired. Hence, a group leader is elected among senders and floods request messages through the network periodically. Network partition can be recovered by the flooding of request messages. When a node P wishes to join a group as a receiver, it waits for a LOCAL_REQ message. If no LOCAL_REQ message is received, P locally broadcasts a MEM_REQ message.

Advantages: 1. A new member can join a group more quickly than other soft-state protocols. 2. It strikes a balance between routing efficiency and path robustness.

Disadvantages: 1. It takes long time on mesh maintenance since each member waits for a period to select the best path. 2. More non-group nodes are involved in a multicast session.

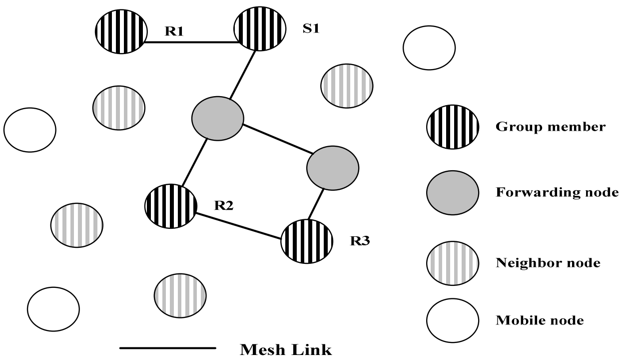

Figure. 11: The mesh structure in NSMP.

4.6 CAMP: The Core-Assisted Mesh Protocol

CAMP [17] is a receiver-initiated protocol. It assumes that an underlying unicast routing protocol provides correct distances to known destinations. CAMP establishes a mesh composed of shortest paths from senders to receivers. One or multiple core nodes can be defined for each mesh, and core nodes need not be part of the mesh, and nodes can join a group even if all associated core nodes are unreachable.

It is assumed that each node can reach at least one core node of the multicast group which it wants to join. If a joining node P has any neighbor that is a mesh node, then P simply tells its neighbors that it is a new member of the group. Otherwise, P selects its next hop to the nearest core node as the relay of the join message. Any mesh node receiving the join message transmits an ACK message back to P. Then P connects to the mesh. If none of the core nodes of the group is reachable, P broadcasts the join message using an expanded ring search.

For ensuring the shortest paths, each node periodically looks up its routing table to check whether the neighbor that relays the packet is on the shortest path to the sender. The number of packets coming from the reverse path for a sender indicates whether the node is on the shortest path. A special message will be issued to search a mesh node and the shortest path can be reestablished. At last, to ensure that two or more meshes eventually merge, all active core nodes periodically send messages to each other and force nodes along the path that are not members to join the mesh.

Advantages: 1. It constructs a mesh without control packet flooding. 2. With correct routing information, shortest paths are included in the mesh and the joining procedure incurs very low overhead.

Disadvantages: 1. It has to rely on certain unicast routing protocols. 2. High storage overhead is incurred for each node due to several maintained data structures. 3. The periodic message exchanges among cores are a high overhead. 4. Non-group nodes may be involved since they may act as cores (unnecessary packet transmissions created like that in Figure. 12).

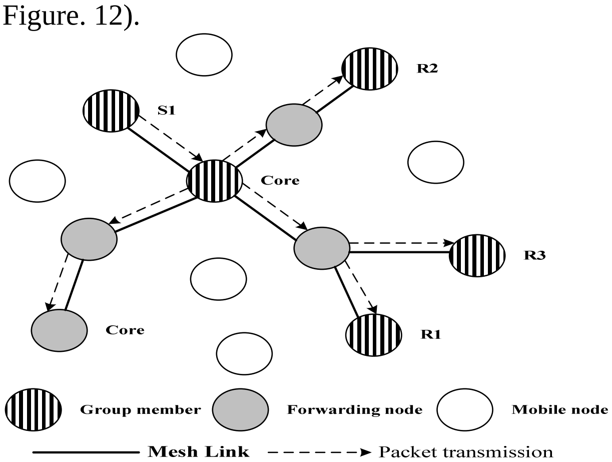

Figure. 12: Packet transmission of S1 in CAMP.

5 Discussion

We discuss the features that a multicast routing protocol should consider and point out directions for designing the protocol. Basically, the design should take three issues into consideration: robustness, multicast efficiency, and control overhead. If the degree of robustness is low, the packet delivery ratio will drop and high control overhead will be incurred. Thus, the mesh structure is more appropriate to be the multicast routing structure. A mesh that is built and maintained by only one core node is robust to low mobility and can avoid duplicate transmissions. Moreover, the number of forwarding nodes in this kind of mesh is limited such that some degree of multicast efficiency is ensured. However, this sort of mesh may not be robust enough to high mobility. An excellent mesh-based protocol should be designed with the connectivity adapted to the degree of mobility.

Since the mesh is constructed and refreshed by one core node, the position of the core node affects the efficiency of the mesh. If the core node is located far away from other group members, multicast efficiency is reduced and longer paths increase the probability of link failures. Therefore, it is important to select a new core located in a better position periodically. How to devise an efficient core migration scheme with low overhead is a crucial issue.

The periodic reelection of the core node results in regular flooding of control messages, so the frequency of flooding needs to be further studied. The soft-state maintenance should be used only for refreshing the mesh; while the hard-state one should be used for repairing broken links.

General multicast protocols often provide shortest paths between senders and receivers. Although shortest paths have low data delivery latency and low probabilities of link failures, they reduce multicast efficiency. Hence, the protocol should strike a balance between multicast efficiency and path lengths.

At last, a mesh may be partitioned because of node movement. Several protocols merge separated meshes by requiring the core node with highest IP address (or other criteria) to be the new core of the merged mesh. This merging procedure is inefficient and time-consuming. In our opinion, it is better for one of the group members that detect more than one mesh existing to be the new core node. This is because that these members are located in the middle of these separated meshes.

6 Conclusions

In this paper, we have reviewed a broad range of multicast routing protocols designed for MANETs. We classify all multicast routing protocols into two categories: tree-based protocols and mesh-based protocols. For each protocol, we summarize the properties, describe the operation, and list the strengths and weaknesses. Then, we suggest directions for the design of a novel protocol. We focus only on general multicast routing protocols for ad hoc networks in this paper. There are other multicast routing protocols that aim at providing reliability, QoS guarantees, security, and so on. We plan to investigate these protocols and make our survey more complete in our future work.

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