FAST RECOVERY FROM TOPOLOGY CHANGES AND COMMUNICATION LINK FAILURES

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ABSTRACT

In our everyday communication infrastructure mobile ad hoc networks plays a central role. In mobile ad hoc networks, how to achieve the multicast communication is a challenging task due to the fact that the topology may change frequently and communication links may be broken because of users’ mobility. We introduced MANSI (Multicast for Ad hoc Network with Swarm Intelligence) protocol, which relies on a swarm intelligence based optimization technique to learn and discover efficient multicast connectivity. The proposed protocol instances that it can quickly and efficiently establish initial multicast connectivity and/or improved the resulting connectivity via different optimization techniques. Using a simulation approach, we investigated performance of the proposed algorithm through a comparison with an algorithm previously proposed in the literature. Based on the numerical results, we demonstrate that our proposed algorithm performs well.

INTRODUCTION

In mobile wireless ad hoc networks attract increasing interest in many application domains since they may be the only solution in situations, where resources such as energy and bandwidth are scarce, it is preferred that networking protocols are resource aware. From the aspect of multicast routing, multicast protocols should be able to establish efficient connectivity among group members with an acceptable level of overhead. One way to achieve this is to find a subset of nodes that can be used to connect all the group members together while yielding the minimum total “cost.” However, finding such a minimum-cost subset is similar to the Steiner tree problem [1,2], which is known to be NP-hard. Although several heuristics have been proposed, they often rely on global knowledge of network topology to perform the calculation.

In traditional static IP networks, the goal of multicast routing is to find a tree of links connecting all routers that belong to a certain multicast group. However, IP multicast protocols [3-5] are inappropriate for ad hoc networks because multicast trees could easily break due to dynamic topologies [6,14]. Many multicast protocols for ad hoc networks have been proposed.

Some protocols still rely on constructing a tree spanning all group members [7,8], which is not robust enough when the network becomes more dynamic with less reliable wireless links. In contrast, many proposed protocols have data packets transmitted into more than one link, and allow packets to be received on links that are not branches of a multicast tree. These protocols fall into a category of mesh-based protocols in that group connectivity is formed as a mesh rather than a tree to increase robustness at the price of adding more redundancy in data transmission. Flooding, where data packets are forwarded to and received from all links, is also considered a mesh protocol since the mesh is in fact the entire network topology. In highly dynamic, highly mobile ad hoc networks, a flooding approach is a better alternative to multicast routing due to its minimal state maintained and high reliability [9].

As the extreme, flooding provides the most robust, but inefficient mechanism since a multicast packet will be forwarded to every node (as long as the network is not partitioned), while tree-based approach offers efficiency but is not robust enough to be used in highly dynamic environments. Furthermore, routing based on a connected dominating set [10-23] can also increase the overall efficiency since the search space is reduced to only nodes in the dominating set during route discovery and maintenance processes.

This paper develops a novel multicast routing protocol for mobile ad hoc networks that adopts swarm intelligence to reduce the number of nodes used to establish multicast connectivity, which allows multicast connections of lower total costs to be learned over time.

1. Multicast Techniques for Mobile Ad hoc Networks:

To provide multicast routing over mobile ad hoc networks, the challenge is to effectively handle frequent topology changes caused by node mobility/failure and link disruption due to interference and jamming. A number of multicast techniques have been proposed to address this issue. These protocols are ranging from a simple flooding scheme to state-based tree or mesh structures, as well as hierarchical and hybrid approaches. Based on their operations, there exist different taxonomy schemes to classify these ad hoc multicast routing protocols, including connectivity among group members (tree-based vs mesh-
Multicast with Hybrid Swarm Intelligence:

Fig. 1 categorizes the aforementioned protocols based on the methodologies of maintaining connectivity among multicast group members. A novel multicast routing protocol for mobile ad hoc networks that adopts swarm intelligence to reduce the number of nodes used to establish multicast connectivity, which allows multicast connections of lower total costs to be learned over time.

Swarm intelligence refers to complex behaviors that arise from simple interactions among individuals, such as ants, but often achieves global optimization objectives.

Similarly, MANSI utilizes small control packets equivalent to ants in the physical world. These packets, traveling like biological ants, deposit control information at nodes they visit similar to the way ants laying pheromone trails. This information, in turn, affects the behavior of other ant packets. With this form of indirect communication, the deployment of ant-like packets resembles an adaptive distributed control system that evolves itself to a more efficient state, accommodating the current condition of the environment.

For each multicast group, MANSI determines a set of intermediate nodes, forming forwarding set, those connects group members together and are shared among group senders. By adopting a core-based approach, the forwarding set is initially formed by nodes that are on the shortest paths between the core and the other group members, where the core may be one of the group members or senders.

In addition, during the lifetime of the multicast session (i.e., when there is at least one active sender), the forwarding set will evolve, by means of swarm intelligence, over time into states that yield lower cost, which is expressed in terms of total cost of all the nodes in the forwarding set. This evolving, including exploring and learning, mechanism differentiates MANSI from other existing ad hoc multicast routing protocols. Since a node's cost is abstract and may be defined to represent different metrics, MANSI can be applied to many variations of multicast routing problems for ad hoc networks such as load balancing, secure routing, and energy conservation.

3. Multicast Ad hoc Network with Swarm Intelligence (MANSI):

MANSI is an on-demand multicast routing protocol that creates a multicast connection among group members by determining a set of intermediate nodes that serve as forwarding nodes. This set, called a forwarding set, is shared among all the senders of the group. The protocol exploits a core-based technique where each member joins the group via the core node to establish a connection with the other group members. Unlike the core-based tree (CBT) protocol [3], however, the core of each group is not statically assigned to a particular node in the network and is not known in advance by the members. Instead, the first member who becomes an active source (i.e., starts sending data to the group) takes the role of the core and announces its existence to the others by flooding the network with a CORE ANNOUNCE packet. Each member node then relies on this announcement to reactively establish initial connectivity by sending a JOIN Request ck to the core via the reverse path. Nodes who receive a JOINR Request dressed to themselves become forwarding nodes of the group and are responsible for accepting and rebroadcast nonduplicated data packets, regardless of which node the packets were received from. Therefore, MANSI does not rely on any unicast routing protocol.

To maintain connectivity and allow new members to join, the core floods CORE ANNOUNCE periodically as long as there are more data to be sent. As a result, these forwarding nodes form a mesh structure that connects the group members together; while the core serves as a focal point for forwarding set creation and maintenance. Since this process is performed only when there is an active source sending data to the group, we do not waste valuable network bandwidth to unnecessarily maintain group connectivity in such dynamic environments.

Similar to other core-based protocols, this process creates a forwarding set consisting of all the intermediate nodes on the paths on which CORE ANNOUNCES are accepted and forwarded from the core to the other members, which are often shortest paths, as illustrated in Fig.2(a). However, group connectivity can be made more efficient by having node A choose another path that is partially shared by node B to reduce the size of the forwarding set, as shown in Fig.2(b), which lowers the total cost of forwarding data packets. Note that the cost is considered on a per-node basis, not per-link, due to the fact that wireless communication is broadcast in nature (i.e., a single data packet broadcast by a node is expected to arrive at all of its immediate neighbors in one transmission). In general, the cost of the forwarding set does not always reflect the number of nodes in the set. Instead, the cost associated with each node can represent different measurements, depending on the desired properties of the forwarding set. For instance, if we aim to reduce the number of nodes in the forwarding set for efficient data forwarding, the cost associated with each node could be one. Table 1 lists a few more examples of what node cost
would represent when MANSI is applied to other variations of the multicast routing problem in wireless ad hoc networks.

Fig. 2: Examples of multicast connectivity among three group members: (a) a forwarding set of six nodes formed by shortest paths from the core to the other two members, and (b) another forwarding set when node A partially shares the same path to the core with node B, which results in more efficient data packet forwarding.

We adopt the swarm intelligence metaphor to allow nodes to learn a better multicast connection that yields a lower (total) forwarding cost. Each member who is not the core periodically deploys a small packet, called a FORWARAD ANT, that opportunistically explores different, and hopefully better paths toward the core. This exploring process is illustrated in Fig. 3. If a FORWARD ANT arrives at a node who is currently serving as a forwarding node for the group (node D in this case), the ant turns itself into a BACKWARD ANT and travels back to its originator via the reverse path. When the BACKWARD ANT arrives at each intermediate node, it estimates the cost of having the node it is currently at join the forwarding set via the forwarding node it previously found. The computed cost, as well as a pheromone amount that is inversely proportional to the cost, are updated on the node's local data structure. These 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, similar to how pheromone is used by biological ants. Let us consider the same example shown in Fig. 3, when the BACKWARD ANT leaves node D and arrives at node C, the cost of having node C join the forwarding set via node D is zero since node D is already a forwarding node and is directly connected to node C.

To prevent the race condition where members attempt to establish group connectivity via one another’s forwarding path and nobody remains connected to the core, each forwarding node is associated with a height which is identical to the highest ID of the nodes that use it to connect to the core. In addition, the core has its height set to infinity. Fig. 4 shows an example illustrating how heights are assigned to forwarding nodes. A FORWARD ANT’s must stop and turn into a BACKWARD ANT to only when it encounters a forwarding node whose height is higher than the ID of the member who originated the ant. That means a member is allowed to connect to the core via an existing path that belongs to another member with a higher ID, but not vice versa, to assure that the core, whose height is always the highest, will eventually be connected to all the other members.

Fig. 4: An example illustrating how heights are assigned to forwarding node s used by the members with IDS 3, 6 and 8

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By following these simple rules, a majority of FORWARD ANTS from each member will choose a path that connects to an existing forwarding node with a smaller total path cost. Nodes on this path are then used to forward multicast data packets, resulting in a lower data forwarding cost. This exploring and learning mechanism enables MANSI to learn a better forwarding set for each group, depending on how node cost is defined, as well as differentiates MAKSI from other existing ad hoc multicast routing protocols. Note that, by doing so, MANSI attempts to evolve multicast connectivity into states that yield lower cost. It, however, does not guarantee that minimum-cost connectivity can be achieved.
RESULTS AND DISCUSSION

To study the characteristics and evaluate the performance of MANSI, we have conducted simulation experiments using the Qual Net simulator. Ten random networks were generated with 50 nodes uniformly distributed over a terrain of size 1000 x 1000 m2. Each node was equipped with a radio transceiver which was capable of transmitting signals up to approximately 250 meters over a 2 Mbps wireless channel, using the two-ray path loss model without fading. We used IEEE 802.11DCF as the MAC layer protocol, and IP as the network layer. Since MANSI does not rely on any unicast routing protocol, no other routing protocols were employed. For each network, a multicast group of 5 members was setup, where each member generated a constant bit rate (CBR) traffic at 2 packets/second to the group for 20 minutes.

Our first set of experiments was setup without mobility to study how MANSI maintains forwarding sets in static environments. For comparison purposes, we used two baseline protocols: FLOOD and CORE, as references. FLOOD is a simple flooding protocol where a data packet is rebroadcast by every node in the network, and CORE is a generic core-based protocol that operates exactly like MANSI, but without ants deployed, where CORE ANNOUNCE are periodically flooded as usual. The cost of each node was set to one, which implies that MANSI would attempt to reduce the size of the forwarding set.

Table 1 summarizes the sizes, averaged over the entire simulation time, of the forwarding sets maintained by MANSI, CORE, and FLOOD on each simulated network. (FLOOD does not really maintain a forwarding set, but the set consists of every node in the network.) The results show that in all cases, except one, MANSI yields forwarding sets that are approximately 15%-20% smaller than those of CORE, and much smaller than FLOOD.

Since the size of the forwarding set indicates how nearly nodes are involved to relay a data packet from one member to the others, this demonstrates the efficiency of MANSI in terms of data forwarding.

Fig. 6 presents packet delivery ratio of the protocols at different mobility speeds. MANSI without the mobility-adaptive mechanism, denoted by MANSI Basic, shows significant performance degradation as mobility increases due to the fact that the forwarding set lacks redundant paths when each member and forwarding node always requests only one of its neighbor to be part of the forwarding set. However, when the mobility-adaptive mechanism is enabled, as denoted by MANSI-Mobile, its results are comparable with FLOOD. Although the delivery ratio is a bit lower than that of the other two protocols, more than 90% of data packets can be delivered at every mobility speed.

In terms of efficiency, both MANSI-Basic and MANSI-Mobile give significantly better performance than FLOOD at low mobility in both channel access and bandwidth utilization aspects, as shown in Fig.7 and Fig.8, respectively.
CONCLUSION

By swarm intelligence, we have introduced an alternative approach to solving the multicast rotating problem in mobile ad hoc networks. The protocol, called MANSI (Multicast for Ad hoc Networks with Swarm Intelligence), is an on demand multicast routing protocol that creates a multicast mesh shared by all the members within each group. The protocol uses a core-based scheme, where each member initiates a request to the core node to establish multicast connectivity with other members. Intermediate nodes who receive such a request become forwarding nodes that are used to relay data packets from one member to the others. Unlike other core-based protocols, MANSI does not always rely on the shortest paths between the core and the members to establish group connectivity. Instead, each member who is not the core periodically deploys a small packet that behaves like an ant to opportunistically explore different paths. This exploring mechanism enables the protocol to discover paths that comprise a better set of forwarding nodes yielding a lower total cost of data forwarding, where the "cost" of forwarding (nodes) can be defined in terms of different application specific performance metrics. MANSI also incorporates a mobility-adaptive mechanism that allows the protocol to remain effective as mobility increases. The simulation results have shown that MANSI performs both effectively and efficiently in static or low-mobility environments, yet still effectively in highly dynamic environments.

REFERENCES

