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A Stability-based Multicast Routing Algorithm for Wireless Ad Hoc Networks

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Abstract. The research on wireless mobile Ad hoc networks has attracted much attention over the past few years, and IP multicast technology supports data transmission from one or several sources to a certain group of receivers. PUMA, as a mesh-based multicast routing algorithm for Ad hoc networks, has been demonstrated to perform better compared with other protocols under high-speed situation. Moreover, node mobility has been one of the dominant factors causing loss of system performance so that the stability is necessary to be taken into account when designing routing protocols. In this paper, a novel stability-based multicast routing algorithm (SMRA) is developed on the basis of PUMA, where the robustness and the congestion are jointly considered. In order to determine the forwarding path and the mesh member status of each node, SMRA utilizes the power information and is implemented across physical layer and network layer. We compare SMRA with PUMA and another well-known tree-based multicast protocol MAODV. Simulation results show that the performance of the proposed algorithm is better than that of PUMA and MAODV in terms of packet delivery ratio and throughput with limited control overhead.

Keywords: Ad hoc networks, control overhead, multicast routing, packet delivery ratio, throughput

1 Introduction

The widespread application of wireless devices and systems currently will certainly lead to a rapid development of wireless network technology. Mobile Ad hoc network (MANET), as a non-infrastructure, multi-hop and self-organized wireless system, is formed by a collection of mobile nodes without centralized administration [1]. In MANET, due to frequent changes of network topology caused by unpredictable mobility of nodes, route breaks continually [2]. Hence, finding and maintaining stable paths for

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transmitting packets with reliable delivery is critical in the designing of routing protocols. Solutions to this issue have been studied recently and researchers have proposed a number of methods of selecting stable paths [3-7]. However, most previous works toward such direction were based on unicast routing without considering multicast scenarios.

IP multicast is a method of sending IP datagram to a group of interested receivers in a single transmission, which is often employed for streaming media applications. Because of the resource limitation in MANET, multicast has been a research focus since it contributes to increasing the bandwidth utilization and improving the system performance [8]. On the other hand, for satisfying the requirements of all receivers in a certain group, the designing of the routing selection algorithm in multicast circumstances is more challenging than that for unicast cases. On the basis of the structure of multicast paths, existing Ad hoc multicast routing protocols can be generally classified into tree-based and mesh-based approaches. Tree-based instances such as Multicast Ad hoc On-demand Distance Vector (MAODV) [9] and Ad hoc Multicast Routing protocol utilizing Increasing Id-Numbers (AMRIS) [10], establish and maintain a fragile shared tree for each group, which causes a poor performance under high-speed situation because of link breaking. In comparison, mesh-based approach such as Protocol for Unified Multicasting through Announcement (PUMA) [11] and On Demand Multicast Routing Protocol (ODMRP) [12], provides more paths for multicast and attains better robustness. Regarding the algorithms mentioned above, there have been a series of research achievements comparing their performances [13-16]. It was shown in [13] that due to the centralized forwarding of the multicast data packets without redundant routes, AMRIS adapts worst to high traffic load or mobility. The results of [14] indicated that in many scenarios ODMRP achieves a better packet delivery ratio, but incurs much higher overhead than MAODV. It is worth noting that ODMRP is more sensitive to the number of senders along with effective traffic load than MAODV. In ODMRP, each source node periodically send requests through the network, which causes congestion and the data delivery ratio drops significantly when the number of sources becomes larger. On the other hand, MAODV maintains only one leader for the group that sends periodic Hellows, which enables MAODV more scalable. Meanwhile, because of collisions that occur from the frequent broadcasts, ODMRP does not scale well with multicast group size. In fact, with the increase of the number of senders or group members, the data delivery ratio of MAODV approaches that of ODMPR closely [15].

For PUMA, it is initiated by receivers and performs better compared with other protocols [16]. The core of the group periodically broadcasts a single control packet, named multicast announcement (MA), to accomplish all the functions needed in building the connectivity and maintaining the mesh. Data flooding within the mesh and the mechanism of using MA jointly ensure high packet delivery ratio and low control overhead of PUMA. However, the processes of route decision and mesh establishment under PUMA are implemented simply based on shortest path. In high-speed situation, such policy may lead to packet loss and unnecessary overhead caused by link breaking and mesh rebuilding. Furthermore, PUMA permits each qualified node to forward packets for multiple groups without any limitation, which may incur throughput decline on account of congestion.

In view of the above-discussed issues, the goal of this paper is to devise improved routing algorithm so as to set up reliable meshes and paths. Following this motivation, a novel stability-based multicast routing algorithm (SMRA) is presented based on the original PUMA. In SMRA, aiming to enhance the system robustness, information of signal received power is used to determine the route and mesh, which is actually a cross-layer scheme across network layer and physical layer. Fig. 1 shows the information exchange. Moreover, we restrict the number of nodes that transmit datagram for multiple groups simultaneously in order to distribute the flow reasonably and reduce the congestion effectively. SMRA is expected to have advantages on packet delivery ratio, throughput and control overhead.

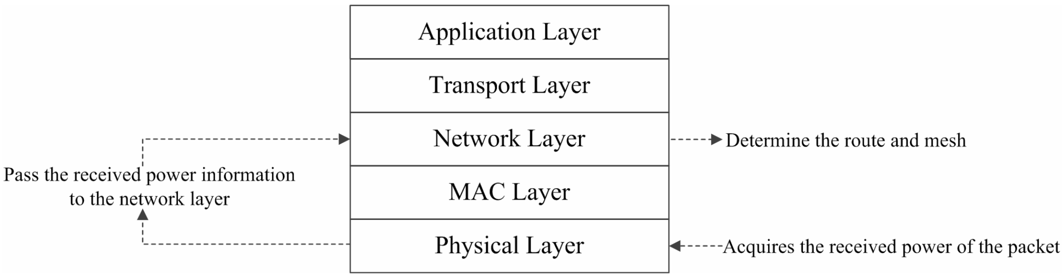


Fig. 1. Information exchange of cross-layer approach

The rest of the paper is organized as follows. Section 2 gives an overview of MAODV and PUMA. The proposed SMRA is described and analyzed in detail in Section 3. Simulation results comparing SMRA with PUMA and MAODV are presented in Section 4. Finally, we conclude and prospect the future work in Section 5.

2 Overview of MAODV and PUMA

2.1 Algorithm Implementation

Multicast Ad hoc On-demand Distance Vector (MAODV), as the multicast routing extension of the unicast protocol AODV [17], establishes routes on demand using a tree-based path-discovery mechanism. In MAODV, a node originates a RREQ message when it wishes to join in a multicast group or has data packets to send to a path-undiscovered group. Nodes who received the RREQ choose to respond or rebroadcast the message depending on different conditions. As the RREQ is broadcast across the network, nodes set up the reverse path in their route tables for the purpose of relaying a response (RREP) back to the source. Immediately as nodes along the path to the source receive RREP, the forwarding path is created. An activation message (MACT) is used to ensure that each multicast tree has single path to any tree node. In addition, for maintaining latest tree information, each group leader sends group Hellows periodically in MAODV.

Protocol for unified multicasting through announcement (PUMA) in Ad hoc networks creates and maintains a shared mesh for each multicast group, without involving a unicast routing protocol or the relocation of cores to groups. The uniqueness of PUMA originates from its use of MA generated by the core of group periodically for establishing connectivity and maintaining mesh. Specifically, functions implemented by MAs include the election of cores, deciding the routes for sources outside a multicast mesh to unicast data packets toward the group, and maintaining the multicast mesh. MAs transmit in a hop-by-hop way from the core to receivers. Each MA contains a sequence number, the address of the group (Group ID), the address of the core (Core ID), the distance to the core, a mesh member flag representing whether the node belongs to the mesh, and a parent field that states the preferred neighbor to reach the core. Succeeding MAs have a higher sequence number than the previous sent by the same core. At the same time, each node keeps a connectivity list for every group to store the information of MAs it received from its neighbors.

The multicast procedure starts with core election. Receivers of a certain multicast group participate in core election by sending MAs and finally the one with highest ID becomes the core of the group. Afterward, the core begins broadcasting MA for the corresponding group with the core ID specified as its own ID. During the MAs propagation, a multicast mesh is established which is rooted at the core. Receivers are all situated on the edge of the mesh except the core. A non-receiver could also be referred to as a mesh member if it lies on one of the shortest paths from a receiver to the core. For the purpose of forwarding data in multicast, packets generated by a source outside the mesh firstly move to the group in a unicast way, until they reach the designated mesh members. As soon as a member receives multicast packets for the group, it then floods the packets within the scope of the mesh. Fig. 2 describes the mesh structure and data propagation in PUMA.

2.2 Protocol Analysis

MAODV utilizes a shared bi-directional multicast tree based on hard state. Such bi-directional character avoids duplicate packets to receivers. However, when the structure of the multicast tree changes caused by node mobility, no alternative path exists and the packet delivery ratio may be influenced seriously. Moreover, MAODV sends the reply in a unicast way and therefore the link breaking may cause the lost of RREP, which would incur lack of routing. For control packets, MAODV needs RREQ, RREP, MACT and Hellow messages to obtain the forwarding path and to maintain or repair the tree, which produces non-trivial overhead.

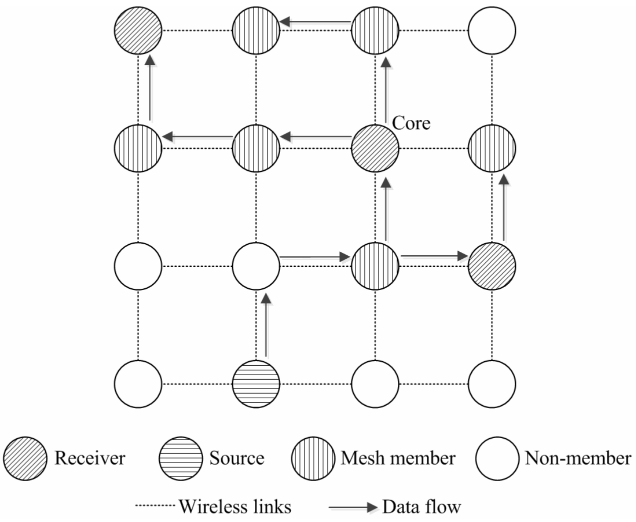


Fig. 2. Mesh structure and data propagation of PUMA

PUMA is a pure network layer protocol without involving MAC layer and physical layer. Because of periodic single control packet and data flooding, PUMA attains a higher data delivery ratio with lower control overhead compared with other multicast protocols. In addition, the constructions of both mesh and route are based on the minimum hop counts. Node chooses the first received MA with the shortest distance to the core as the best MA and the neighbor from which is regarded as parent. Such policy may incur stability issue due to node mobility, frequent rebuilding of mesh or route will be bound to cause loss of performance. It is further noting that each qualified node could forward packets for multiple groups without any limitation, which may cause congestion and packet loss. An illustration is given in Fig. 3 to explain the congestion problem involved in PUMA when multiple groups exist.

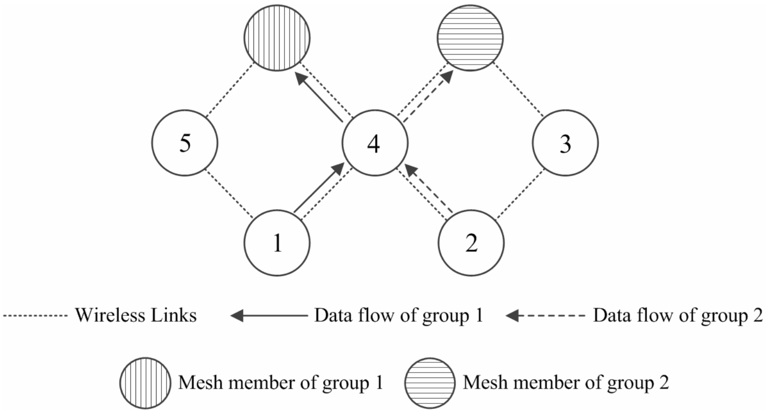


Fig. 3. Congestion issue involved in PUMA

As shown in the figure above, non-member node 1 and 2 are respectively the sources of multicast group 1 and group 2. Based on PUMA, they both select neighbor 4 as parent because the MA from 4 is received earlier than that from 3 or 5. When the sources have data packets to transmit to the multicast groups, they broadcast the packets. Only node 4 receives the packets and forwards them to the corresponding mesh member. Such approach for routing may lead to datagram congestion and packet loss at the intermediate node 4. In addition, nodes on the path of multiple groups may run out of the energy in a short time due to a mass of forwarding. Hence, the overall system performance, such as throughput, will be influenced if the amount of such nodes as 4 is large. Regrettably, there is no restrictive measure for solving this problem in PUMA. Consequently, as a well-performed multicast routing protocol, PUMA still has room for improvement.

3 Stablity-based Multicast Routing Algorithm

In this section, a novel stability-based multicast routing algorithm (SMRA) is developed, which is a cross-layer protocol encompassing network layer and physical layer. For promoting the overall system performance, SMRA uses information of powers provided by the physical layer and classifies neighbors of each node into different levels, which differentiates SMRA with PUMA. Also a modified mechanism is presented to limit the number of nodes transmitting packets for multiple groups, which will be helpful to throughput.

3.1 Node's Stability Level

According to the rules of wireless communication, physical layer of each node detects the received power of MAC frame, which attenuates with distance increasing. Without loss of generality, this paper considers free space model and a classic formulation that defines the functional relationship between received power P_r in watts and distance d in meters is given by [18]

$$P_r(d) = P_t(\frac{\lambda}{4\pi d})^2 \quad \textbf{(1)}$$

where P_t denotes the transmitted power in watts, λ represents the wavelength of radio. It is worth noting that here we made a simple assumption that there is no antenna gain and the power decline comes entirely from the path loss. Actually, our results also apply to other communication models that have different path losses. One can obtain the corresponding relation between the power and the distance in any wireless signal model. From (1), it can be found that the received power should be inversely proportional to the distance on condition that the transmitted power is a constant. Hence, d could be estimated by acquiring P_r and calculating the inverse function of (1). A node will drop the packet if P_r is below some known threshold and the corresponding distance is denoted by $r_{threshold}$.

Clearly, the reception range of each node is round with the radius of $r_{threshold}$ and a neighbor is said to be feasible if $d < r_{threshold}$. In SMRA, all feasible neighbors are classified into stable and untrusted levels. Fig. 4 illustrates the level partition for neighbors of a random node 1. Stable region is defined as the inner round area with a radius of $r_{stable} = \gamma r_{threshold}$ and the untrusted region is characterized by the shadow annulus with ring width $r_{untrusted} = (1-\gamma)\, r_{threshold}$, where $0 < \gamma < 1$. Thus, neighbor node 2 is classified as stable level since it locates in the stable region whereas node 3 is on untrusted level. In this paper, it is assumed that each node in the network has the same $r_{threshold}$ and P_t. Because of mobility, a feasible neighbor might move out of the reception range at any time. In order to avoid frequent link breaking, stable-level neighbors are more preferred to participate in building the route or mesh. As to how to participate, we will describe in detail hereinafter.

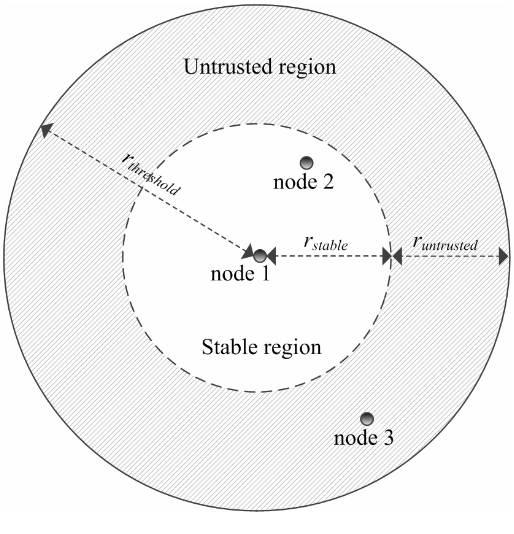


Fig. 4. Level partition for neighbors of node 1

3.2 Structures of MA and Connectivity List

In SMRA, a MA has seven fields: Core ID, Group ID, Stable Distance to Core, Sequence Number, Mesh Member and Parent. Compared with PUMA, the stable distance to core is not just a hop count but a new measurement based on stability level. The definitions of other five fields are the same as PUMA. It is worth noting that the assignments of mesh member and parent are different from that of PUMA based on our algorithm. When generating a MA, the node set the source IP address to its own IP, and the destination IP is set to the broadcast address (255.255.255.255). The construction of a MA is given in Fig. 5.

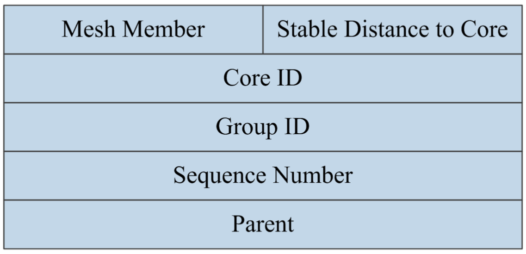


Fig. 5. Construction of multicast announcement

As MAs travel through the network, every node creates a data structure called connectivity list for each group. Each entry in the list corresponds to a MA received or a neighbor who sent the MA. In addition to recording the information of MA and storing when and where it received the announcement, each entry also keeps the stability level which is added for quantifiably evaluating the link reliability between neighbors. Newer MAs with higher sequence numbers overwrite the entries with lower sequence numbers for the same group. Therefore, for every multicast group, a node only keeps in its connectivity list the latest information from a particular neighbor for a given core. Fig. 6 shows the format of the connectivity list in our algorithm.

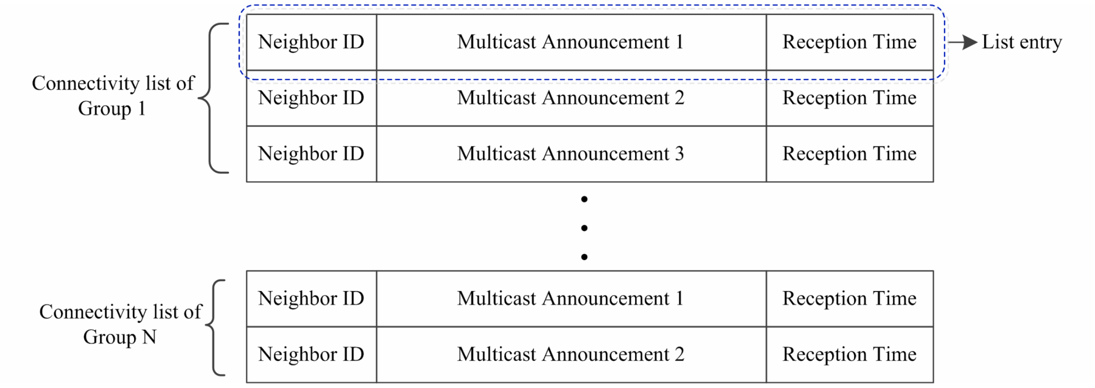


Fig. 6. Connectivity list format in SMRA

3.3 Core Election and Mesh Establishment

Like PUMA, SMRA selects a receiver of the group as the core. A receiver who is not aware of the core participates in the election by broadcasting MA to its neighbors. In MA, it sets Core ID to its own ID, and Group ID to that of the corresponding group. When more than one receiver participates in the election, intermediate nodes will forward MAs with higher Core ID and drop the ones with lower Core ID. Eventually, the participating node with the highest ID wins the election and is selected as the core of the group.

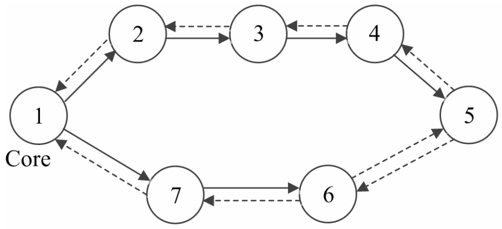
Once a core is elected it begins periodically broadcasting MAs to build and maintain the multicast mesh. The core sets Stable Distance to Core to zero, Mesh Member to true and Parent to INVALID_ADDRESS (because it has no parent). MAs transmit hop by hop throughout the entire network. Immediately after an intermediate node receives a fresh MA, it writes the information of MA into the related entry and calculates the stability level of the neighbor who sent the announcement according to the following rule:

$$\text{Stability Level} = \begin{cases} m_s & \text{if the neighbor is on stable level} \\ m_u & \text{if the neighbor is on untrusted level} \end{cases} \tag{2}$$

where we set $m_s = 1$ and $m_u = 2$ in this paper. Because of flooding, each node may receive multiple latest MAs from different neighbors for a certain group. For this case, nodes wait for a short period to collect all MAs before generating their own announcements.

In SMRA, a MA is considered as the best MA if it has the smallest value of stable distance to core within all entries of the connectivity list, and the neighbor from which it has been received is referred to as the best neighbor or parent for the relevant group. Based on the list entries, a node generates its own MA that has the same Core ID, Group ID and sequence number as parent, and the value of the stable distance to core is obtained by adding the stability level of itself to the stable distance to core of the parent.

Fig. 7 shows the propagation of MAs with Core ID = 1, Group ID = 224.0.0.1 and Sequence Number = 79. The solid arrows indicate the neighbor from which a node receives its best MA. As depicted in the figure, node 5 has two neighbors who broadcast MA for the group: node 4 and 6. The connectivity list of node 5 is described in Table 1, where two entries exist. According to the statement above, node 4 is chosen as the best neighbor because of smaller stable distance to core. The stability level is figured out via formula (2), which indicates that neighbor 4 is on stable level and neighbor 6 is on untrusted level. Reception time is defined as a time sequence of received MAs. Thus, node 5 forms its own MA with Parent = 4 and Stable Distance to Core = 3 + 1 = 4. However in PUMA, node 6 will be regarded as the best neighbor or parent since it has shorter distance to the core.



Core Id = 1, Group Id = 224.0.0.1, Seq. No. = 79

Fig. 7. Dissemination of multicast announcements

Table 1. Connectivity list of node 5 (Core ID = 1, Group ID = 224.0.0.1, Seq. No. = 79)

Neighbor	Stable Distance to Core	Parent	Mesh Member	Stability Level	Reception Time
4	3	3	true	1	2
6	4	7	false	2	1

It can be observed that SMRA selects parents based on stability and nodes on stable level are preferred. Compared with the original PUMA where hop count is the only measurement standard, our mechanism not only constructs more reliable meshes and routes without frequent rebuilding, but also avoids overlong distance to the core. One should note here that a node may have more than one best neighbor. In this situation, with regard to the selection of parent, SMRA considers other factors such as congestion and reception time. For the purpose of reducing the impact of congestion mentioned in Section 2.2 when multiple groups exist, each node chooses its parent among the best neighbors for a certain group according to the following regulation.

- The node traverses all its connectivity lists;
- The best neighbor from which the MA has been first received (i.e., smallest reception time) will be referred to as parent, if neither of the best neighbors locates on the upstream for other groups (i.e., exists in the entry of other connectivity lists and has the corresponding stable distance to core smaller than that of the node itself);
- Otherwise, the best neighbor locating on the upstream for minimum number of other groups will be chosen as parent.

The procedure of mesh establishment starts from receivers. For a particular group, all receivers set

Mesh Member field to true. Non-receivers think of themselves as mesh members if they have at least one mesh child in their connectivity list. A neighbor is a mesh child if all the following conditions are satisfied: (a) its Mesh Member field is true; (b) the Stable Distance to Core of the neighbor is greater than the node's own; (c) within two MA intervals the announcement corresponding to this entry was received. In addition to receiving a fresh MA, detecting a change in mesh member status also generates a new announcement. This process is done immediately when the changing occurs, which reduces the delays in critical operations. Hence, as the MAs caused by changing in mesh member status reach the core, the multicast mesh is build up for the group. Fig. 8 shows the mesh creation in SMRA.

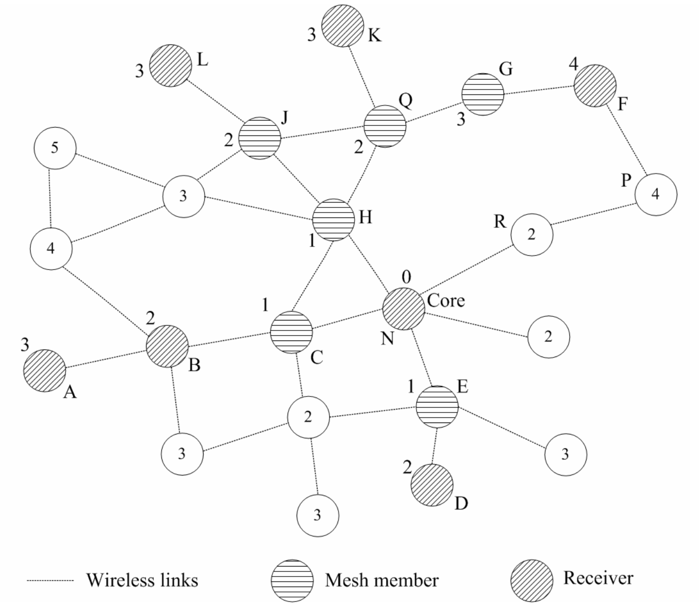


Fig. 8. Mesh creation in SMRA

As we can see from the figure above, node N is elected as the core, and the number indicates the stable distance to core in the diagram. All receivers (A, B, D, F, L, K and N) have their Mesh Member field set to true in their MAs. Non-receivers (C, E, G, H, J and Q) consider themselves as mesh member based on the above-mentioned policy. Node F succeeded as a mesh child of node G and selects path F-G-Q-H-N since it has greater stable distance to core than that of node G. Comparably, Original PUMA will choose path F-P-R-N to set up the mesh due to smaller hop counts. However, the shortest path might not be the best one. In SMRA, we take the stability factor into account and construct the mesh with better reliability. Meanwhile, the definition of stability level in (2) effectively avoids overlong paths to the core within the mesh.

3.4 Data Packet Forwarding

The application layer protocols generate multicast traffic and pass them down to the network layer. In addition to setting respectively the source and destination to the IP addresses of multicast source and multicast group, SMRA adds a forwarder field in the IP header of each data packet, which indicates the IP address of the forwarding node's own. Such mechanism enables nodes to identify the particular neighbor from which the datagram is received, thereby to make forwarding decisions according to the situation. SMRA differentiates MA and the data packet based on two facts: i) the destination address of MA is 255.255.255.255; ii) data packet contains a forwarder field in the IP header. Multicast datagrams are forwarded unpredictably without extra control packets, such as RTS/CTS. Nevertheless, a random delay between 0 and a SMRA broadcast jitter is experienced before transmitting. Jitter has been shown to reduce collision in MANET.

For the purpose of forwarding multicast data packets, non-member needs to transmit packets when the source locates outside the mesh. Based on the parent field of the connectivity list entry, a node forwards a data packet it received from its neighbor if it is the selected parent of the neighbor, which enables nodes that are non-members to forward multicast packets towards the mesh of a group. Consequently, multicast data packets move hop by hop in a unicast way, until they reach the designated mesh member. The packets are then flooded within the mesh. For dealing with the packet duplicates, mesh members maintain a packet ID cache to identify and discard packet duplicates.

The cache is also used to update connectivity lists. As we know, since wireless communication is done in a broadcast way, immediate node also receives data packet from its chosen parent. When a non-member forwards data to its parent, it waits for a short time-slot, called timeout interval, to receive data packet from the parent. If the node has not received any packet (data or MA) from its parent within the timeout interval, it will remove the parent from its connectivity list and select a new one. Such process is implemented in SMRA. Fig. 9 shows the structure of the packet ID cache.

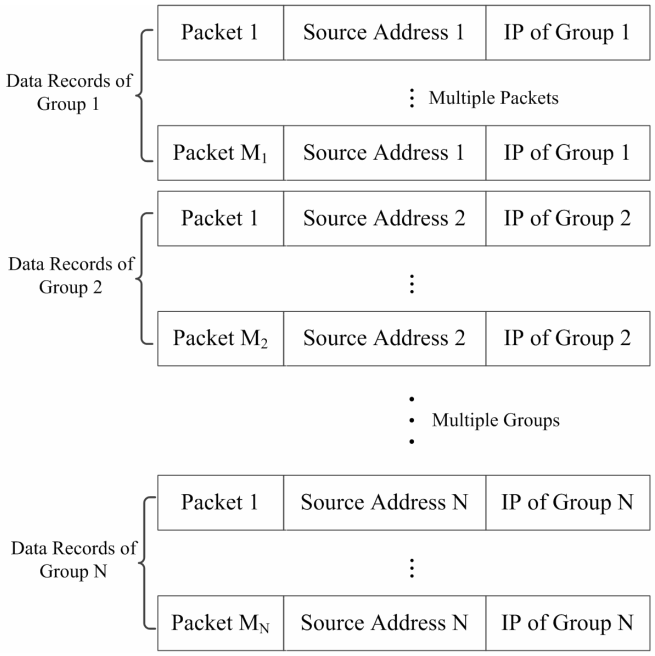


Fig. 9. Structure of the packet ID cache

When a node receives a data packet, it checks to see whether the packet ID, source address and group ID in the IP header of the packet match with an existing entry in its packet ID cache. If yes, the packet is discarded, otherwise it is processed as follows:

- If the node is a mesh member of the corresponding group, the data packet is then forwarded.
- If the node is considered as parent of the previous hop of the data packet, it then forwards the packet.
- Otherwise, the data packet is dropped.

It is worth noting that only packets that qualify to be forwarded form the entries in the packet ID cache. Every time an entry is inserted into the cache, a timer is operated with a period equal to SMRA flush interval. When the timer expires, the earliest-inserted entry is removed. Hence, no entry remains for longer than SMRA flush interval and the size of packet ID cache is controlled not too large. SMRA flush interval should be set longer than the duration of the data packet floating.

3.5 Qualitative Comparison of SMRA and PUMA

As the improved version of PUMA, SMRA has a lot in common with PUMA. To be specific, they are both mesh-based and are initiated by receivers. A periodic multicast announcement message is used for maintaining the meshes. The data packets generated by the source move to the desired mesh in a unicast way and reach the receivers by flooding in both SMRA and PUMA. However, there are several important differences in the implementation algorithms of the two protocols, which may give rise to significant performance differences.

Firstly, PUMA builds the meshes and routes based on minimum hops. However, the shortest path might not be the best one. Frequent link breaking caused by node mobility would incur both a decline of the packet delivery ratio and an increase of the control overhead. While in SMRA, neighbors are classified into two levels, stable-level ones are more preferred. The stability-based mechanism of SMRA ensures the meshes and routes more robust in the high-speed mobile scenarios. Therefore, SMRA scales better than PUMA with mobility.

Secondly, PUMA faces a congestion issue when multiple groups exist, which may lead to packet loss. By employing a novel parent selection mechanism, SMRA distributes the traffic reasonably and relieves the congestion effectively, which is helpful for throughput improvement.

Thirdly, SMRA is implemented without adding any extra control packet compared with PUMA. With the establishment of stable meshes and routes, the overhead cost by SMRA would be controlled validly.

4 Simulation Results

Performance evaluation is conducted by comparing our proposed SMRA with PUMA and MAODV. The standard contention-based 802.11 DCF [19] is used as the MAC layer protocol. The network layer of SMRA shares information of the physical layer. Three metrics are used for our evaluation: packet delivery ratio, throughput and control overhead. Packet delivery ratio is defined as the number of data packets received successfully divided by that of the packets expected to be delivered. Throughput is the total amount of data transmitted by all nodes in the network within unit time. Control overhead is denoted by the ratio between the amount of control packets and that of the data packets delivered.

4.1 Parameter Configuration and Simulation Environment

Table 2 presents the values of certain default parameters related to SMRA, which definitely have an effect on the performance of the protocol.

Table 2. Parameter configuration in SMRA

Parameters	Value
MA Interval	3s
Timeout Interval	50ms
MA Delay	100ms
SMRA Broadcast Jitter	15ms
SMRA Flush Interval	6s

We use the NS-2 simulator for our experiments. Table 3 lists the general parameters that characterize the simulation environment. The terrain size used is 1500m × 1500m for all experiments. The maximum node speed is 20m/s and the length of the packet is 512bytes. The movement of node is “random waypoint”. The radio range of each node is 200m and γ is assumed to be 0.5, i.e., the radius of the stable region is 100m. There exist 5 groups each with 10 receivers and one source in our scenario. Sources continuously send data packets towards multicast groups during the whole simulation. In our simulation, all results are achieved by averaging 10 times experimental results.

Table 3. General parameters of simulation environment

Parameters	Value
Total Nodes	100
Simulation Time	900s
Simulation Area	1500m×1500m
Node Placement	Random
Mobility Model	Random Waypoint
Radio Range	200m
Stable Range	100m
Channel Capacity	2Mbps
MAC Protocol	IEEE 802.11 DCF
Data Packet Size	512bytes

4.2 Performance Evaluation

Fig. 10 shows the results of packet delivery ratio (PDR) changing with varying node speed and traffic load. As we can see, all three protocols are faced with PDR dropping as nodes move faster. This is because dynamic topology leads to path breaking. It is obvious that SMRA has a PDR higher than that of PUMA or MAODV. With the increasing of the mobility, PDR of PUMA and MAODV decline quickly whereas that of SMRA changes slowly. Even though nodes move at a speed of 20m/s, SMRA can still attain a PDR above 0.85. From the analysis above, both PUMA and MAODV are implemented based on shortest path, whereas SMRA provides more stable mesh and route, which is a significant superiority of our proposed algorithm. In addition, as the traffic load increases, SMRA has the best scalability since it alleviates the congestion and thereby reduces the packet loss caused by collisions.

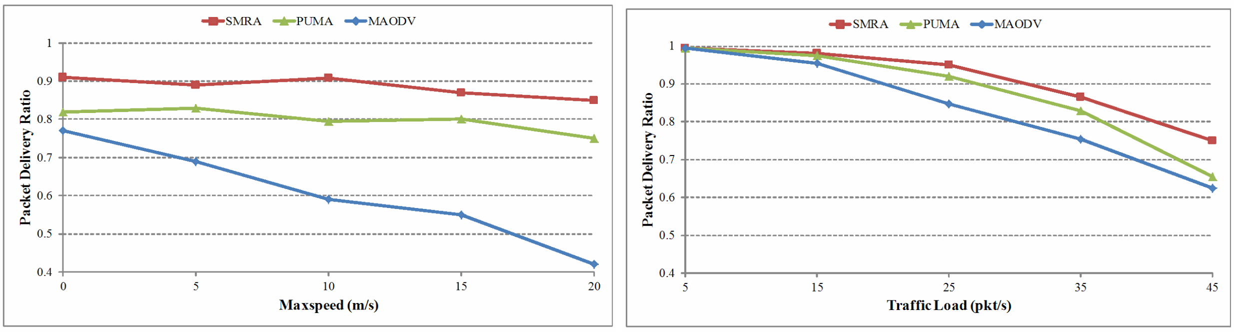


Fig. 10. Packet delivery ratio vs. mobility (Traffic Load = 20pkt/s) and traffic load (Mobility = 10m/s)

From Fig. 11, one can find throughput descends with the mobility increasing but ascends with the rising of the traffic load. SMRA achieves a better performance than that of PUMA and MAODV. Using our proposed algorithm, building stable meshes and routes reduces link breaking effectively. At the same time, the congestion phenomenon on nodes who forward data for multiple groups is controlled and the survival time of such nodes extends in SMRA. These factors jointly contribute to the throughput improvement.

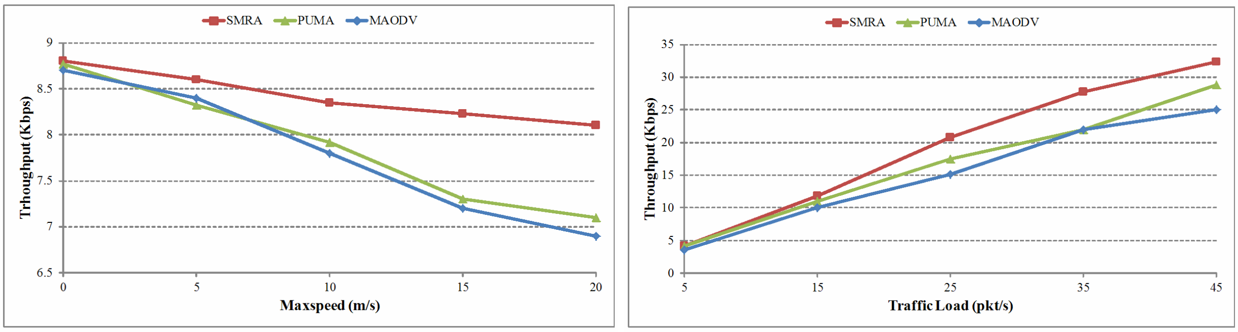


Fig. 11. Throughput vs. mobility (Traffic Load = 20pkt/s) and traffic load (Mobility = 10m/s)

Fig. 12 reflects the Control Overhead cost by the three protocols. With the node speed increases, control overhead rises apparently. As one can see, the curves of SMRA and PUMA keep on a relatively low level, whereas that of MAODV appears higher evidently. That is because both SMRA and PUMA utilize a single control packet to build and maintain the meshes and routes, which greatly reduces the overhead. Furthermore, SMRA attempts to operate based on stability without adding any control packet, which enables SMRA to perform with least cost due to mitigatory link breaking and mesh rebuilding. In the case of higher traffic load, MAODV scales worst because it may erroneously infer link breakage when Hellow packets are lost due to collisions. On the other hand, SMRA limits the number of nodes that transmit packets for multiple groups hence the impact of congestion is reduced.

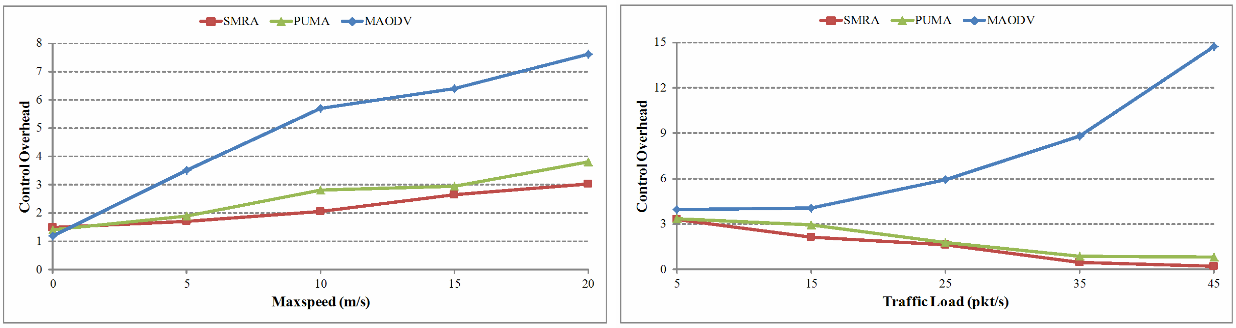


Fig. 12. Control overhead vs. mobility (Traffic Load = 20pkt/s) and traffic load (Mobility = 10m/s)

5 Conclusion and Future Work

In order to overcome the shortcomings of the mesh-based multicast protocol PUMA, i.e., frequent link breaking under high-speed mobile environment and data congestion on immediate nodes when multiple groups exist, a stability-based multicast routing algorithm, named SMRA, is developed for wireless Ad hoc networks in this paper. SMRA utilizes a cross-layer approach under which the network layer can be aware of the power information from the physical layer. At the same time, SMRA considers stability and selects more reliable links to build the meshes and routes whereas PUMA is implemented simply based on the hop counts. Moreover, our proposed algorithm limits the number of nodes transmitting packets for multiple groups, distributes the data flow reasonably and reduces the congestion.

For evaluating the performances, simulation experiment is conducted based on NS-2 simulator. It is shown from the simulation results that SMRA outperforms PUMA and another tree-based protocol MAODV in terms of packet delivery ratio, throughput and control overhead, which confirms our analysis.

Nowadays, with the fast development of wireless communications technology, spectrum resource has become more and more scarce. For the purpose of making full use of the limited spectrum bandwidth, researchers have proposed some solutions, such as cognitive radio (CR) technology [20] [21] and multi-channel scheduling algorithms [22] [23]. CR was put forward to enable the unlicensed users to sense and intelligently access the unoccupied spectrum. In CR networks, a cognitive user (CU) firstly senses and gets available spectrum named spectrum opportunity (SOP), then divides the SOPs into multiple channels and selects one of them without interfering the primary user (PU) to transmit data. Multi-channel scheduling is applied to schedule the wireless links on multiple channels respectively so as to avoid interference and improve throughput, which is operated in MAC layer. In the future, we will work to combine CR and multi-channel technology with multicast routing algorithm and design cross-layer scheme with intelligent spectrum utilization.

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