# Overlay Small Group Multicast Mechanism for MANET

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**Abstract.** In order to provide the multicast service in MANET, a lot of multicast routing protocols have been proposed. Most of them create tree or mesh-based graphs and require network nodes over the tree or mesh to maintain the membership information. In particular, high node mobility causes the tree or mesh to be broken and reconstructed by generating much overhead to manage the membership at network nodes. In accordance with overlay multicast protocols to reduce such overhead, which enables the packet transmission regardless of the movement of intermediate nodes over the paths between group members, we propose an overlay small group multicast mechanism, called SPM (Shortest Path overlay Multicast) for MANET. SPM multicasts packets over the shortest paths from a source to each group member without duplicate packet delivery over common partial paths. When creating a multicast overlay tree, SPM utilizes the route information provided by ad hoc unicast routing protocol without further control messages and any other information. Extensive simulations through NS-2 simulator proved that SPM has better throughput, loss rate and packet transmission delay than MAODV, a typical tree based multicast routing protocol used in MANET.

## 1 Introduction

MANET is a wireless network where all nomadic nodes are able to communicate each other through the packet forwarding service of intermediate nodes. Specially, since packet forwarding and routing is done via intermediate nodes, the MANET working group in IETF has been trying to standardize its routing protocols [1].

Recently, in order to provide the multicast service in MANET, a lot of multicast protocols have been proposed. However, most of them are based on tree or mesh graphs and they require all network nodes to participate in a multicast routing. In particular, the tree or mesh should be reconstructed when the network topology is affected by the movement of nodes over the tree or mesh. Even more, during the reconstruction with additional control messages, packets cannot be transmitted successfully. In addition, if a forwarding node over the tree or mesh fails to send a multicast packet to its neighbors, other group members reachable via this node cannot receive the packet in the event.

In order to address these problems, the overlay multicast routing mechanisms which provide multicasting capability using the unicast routing protocol among

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group members have been proposed [2] [3]. They are not affected by the movement of network nodes if there exist paths among group members because its underlying unicast routing protocol is responsible for route discovery. Since a source should have the information on all group members and put their IP addresses in all transmitted packet headers, they are suitable for the small group multicasting.

Although efficient overlay multicast protocols for MANET have been proposed in [3], they need crucial location information of nodes and there is no mention about how to notify nodes of other nodes' location. In addition, although the paths among group members have the overlapped partial paths, most overlay multicasting techniques require independent unicasting transmissions among group-member pairs to be executed, which results in duplicate packet delivery.

In this paper, we proposed an overlay small group multicast mechanism for MANET, called SPM (Shortest Path overlay Multicast) which delivers packets through the shortest path from a source to each small group member and avoids the packet duplication over common paths. In particular, SPM utilizes route information provided by ad hoc routing protocols without additional control messages for location information and group management. In our previous work [4], we proved that our SPM shows better performance than other overlay multicast protocols for MANET.

The rest of this paper is as follows. In section 2, closely related work to SPM is introduced. In section 3, our SPM protocol is described in detail. We compare SPM with MAODV (Mobile Ad-hoc On-demand Distance Vector) [5], the most well-known multicasting protocol, in section 4. Finally, some concluding remarks are given in section 5.

## 2 Related Work

### 2.1 MAODV

Multicasting in MANET has primarily received an attention in terms of providing multicasting capability at network layer. In particular, MAODV [5] allows the route information obtained for multicasting packets to be used in a unicast routing, and vice versa. MAODV builds up a multicast tree based on AODV unicast routing protocol. Each node keeps its Route Table when it requests a route as in AODV. In MAODV, sources, multicast group members and tree members maintain a sharing tree for each multicast group. Each selected group leader periodically broadcasts Group Hello message (GRPH) throughout the whole network, in order to indicate the existence of its group. A joining node participates in the group by especially requesting a route (RREQ), and receiving Route Replies (RREPs) that include the shortest paths to other existing nodes in the multicast tree. The joining node sends ACK message over the best appropriate path (generally, the shortest path) during which all intermediate nodes over the selected path maintain the session information and play roles of multicast tree members. Figure 1 shows the RREQ/RREP message exchanges in MAODV.

However, MAODV has a disadvantage in that the intermediate nodes, even non-group members of a multicast group, need to keep routing table information for a multicast session with much overhead by generating too many control

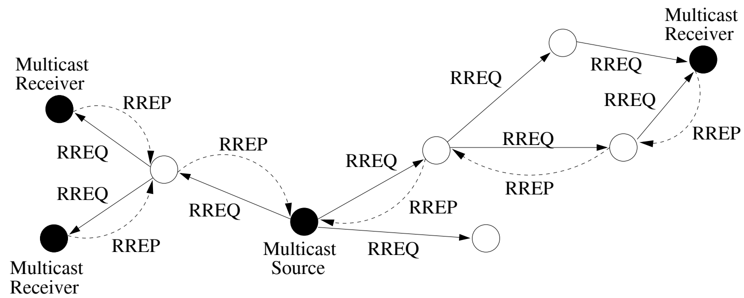



**Fig. 1.** MAODV Mechanism.

messages in order for each node to maintain it, which results in wasting scarce wireless bandwidth.

### 2.2 Overlay Multicast

The overlay multicast technique creates a multicast packet delivery tree at application layer and transmits packets by using its underlying unicast routing protocol over the tree. Location-guided multicasting [3], one of the overlay multicast schemes, tries to allow the intermediate nodes to avoid maintaining the global multicast session information. The multicast packets are transmitted from the source to all group members using unicast routing methods through a specific header encapsulation after creating two kinds of tree using the nodal location: location-guided $k$-ary tree and location-guided Steiner tree. Therefore, it is enough that only the source keeps the group membership information in order to manage the multicast tree. However, the scheme depends on the accurate location of nodes and there is no description on how to notify the nodes of other nodes' location under an environment where node mobility is allowed. Furthermore, all nodes should be equipped with GPS device, which is quite a tough requirement practically. In [4], we compared SPM with the location-guided schemes and proved that our SPM is more suitable for an overlay multicast protocol for MANET.

## 3 SPM (Shortest Path overlay Multicast) Mechanism

### 3.1 Overview of Proposed Approach

We propose SPM (Shortest Path overlay Multicast) to build the multicast packet delivery tree which provides shortest paths from a source to each group member, which allows the loss rate and packet transmission delay consumption to be minimized. In SPM, the source can manage multicast group membership because it supports a small group. For the membership creation, a node which desires to receive the multicast packets should subscribe to the multicast group by requesting the subscription to the source. Thereafter, the source tries to attach the new member to the existing tree. When a packet is multicasted, the packet header defined in SPM contains the IP addresses of nodes participating in the multicast (the header format is shown in Figure 4) as in other overlay protocols like [2]. In particular, SPM utilizes the routing information provided by its underlying unicast routing mechanism when constructing the multicast packet delivery tree. The route path acquisition techniques are given in detail according to its selected routing protocols in Section 3.4.

Since common paths exist among the shortest paths between the source and each group member, SPM transmits a packet to the last node of the common path in order to avoid duplicate transmissions of the same packet over the path. After arriving at the last node, the packet is replicated and forwarded to different directions for the rest of each shortest path. Therefore, it enables the packet to be transmitted through the shortest path to each group member, which results in reducing the distribution delay. Furthermore, SPM saves the network bandwidth due to avoiding the duplicate packet transmissions over the common path.

### 3.2 Assumption and Notation

Since SPM should put the IP addresses of nodes participating in a multicast into the packet header, we assume that SPM is more suitable for the small group applications. Since a node should subscribe to a multicast group membership through a source, it is assumed that all nodes know the IP address of the multicast source. In addition, SPM is provided with the routing path information by ad hoc unicast routing protocols and the path from the source to each node is assumed as the shortest one.

For the description of our SPM, we use the following notations in this paper.

- $G = (V, E)$ : $G$ represents the directed graph of a network topology, where $V$ and $E$ are the set of MANET nodes and physical links among the nodes, respectively.
- $p_i = (V_i,\, E_i)$ : $p_i$ is a simple graph. It is a set of nodes on the path from a source to multicast member $v_i$ and the set of physical links $E_i$ to connect those nodes.
- $G_s = (V_s, E_s)$ : $G_s$ represents a shortest path tree, where $V_s$ and $E_s$ are the set of nodes and physical links over the shortest path tree;
- $G_m = (V_m, E_m)$ : $G_m$ represents a multicast packet delivery tree, where $V_m$ and $E_m$ are the set of all network nodes to participate in a multicast and network-level links among them over an overlay tree, respectively.
- $P = \{\, p_1, p_2, \ldots, p_{n-1}, p_n \,\}$, $n$ is the number of multicast group members.
- $G_1 + G_2 = (\, V_1 \cup V_2,\, E_1 \cup E_2)$
- $G_1 - G_2 = (\, V_1 - V_2,\, E_1 - E_2)$
- $G_1 \cap G_2 = (\, V_1 \cap V_2,\, E_1 \cap E_2)$
- $outdeg(v)$ = the number of out-going edges from node $v$.

### 3.3 Multicast Packet Delivery Tree Construction

The multicast packet delivery tree ($G_m$) in SPM consists of all network nodes to participate in a multicast ($V_m$) and network-level links ($E_m$) among $V_m$ over an overlay tree. The algorithm for multicast packet delivery tree construction has two phases; Shortest-Path-Tree-Creation (SPTC) and Overlay-Creation (OC) (see Algorithm 1).

**Algorithm 1** SPTC–OC Algorithm

**Input:** The shortest path set $P$ from the source($v_{src}$) to each member($V_m$)
**Output:** Multicast overlay tree $G_m$

$P = \{ p_i \mid p_i$ is the shortest path from the source to multicast member $v_i, 1 \le i \le n$, $n$ is the number of multicast members $\}$
$p_{common} = \{ V_{common}, E_{common} \}$ // $p_{common}$ consist of ($V_{common}$, $E_{common}$), where $V_{common}$ is a set of nodes over a tree or path and $E_{common}$ is a set of their edges.

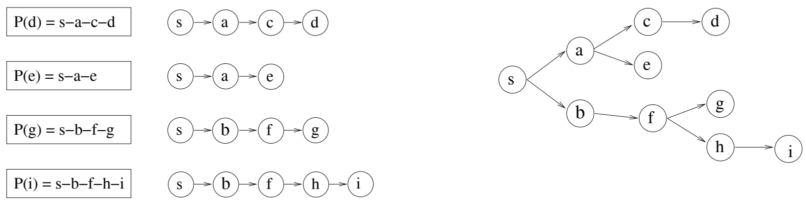
In order to acquire $G_m$, the shortest path tree, $G_s = (V_s, E_s)$ is created.
$G_s := ( \{v_{src}\}, \phi )$ // $G_s$ is initialized with $\{v_{src}\}$
$V_{JN} := \phi$ // initialize the set of junction nodes.

**for** $i := 1$ to $n$ **do**
  $p_{common} := G_s \cap p_i$ // search for the longest path between $G_s$ with $p_i$
  let $v_{last}$ be the farthest element of $\{ v \mid v \in V_{common}, v \neq v_{src} \}$ from the source.
  $V_{JN} := V_{JN} \cup \{ v_{last} \}$
  $G_s := G_s + p_i$
**end for**
$V_m := V_m \cup V_{JN}$
$V_m := V_m - \{ a \mid outdeg(a) = 1, a \in V_s, a \notin V_m, a \neq v_{src} \}$
$E_m := \{ e \mid e$ is a link to $V_m$ at the network layer $\}$
$G_m = ( V_m, E_m )$
**return** $G_m$

In SPTC phase, at first, the shortest path tree $G_s$ should be found that contains all intermediate nodes over the shortest paths between the source ($v_{src}$) and each group member. $G_s$ is initialized with ($\{v_{src}\}$, $\phi$), where $v_{src}$ is the source node. $G_s$ is expanded in a greedy manner by using the longest common path match. Through the longest common path match, a node can be found at which the common path between $G_s$ and $p_i$ ends ($p_i$ is the shortest path from a source to a multicast member, $v_i$). The last node over the longest common path is called a junction node ($v_{last}$). Then, the partial paths from the $v_{last}$ to each group member which can be reached through the $v_{last}$ are attached to $G_s$. With the set of paths not included in current $G_s$, the procedure is repeated until all group members are in $G_s$.

Figure 2 illustrates an example of the SPTC phase. Suppose the existence of four group members, nodes $d$, $e$, $g$, and $i$, whose shortest paths from a source, node $s$, are $p_d$, $p_e$, $p_g$, and $p_i$, respectively. $G_s$ is initialized with ( $\{s\}$, $\phi$ ). Through the longest common path match, the node $s$ is selected as the $v_{last}$ node. Therefore, the partial path toward node $d$ (or $p_d$) is attached to $G_s$. Similarly, from the new $G_s$, the partial paths toward node $e$ (or $p_e$), node $g$ (or $p_g$) and node $i$ (or $p_i$) are attached to $G_s$ in the order.

Through the SPTC phase, we could find the shortest path tree from a source to each group member. Thereafter, when the source multicasts packets, each packet should include a data structure representing the tree in its header. The data structure consists of only junction nodes and group members. Therefore, when each junction node receives a multicast packet, it replicates the packet




(a)The shortest paths for group members. (b)The shortest path tree.

**Fig. 2.** An Example of Shortest Path Tree Construction.

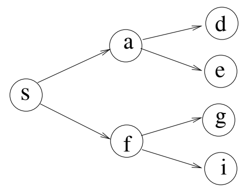


**Fig. 3.** An Example of Overlay Creation.

and forwards it to the corresponding group members or next junction nodes by using its underlying unicast routing protocol as in most overlay-based multicast protocols. Therefore, SPM is interested in the tree whose nodes are junction nodes and group members, not in the tree obtained through the SPTC phase. SPM makes the overlay tree by using OC phase, where the multicast packet delivery tree ($G_m$) is finally derived by excluding the nodes with one out-going edge from the shortest path tree. Figure 3 shows one example of the tree after the OC phase is applied to Figure 2(b).

SPM is currently implemented at application layer. However, since SPM can be extended to be implemented as a thin layer between TCP/UDP and IP, we defined a protocol field in the header. In the case, the SPM message is encapsulated using IP packet. The protocol fields in the IP header and the SPM header indicate the SPM protocol and its upper layer protocol, respectively (see Figure 4). The SPM header particularly represents the overlay tree, which consists of fixed and extension headers. The fixed header includes the source-based multicast session information as well as the number of nodes (the field, # of nodes) which should process the multicast packet (i.e., junction nodes and group members). The extension header includes the data structure, where $P_i$ field in the header indicates the parent node of the field $N_i$ over the overlay tree. $P_i$ is used as an index in the list of the IP addresses. For example, when the $P_i$ value is 2, the parent node of $N_i$ is the node with the IP address of $N_2$.

### 3.4 Routing Path Acquisition

SPM needs all routing paths from the source to each multicast member in order to perform the SPTC procedures. In source routing protocols like DSR [6], during the route discovery process, since the RREQ (Route Request) message flooded by a source accumulates the visited intermediate nodes and the RREP

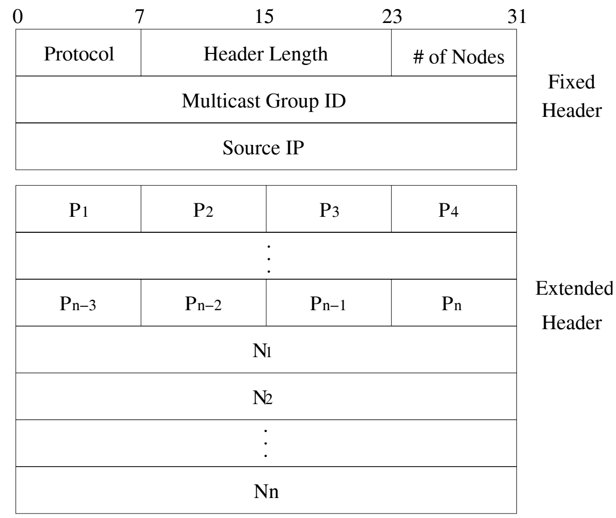



**Fig. 4.** SPM Header.

(Route Reply) message notifies the source of each accumulated path, the source can easily collect the path information for all group members. However, in case of table-driven routing protocols like AODV [7], since each intermediate node creates a routing entry towards each corresponding member, some modifications to AODV are needed to let the source know the accumulated path information for each group member. While propagating the RREP message which is traversed over the reverse path towards the source from a receiver, it is enough that the RREP message accumulates the intermediate nodes over the path. Otherwise, like DSR, during RREQ flooding, the path accumulation is performed and it can be returned to the source during the RREP transmission (refer to [4] for the modified RREP message).

### 3.5 Multicast Join/Leave

This subsection provides a brief overview of the concept of multicast join and leave procedure. As mentioned in Section 3.2, all nodes in the network already know the IP address of a multicast source in advance.

A new node joining a multicast group sends a group join message to the multicast source in a unicast manner. On receiving the join message, the multicast source creates a new multicast packet delivery tree including this joining node by executing the tree construction procedure and replies a join acknowledgement message to the node. When a node wants to leave a group, the node sends a group leave message to the source and the source creates a new multicast packet delivery tree excluding the leaving node. In addition, a periodic tree reconstruction resolves the case that a node left abruptly without sending any leave message gracefully.

## 4 Performance Evaluation

In this section, we evaluate our SPM and compare it with MAODV using the NS-2 simulator [8]. In Table 1, more simulation parameters are defined.

**Table 1.** Simulation Parameters

| Parameter | Value |
|---|---|
| Total Number of Nodes | 50 nodes |
| Multicast Group Size | 5, 10, 15, and 20 nodes |
| Simulation Area | 1500 m x 1500 m |
| Simulation Time | 1000 seconds |
| MAC Layer | IEEE 802.11b |
| Packet Size | 256 bytes |
| Traffic Source Type | UDP |
| Mobility Model | Random waypoint |
| Node Mobility | 1 m/s |

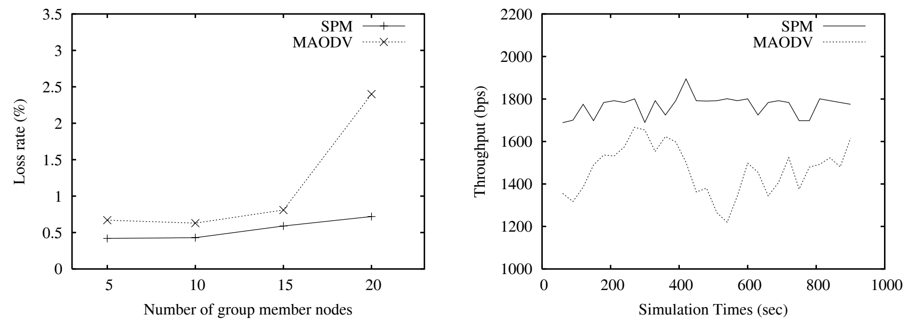
### 4.1 Performance Metrics

We define the following performance metrics.

- *Loss Rate*: A ratio of the number of lost packets to the total number of transmitted packets.
- *Throughput*: The amount of bits received by each group member per second over simulation time.
- *Distribution Delay*: The time elapsed until every multicast member receives a packet successfully.
- *Average Transmission Delay*: The average time that it takes for each group member to receive a packet successfully.

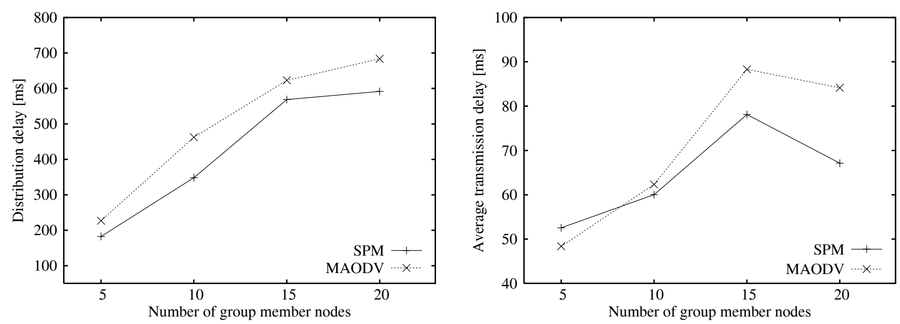
### 4.2 Performance Analysis

Figure 5 shows the loss rate and throughput of our SPM and MAODV. In MAODV, since a forwarding node fails to send a multicast packet to its neighbor tree members due to channel contention or node mobility, other group members reachable via the node cannot receive the packet in the event. In particular, note that MAODV needs a reliable multicast MAC protocol for recovering the packet loss at link level. In SPM, although the movement of nodes over paths created from the OC phase can occur and the paths can be broken, the trials to repair the breakage from its underlying unicast protocol allows the packet loss to be reduced compared to MAODV. Since a unicasting utilizes a link-level reliable transmission, the link-level packet loss is recovered by its underlying data link protocol. In addition, since a new shortest path based tree is created in SPM when a new node joins the multicast group, more performance improvement is expected.




(a) (b)

**Fig. 5.** Performance Comparison: (a) Loss Rate and (b) Throughput.




(a) (b)

**Fig. 6.** Performance Comparison: (a) Distribution Delay and (b) Average Transmission Delay.

Figure 6(a) shows the distribution delay of the SPM and MAODV. Since SPM utilizes the shortest path to each group member, it has less time elapsed until each member receives a multicast packet than MAODV. In MAODV, however, since the shortest path to the existing tree from a joining node is selected, it cannot guarantee the shortest paths from a source to each group member, which results in experiencing more delay.

Due to the similar reasons, SPM showed better performance than MAODV with respect to the average transmission delay as shown in Figure 6(b). However, when the number of group nodes is quite small (for example, 5 nodes in Figure 6), MAODV may have better performance because SPM carries out independent unicasting transmissions for each group member due to lack of the common paths.

## 5 Conclusion

We investigated the benefits of using an overlay multicasting for small group in mobile ad hoc networks. In this paper, SPM (Shortest Path overlay Multicast) mechanism was proposed, which is suitable for small group multicasting in MANET. SPM utilizes a stateless overlay multicast routing philosophy to avoid the overhead that requires intermediate nodes to manage the membership and routing information. SPM has two phases: Shortest Path Tree Construction (SPTC) and Overlay Creation (OC). In the SPTC phase, a shortest path tree is constructed from the paths provided by an underlying unicast routing protocol. In the OC phase, an overlay tree for an actual multicast packet delivery is created to save the network bandwidth.

Using the acquired overlay tree, SPM multicasts packets over the shortest paths from a source to each group member without duplicate packet delivery over common partial paths. In particular, SPM utilizes the route information provided by ad hoc unicast routing protocol without additional control messages and any other information. By using NS-2 simulator, we proved that SPM shows a better performance than MAODV in terms of throughput, loss rate and packet delivery delay.

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