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Resource Allocation Algorithm for Reliable Multicast in Ad-Hoc Networks

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Abstract

Mobile ad hoc network is an autonomous system of mobile nodes characterized by wireless links. The major challenge in ad hoc networks lies in adapting multicast communication to several environments, where network resources are limited. This leads to inefficient utilization of network resources.

Reliable multicast transport delivery requires a multicast message to be received by all mobile nodes in the communication group. The recovery mechanism requires feedback messages from each one of the receivers. In the tree-based recovery protocols, only a forwarding node contribute most resources and are involved in performing the multicast functionality. This leads to an uneven and inefficient utilization of network resources. Therefore, this paper presents a distributed algorithm to construct minimum multicast tree (MMT) to improve the performance of the Source Tree Reliable Multicast (STRM) protocol. MMT mechanism allow for the transmission range of a multicast to be adjusted to those nodes requested a message. This limits the effect of multicasts on neighboring nodes that not within a multicast group. STRM utilizes the MMT in distributed manner, thus reducing the packet duplication. Simulation results demonstrate the scalability of the proposed algorithm in comparison to STRM protocol. The algorithm shown to scale significantly better in terms of reducing packet duplications than the STRM protocol that based upon a constant transmission range.

INTRODUCTION

A Mobile Ad hoc Network (MANET) (Sobeih et al., 2004; Bettstetter et al., 2003) is a wireless communication that allows its nodes to communicate with each other without the existence of an infrastructure. Therefore, nodes can act as routers to route the packets between the source and destination nodes which are outside the transmission range of each other. MANETs are characterized by mobile nodes and a constantly changing network topology. In addition, wireless connectivity between nodes are limited by transmission range, signal attenuation, interference and terrain. Nodes switch off or move into or out of the range of other nodes in MANET leads to changing the MANET topology frequently. Thus, MANET is characterized by dynamic topology, high error rates, low bandwidth and intermittent connectivity (Sadok et al., 2000; Sobeih et al., 2004; Yang and Wu, 2005).

Multicasting is a kind of information dissemination that transmits data packets to a group of receivers identified by a particular destination address (Tang and Gerla, 2001). Reliable multicast is essential for many applications in MANET to guarantee reliable data delivery to a large number of receivers simultaneously. When group communication is required, reliability is often a critical issue since missed packets cause tremendous negative consequences (Floyd et al., 1997).

In MANET, the membership of a host group is dynamic. Thus, the nodes are free to move in and out of the transmission ranges of the other nodes at any time. Also, the location or the number of members in a host group is unrestricted. A node can be a member of multiple groups at any time. Membership is not a precondition to sending packets to a multicast group. Reliable multicasting implies that all nodes in multicast group should get a packet that is transmitted to the group address. In a typical MANET environment, network nodes work in groups to fulfil a certain task.

The tree-based protocols are well-known protocols to provide high scalability, as well as reliability (Wu and Bonnet, 2004; Alahdal et al., 2008a; Ahi et al., 2006; Baek and Munene, 2007; Lane et al., 2007; Özkasap et al., 2006). They construct a logical tree at the transport layer for error recovery. This logical tree comprises three types of nodes: a sender node, repair nodes and receiver nodes. The sender node is the root of the logical multicast tree and controls the overall tree construction. Each repair node maintains in its buffer all the packets it has recently received and performs local error recovery for all its children nodes. As a result, tree-based protocols achieve scalability by distributing the retransmission workload among the repair nodes.

As a continuation of our previous research (Alahdal et al., 2008a), the work presented here implement MMT to improve the performance of the STRM protocol. STRM protocol provides reliable multicast by constructing a logical tree at the transport layer for error recovery. It allocates Forward Server nodes (FSs), from the sender one hop neighbours. The FSs send their status to the sender at periodic intervals. Also, each receiver sends its status to its FS respectively at regular intervals. The FS nodes are actively involved in implementing multicast functionality and responsible for error recovery and a large number of leaf nodes that only act as receivers of packets. These leaf nodes do not contribute any resources to the multicast tree. This lead to certain of nodes will run out of resources (e.g., battery strength) faster than other nodes. Proper resource allocation is essential for extending the life a multicast network.

This paper concentrates on constructing low-weight multicast trees to reduce the overall delay. We present a distributed algorithm for building minimum multicast trees (MMT) for small group multicast. MMT aim to uniformly distribute the multicast functionality across all the nodes in the group with little impact on the multicast delay. The algorithm allow for the transmission range of a multicast to be adjusted to only include those nodes requested the message within a multicast group. This limits the effect of multicasts on neighboring nodes that may not within a multicast group. MMT Algorithm utilizes the minimum spanning tree (MST) in distributed manner and the ability for relay nodes to be self selecting, thus reducing the per packet overhead found in STRM.

The rest of this paper is structured as follows. Section 2 examines previous work done in this area. Section 3 provides a detailed description of our algorithm. Section 4 presents simulation results to analyse and compare MMT. Finally, Section 5 concludes this paper and presents directions for future research.

2. Related Research

Several overlay multicast protocols have been proposed and studied for MANETs. All of them are based on single-tree multicast and are geared to address the efficiency issues of overlay multicast. In recent years, the issue of resource allocation has caught the attention of many researchers (Sobeih et al., 2004; Tang and Gerla, 2001; Thiagaraja et al., 2002; Viswanath et al., 2006; Özkasap et al., 2006). These protocols use different approaches to improve packet delivery of multicast routing protocols in MANETs. One approach is NAK suppression (Sobeih et al., 2004; Ken et al., 2002; Viswanath et al., 2006). In this approach, the receiver is responsible for reliable delivery. Each receiver maintains receiving records and requests repairs via a NAK when errors occur. But the problem of this approach is the long end-to-end delay because the sender must wait for the next multicast packet to determine if the previous one is successfully delivered or not. Therefore, it is applied only when the sender has several packets to be sent. Another way to improve packet delivery is via hierarchical receiver-oriented approach (Tang and Gerla, 2001; Thiagaraja et al., 2002; Wu and Bonnet, 2004; Özkasap et al., 2006). A tree for the reliable multicast session is made up of ordinary and special receivers which are called the forwarding regions (Sobeih et al., 2004, Alahdal et al., 2012). Commonly used reliable protocols include the Scalable Reliable Multicast (SRM) (Floyd et al., 1997) and the Reliable Multicast Transport Protocol (RMTP) (Paul et al., 1996). SRM is based on an application level framework; the same concept used in Reliable Multicast Protocol for ad Hoc (ReMHoc) where it is the application’s responsibility to guarantee packet sequencing. (Torkestani and Meybodi, 2011) proposed a link stability- based multicast routing protocol for wireless MANETs in which the multicast packets are forwarded along the Steiner tree links. The weight associated with a communication link is defined as its expected duration time which is assumed to be a random variable with unknown distribution. Expected link duration time is defined as the period of time during which the link is expected to be connected, and expected duration time of a multicast route is defined as the expected duration time of the weakest link. This protocol called LLMR aims at finding the most stable multicast route against the host mobility. LLMR is composed of a number of iterations and at each iteration a multicast route is constructed by finding a Steiner tree of the network topology graph. At each iteration, the selected multicast route is rewarded, if its expected duration time is longer than those seen so far and it is penalized otherwise. As the proposed algorithm proceeds, the choice probability of the most stable multicast route converges to one.

Some approaches which provide reliable multicasting in wireless MANETs include Congestion Control Anonymous Gossip (CCAG) (Kapse et al., 2014) and COMAN (Mottola et al., 2008). CCAG works in two phases. In the first phase any suitable protocol is used to multicast the message to the group, while in second phase, the gossip protocol tries to recover lost messages. The main drawbacks of MAODV are long delays and high overheads associated with fixing broken links in conditions of high mobility and traffic load. Also, it has a low packet delivery ratio in scenarios with high mobility, large numbers of members, or a high traffic load. Because of its dependence on AODV, MAODV is not flexible. Finally, it suffers from a single point of failure, which is the multicast group leader. On the other hand, COMAN is able to self-repair to tolerate the frequent topological reconfigurations characteristic of MANETs and minimize the changes at the upper CBR layer. In essence, when mobility is present, COMAN suffers from loop formation, creates nonoptimal trees, and requires higher overhead to assign a new core. Also, COMAN suffers from a single point of failure of the core node.

3. Materials and Methods

The MMT algorithm can be considered as several instances of a modified STRM protocol (Alahdal et al., 2008a). The STRM protocol is designed for multicast applications with only one sender using a tree-based hierarchical approach (Paul et al., 1996). The key idea behind hierarchical approach is to group receivers into local regions and to use special receivers called FS as representatives of local regions of receiver nodes. The STRM allocates FS nodes in each local region and makes these FS nodes responsible for error recovery for all the other receivers in the same region. These FS nodes retransmit the lost packets to all group members that belong to its local region. Therefore, this retransmission causes duplication for members which have already received the same packet correctly. The presented algorithm can be applied to tree-based multicast protocols. Furthermore, the dedicated support is provided for protocols which coordinate their group members using local group multicast.

A. Preliminaries

MMT is a reliable, distributed and optimized multicasting mechanism for ad hoc networks. MMT utilizes the Minimum Spanning Tree (MST) algorithm with local one hop neighbor knowledge in a distributed manner to improve the performance of STRM protocol. MMT mechanism allow for the transmission range of a multicast to be adjusted to those necessary nodes within a multicast group. The MST is used by each node to determine those closest neighboring nodes that it must include within any transmissions, to ensure a connected graph, thereby ensuring a multicasting propagates throughout an ad hoc network. MMT extends STRM protocol by utilizing the unique nature of the distributed MST that results in a connected graph with minimum neighbor degree. Given that the prior multicast node is included and may therefore be removed, this creat a Multicast Set (MSET) for the MST.

B. MMT Algorithm

MMT algorithm is a reliable, distributed and optimized multicasting mechanism for ad hoc networks. MMT utilizes the Minimum Spanning Tree (MST) algorithm with local one hop neighbor knowledge in a distributed manner to improve the performance of STRM protocol. When using MMT mechanism as shown in Figure 1, the transmission range of a multicast adjusted to those necessary nodes within a multicast group. The MST is used by each node to determine those closest neighboring nodes that it must include within any transmissions, to ensure a connected graph, thereby ensuring a multicasting propagates throughout an ad hoc network. MMT extends STRM protocol by utilizing the unique nature of the distributed MST that results in a connected graph with minimum neighbor degree. Given that the prior multicast node is included and may therefore be removed, this resulting Multicast Set (MSET) for the MST as shown in the MMT algorithm in the Figure 1, Lines 6,7. This low neighbor degree can be seen in the distributed MST.

C. Calculation of MST

The MST algorithm MST(j, RS) in Figure 2, called in MMT algorithm is based upon Prim's algorithm (Prim, 1957). In Prim's algorithm, the MST tree is grown from a specific node. This is done by repeatedly adding edges of

Figure 1: MMT Algorithm

Figure 2: MMT Algorithm

smallest cost and using a priority based queue to store the list of edges that need to be considered. The MST implement on a network of "n" nodes and construct "m" multicast subtrees (RS1, RS2,… , RSm) with a few overlapping edges (satisfying a particular threshold criteria). Given a graph G = (V,E), where V is a set of vertices and E a set of edges, then for each vertex v in V, we maintain its priority in priority[v] equal to the minimum weight (distance in this case) of any edge e in E connecting v to the partial MST. If there is no edge connecting v to the partial MST then the weight is equal to 0. The parent of each v for an edge of minimum weight is maintained in p[v]. If there is no parent then it is an empty set. T is the resulting list that contains a set of vertices (v1, v2, …) that form the MST.

The following is an example of finding the MST for the node layout in Figure 3 using algorithm MST(j, RS). Figure 3 shows four nodes A, B, C and D along with the distance between them. The edges between the nodes are shown by undirected lines along with their respective distances. Node A is the source node from which we intend to find the MST. Algorithm MST(j, RS) first calculates the priority queue of each vertices in Q as (priority, parent).

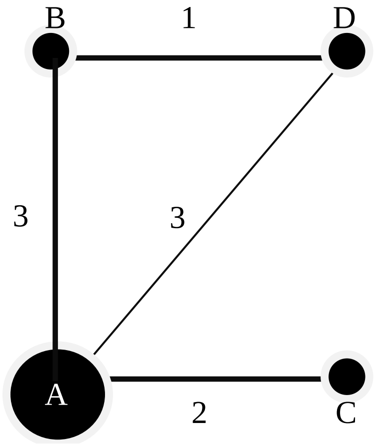

Figure 3: MST Graph of 4 nodes and their weighted edges

Q = {A, B, C, D} ⇒ {(0, nill), (∞, nill), (∞, nill), (∞, nill)}. Node A will remove from the priority queue, Q, as it has lowest priority (least distance): Q = {B, C, D} ⇒ {(3, A), (2, A), (3, A)}. Node C will remove from Q as it has the least distance from A. Thus resulting in T={(A, C)}. Q = {B, D} ⇒{(3, A), (1, C)}. Node D will remove from Q as it has the least distance from A. Thus resulting in T={(A,C), (C,D)}. Q = {B} ⇒ {(3, A)}. Node B will remove from Q as it has the least distance from A. Thus algorithm MST(j, RS) will return the resulting MST as T={(A,C), (B,D), (A,B)} and Q=ϕ. The resulting MST graph is shown in Figure 3 by the directed lines.

D. MMT Example

Figure 4 shows the results of distributed MST as calculated by each node and shown in the figure by a thickened black line between the nodes. Node A determines its local MST using algorithm MST(j, RS) resulting in MSET={B,C}. Node A adjusts its transmission power to include the furthest node in its MSET, in this case node C. A shaded circle represents the adjusted transmission range, whereas a solid lined circle represents the full transmission range. The multicast from node A is received by nodes B, C and D. Node C has no MST neighbors other than node A that it received the multicast from. Node C therefore calculates an empty MSET, which inhibits it from remulticasting. Node B, receives the multicast and calculates a MSET={D}. However, node D is eliminated from the MSET of node B as MMT algorithm implementation at node B determines that node D has received the multicast given the transmission range.

Node D, although not an MST neighbor of node A, receives the multicast and determines a MSET={B,E}. Node B is eliminated as it has received the message resulting is a MSET={E}. Node D therefore adjusts its transmission range and multicasts to node E. Node E is inhibited from remulticasting the message as it has no MST neighbors other than node D and therefore calculates an empty MSET.

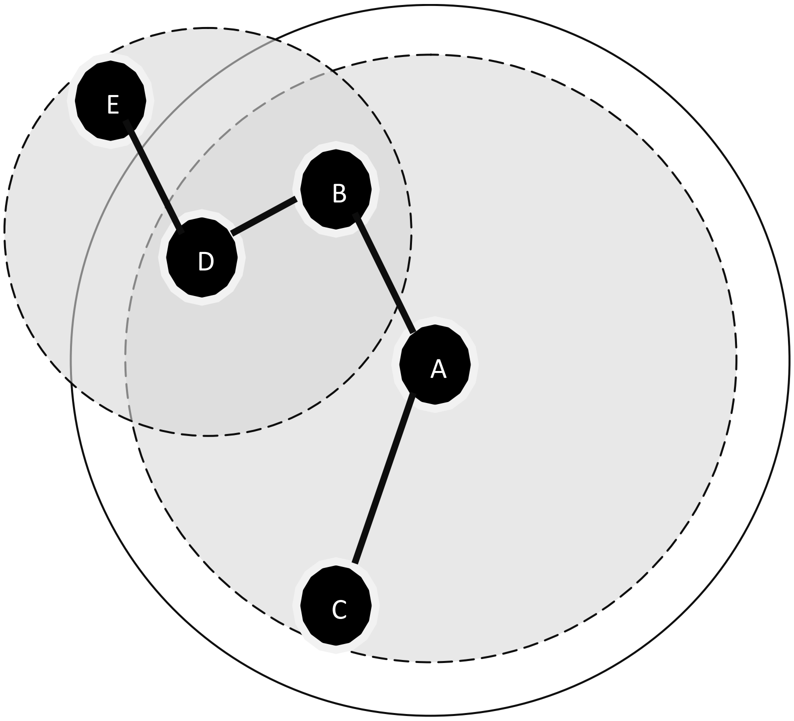

Figure 4: Distributed MMT Example

4. Results and Discussion

Our simulator is based on our previous work described in (Alahdal et al., 2008a). In the simulations, 100 nodes are randomly placed in a 1000 m^2 field. Each node transmits a maximum of 1000 packets (256 bytes each) at various times during the simulation. Nodes' channel bandwidth is set to 2 Mbit/sec and their transmission range is 250 meters. The parameter setting and values used in the simulation are shown in Table 1. These values are taken from the based study of (Alahdal et al. 2008a). Each simulation result is an average of 25 samples for the same topology and input variables. In all the simulations, the edge weight for a link between two nodes is directly proportional to the distance between them. Based on the results from our previous work (Alahdal et al., 2008a), (Alahdal et al., 2008b), sender is chosen randomly from the multicast group members. All member nodes join at the start of the simulations and remain members throughout the duration of the simulation. The multicast delivery tree is rooted at the sender and spans over all other receiver nodes. The sender sent window of data packets to the receivers periodically, one window of data packet per 500ms. We assume that the wireless links are symmetric and the packet transmissions error caused by node movements and wireless link error.

Each node moves according to the random waypoint mobility model defined in (Bettstetter et al., 2003). Initially, the nodes start off at random positions within the field for a certain period of time (i.e., a pause time). Once this time expires, the node chooses a random destination in the terrain boundary and a speed that is uniformly distributed between 0 and 25 m/s with a step of 5 m/s. Once having reached the destination, the node pauses again for another pause time. Then it selects another random destination and speed and moves again.

We use five different pause times in the simulation: 1, 5, 10, 15 and 20 s. These shorter pause times were used for higher mobility nodes. More details about the simulation model can be found in (Alahdal et al., 2008b). The evaluations were performed using a workstation with a Pentium 4-1.8 GHz CPU, 1 GB of RAM and MS Windows XP.

The experimental results of the MMT algorithm is compared with STRM protocol in (Alahdal et al., 2008a) and the Pure Source-Based scheme (PSB), where only the original sender in STRM allows the retransmission of packets in response to receiver feedbacks. The aim of this comparison is to study the effectiveness of STRM’s local recovery mechanism. A parameter called the reliable delivery ratio is defined as the fraction of packets successfully delivered to all receivers over the total number of packets sent. This number represents the routing effectiveness of a protocol.

The larger the delivery ratio, the larger the number of lost packets that can be recovered, and the better the performance.

Table 1: Simulation parameters

Description	***Unit***	***Value***
PACKET_SIZE	byte	512
NO_NODE	-	100
LINK_BW	mbps	2
AREA_SIZE	m^2	1000
MESSAGE_SIZE	packets	2000
LOSS_RATIO	-	0.1
NODE_SPEED	m/sec.	0, 5, 10, 15, 20, 25
PROPAGATION_DELAY	ms	10
PAUSE_TIME	sec.	1, 2, 5, 10, 15, 20
HELLO_TIME	sec.	1

Figures 5 and 6 shows the effect of the session size and mobility speed on the percentage of duplicate packets. Each member calculates the percentage of the duplicated and the retransmitted packets it has received. The result is averaged over all receivers in the group. MMT technique shows less transmissions than STRM, this is a result of there being fewer edges associated with the MST graph compared to the RNG graph (hence less redundancy) as shown in Figure 5. Because PSB does not use transmission power control, if the density of nodes increases and the network area is maintained then the number of transmissions required to cover all nodes does not grow as quickly as the other mechanisms.

Also, the less percentage of duplicate packets can be observed for MMT when the mobility speed increase in Figure 6. PSB show increasing in the percentage of duplicate packets than others in both figures the reason is when the PSB retransmit lost requested packets it multicast it to the entire receiver group this causes duplicate in the receiver which received the same packets in transmission time.

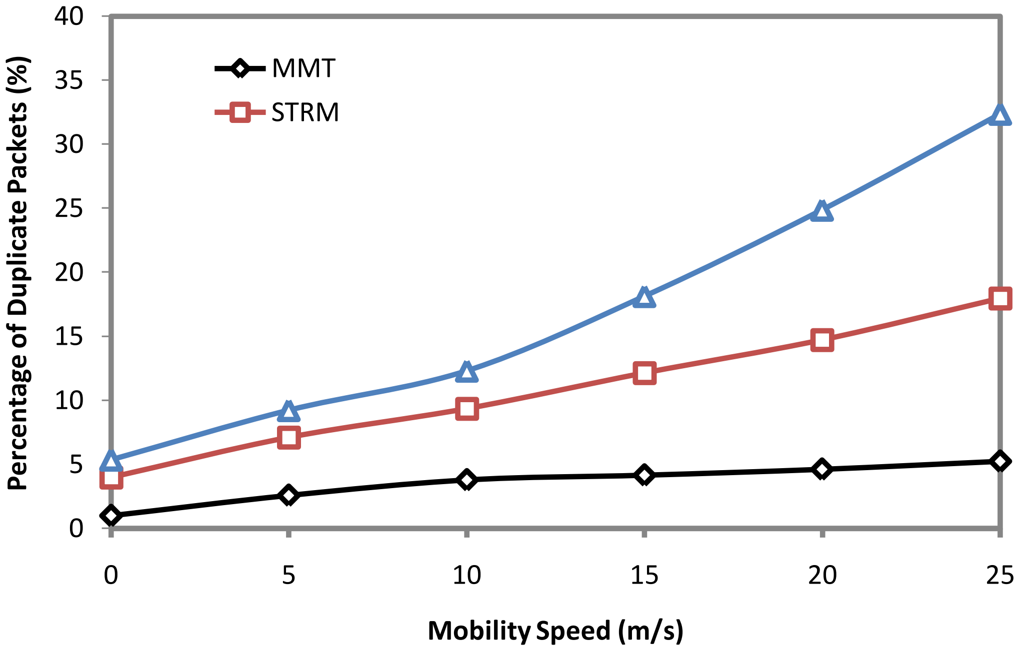

Figure 5: Percentage of duplicate packets when the mobility speed increase

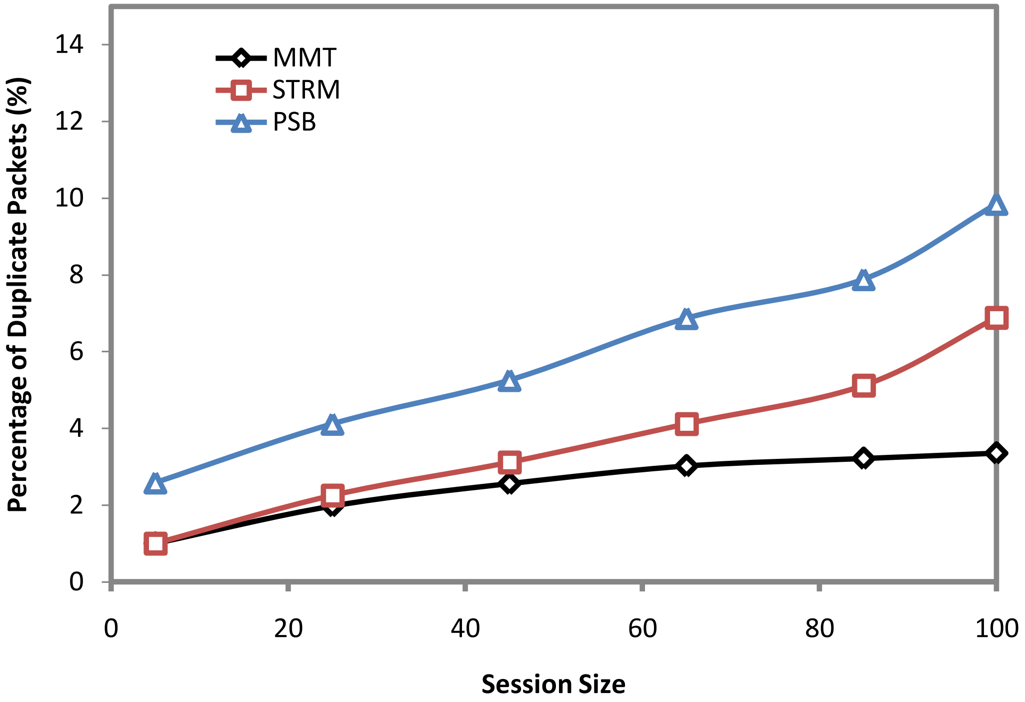

Figure 6: Percentage of duplicate packets when the session size increase

5. Conclusion and Future Work

This study detailed the proposed MMT—a distributed algorithm for building multiple minimum multicast tree. It can be used to solve the resource utilization issue in any multicast network. And decrease the number of duplicated packets in the STRM protocol. MMT can also be used to improve the reliability and robustness of the network. MMT is a distributed multicast mechanism that calculates the MST from local one hop neighbor knowledge. MMT mechanism utilizes transmission distance to select an optimal multicast set of nodes with minimal transmission range. The resulting distributed MST graph does not exhibit the tree like structure of the centralized MST graph with global topology knowledge. The use of MST allows each node to be self selecting and thus determine whether or not it is required to retransmit a packet. MMT significantly reduces average transmission range and results in nodes receiving less duplicate packets during a multicast. As a future study, since there is a large overhead in forwarding nodes, their buffers should be managed in an efficient manner. Also we hope to conduct large-scale experiments in more realistic environments and to compare performance of STRM with other multicast protocols.

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