S-REMiT: A Distributed Algorithm for Source-based Energy Efficient Multicasting in Wireless Ad Hoc Networks

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Abstract— **In this paper we propose a distributed algorithm called S-REMiT for building an energy-efficient multicast tree in a wireless ad hoc network (WANET). S-REMiT employs a more realistic energy consumption model for wireless communication, which takes into account the energy losses not only due to radio propagation but also the energy losses in the transceiver electronics. This enables S-REMiT to adapt a given multicast tree for a wide variety of wireless networks irrespective of whether they use long-range radios or short-range radios. Our simulations show that it performs better than BIP/MIP and EWMA algorithms.**

I. Introduction

In contrast to wired network, availability of limited energy at nodes of a wireless ad hoc network (WANET) has an impact on the design of multicast protocols. For example, the set of network links and their capacities in WANETs is not pre-determined but depends on factors such as distance between nodes, transmission power, hardware implementation and environmental noise. Thus in WANETs, there is a trade-off between the long "reach" of one-transmission (but received simultaneously by several nodes in the transmission range) and interference effects it creates in its communication neighborhood [1]. We assume that the transmission power level can be dynamically varied between specified lower and upper bound [2][3]. Therefore, there also exists a trade-off between reaching more nodes in a single hop by using more power and reaching fewer nodes in a single hop by using less power but requiring multiple hops for reaching all the nodes in the multicast group [1]. Hence new approaches are needed to account for these characteristics.

In this paper, we focus on source initiated multicasting of data in WANETs. Our main objective is to construct a *minimum-energy multicast tree* rooted at the source node. We explore the following two problems related to energy-efficient multicasting in WANETs using a source-based multicast tree: 1) How to reduce the total energy cost for multicasting in a source-based tree? 2) How to build an energy-efficient multicast tree in a distributed manner? In this paper, we study these two problems and propose S-REMiT (An algorithm for Refining Energy-Efficient Source-based Multicast Tree) for building an existing multicast tree into a more energy-efficient multicast tree. As a distributed algorithm, S-REMiT uses *minimum-weight spanning tree* (MST) or *single-source shortest path tree* (SSSPT) as the initial solution and improves the multicast tree energy efficiency by switching some tree nodes from their respective parent nodes to new corresponding parent nodes. The selection of the initial tree is dependent on the energy model used (see details in Section V).

The rest of the paper is organized as follows. Section II summarizes some related work. Section III describes the system model used. The multicast energy cost metric is described in Section IV. Section V describes S-REMiT algorithm. In Section VI, we present the simulation result of S-REMiT and compare it with BIP/MIP, EWMA algorithm. Section VII discusses the difference between S-REMiT and G-REMiT [4]. We provide some concluding remarks in Section VIII.

II. Related Work

The energy-efficient broadcasting/multicasting tree problem is presented in [5]. Wieselthier et al. have proposed a "node-based" elastic model for wireless multicast and the concept of *wireless multicast advantage* [5]. Because the problem of constructing the optimal energy-efficient broadcast/multicast tree is NP-hard, several heuristic algorithms for building a source-based energy-efficient broadcast/multicast tree have been developed recently [6]. Wieselthier et al. presented BIP/MIP algorithm which is a centralized source-based broadcast/multicast tree building centralized algorithm [5]. They also presented two distributed version of BIP algorithm (Dist-BIP-A,Dist-BIP-G), but these two distributed algorithms have slightly worse performance than centralized version [2].

Banerjee et al. have presented the reliability issues and energy cost metrics suitable for energy-efficient source-based broadcast/multicast tree [7]. Cagalj et al. have presented an Embedded Wireless Multicast Advantage (EWMA) algorithm to enhance energy efficiency of source-based broadcast tree by refining a MST [3]. They also described a distributed version of EWMA algorithm. We propose a distributed algorithm called S-REMiT which is a part of a suite of algorithms called REMiT (Refining Energy efficiency of Multicast Trees) which we are designing to achieve various energy-efficiency goals related to multicasting in WANETs. REMiT algorithms are distributed algorithms which refine the energy-efficiency of a pre-existing multicast tree using local knowledge at each node. The REMiT algorithms can be categorized along energy-metric dimension (minimizing energy-consumption or maximizing lifetime) and multicast-tree type dimension (source based or group-shared tree). For example, we have previously presented G-REMiT [4] which minimizes energy-consumption for group-shared trees and L-REMiT [8] which maximizes lifetime for source-based trees, respectively. Both S-REMiT and EWMA algorithm refine an existing initial tree to an energy-efficient tree. EWMA is not extensible to energy-efficient group-shared tree. However, S-REMiT can be easily extend to group-shared tree by incorporating multicast message generation rate in node metric [4]. We will discuss the difference between S-REMiT and G-REMiT in Section VII.

III. System Model and Assumptions

We make the following assumptions in our model:

1) Nodes are stationary in the WANET.
2) Each node in the WANET uses omni-directional antennas.
3) Each node knows the distance between itself and its neighboring nodes using distance estimation schemes such as [9] and [10].

We use wireless communication model in [11]. The connectivity of network depends on the transmission power. Each node can choose its power level p, where $0 \leq p \leq p_{max}$. A node may use different power level for each multicast tree in which it participates. Let $E_{i,j}$ be the minimum energy cost (per bit) needed at node i on the link between nodes i and j in a packet transmission. Then,

$$E_{i,j} = E^T + K(r_{i,j})^\alpha, \qquad (1)$$

where $r_{i,j}$ is the Euclidean distance between i and j, E^T is a distant-independent constant that accounts for real-world overheads of electronics and digital processing, K is constant dependent upon the properties of the antenna and α is a constant which is dependent on the propagation losses in the medium [5][1]. Some of the related work in this area, such as [5][3], did not consider E^T. However, E^T is not negligible especially for short range radios, since E^T can substantially exceed the maximum value of the $K(r_{i,j})^\alpha$ [11].

Compared to wired networks, WANETs have "wireless multicast advantage" which means that all nodes within communication range of a transmitting node can receive a multicast message with only one transmission if they all use omni-directional antennas [5].

In our model, every node (say node i) has two kinds of coverage area. One is Control coveRage area (CR_i), another is Data coveRage area (DR_i) such that $DR_i \subseteq CR_i$. For example, in Figure 1, radius of CR_{10} is 3.2, it means that node 10's control message may reach node 7, but radius of DR_{10} is 2.75, it means that node 10's data message may only reach node 6.

Neighbors of node i are the nodes within CR_i. We use V_i, $V_i \subseteq CR_i$, to denote the set of **tree neighbors** of node i, i.e, those neighbors of node i which also belong to the multicast tree T. A **connected tree neighbor** j of a node i is a tree neighbor of node i which is connected to the node by a *branch*, i.e., link $(i,j) \in T$. A **non-connected tree neighbor** j of a node i is a tree neighbor of node i which is connected to the node i by more than one branch in T, i.e. the length of the unique path between i and j in T is greater than 1. We denote the set of connected and non-connected tree neighbors of node i as CTN_i and $NCTN_i$, respectively. Note that $NCTN_i = V_i - CTN_i$.

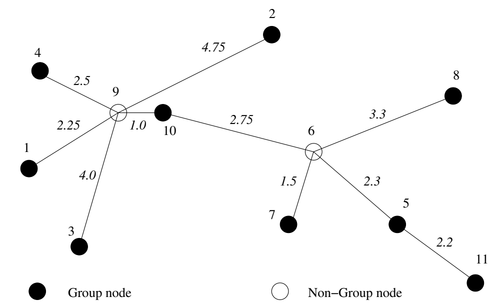

Fig. 1. Node 10's source-based Multicast Tree. Node 10's neighbors are node 1,2,3,4,6,7,9. Node 10's tree neighbors are 6,9. Only branches are shown for clarity and since S-REMiT ignores other links. Branch labels denote the Euclidean distance between their endpoints.

IV. Multicast Energy Efficiency Metric

The energy consumption (per bit) at every tree node is determined by the distance between the children nodes. For example, consider node 10's source-based multicast tree shown in Figure 1. Node 10 will send each multicast message along the branch to nodes 6 and 9. Node 9 will forward them to nodes 1, 2, 3 and 4. Similarly, node 6 will forward them to nodes 5, 7 and 8, and so on. The energy consumed (per bit) at node 9 on the tree links in node 10's source-based multicast tree, using the source-based multicast tree in Figure 1, is $max\{E_{9,1}, E_{9,2}, E_{9,3}, E_{9,4}\} = E_{9,2}$.

We use E^R to denote the energy cost (per bit) at the receiver side to receive a multicast message. Let d_i be i's maximum length between i and i's farthest children. We calculate $E_i(T,s)$, the **energy cost metric** of node i on the multicast tree T in node s's source-based multicast tree, as follows:

$$E_i(T,s) = \begin{cases} E^T + Kd_i^\alpha & \text{if } i \text{ is the source node;} \\ E^T + Kd_i^\alpha + E^R & \text{if } i \text{ is neither the source} \\ & \text{nor a leaf node in } T; \\ E^R & \text{if } i \text{ is a leaf node in } T, \end{cases} \qquad (2)$$

We use $TEC(T,s)$ to denote the Total Energy Cost of all the nodes in the multicast tree T in node s's source-based multicast tree. So $TEC(T,s)$ in s's source-based multicast tree as:

$$TEC(T,s) = \sum_{i \in T} E_i(T,s), \qquad (3)$$

So the *problem of minimizing the energy consumption of multicast tree* becomes the problem of minimizing the energy cost (per bit) at every node in the multicast tree as much as possible.

V. S-REMiT Algorithm

S-REMiT tries to minimize TEC of the initial multicast tree by changing a node's parent to another tree node so that the tree's TEC is reduced. We use MST or SSSPT as the initial tree because these two trees perform quite well for our problem based on our experimental results. These two trees are used for different scenarios: when nodes use long range radios, MST is the initial tree, and when nodes use short range radios, SSSPT is the initial tree. We use $Change_i^{x,j}$ to refer to the refinement step in which node i switches from node x to node j. Let T be the initial multicast tree, and T' be the resulting graph after refinement $Change_i^{x,j}$ is applied to T. The following lemmas, presented here without proof, guarantees that T' is a tree and identify which node's energy cost change due to refinement:

Lemma 1: If node j is not a descendant of node i in tree T, then the tree remains connected after $Change_i^{x,j}$.

Lemma 2: Nodes j and x are the only nodes in the tree whose energy cost may be affected by $Change_i^{x,j}$.

A. Criterion for Switching Parent

The TEC value of the multicast tree may change as a result of performing a refinement. In our heuristic, we call the change in the tree's TEC due to refinement $Change_i^{x,j}$ as $gain$ in the tree's TEC, i.e. $gain = TEC(T,s) - TEC(T',s)$. S-REMiT uses $gain$ as the criterion for changing the parent of a node: the refinement $Change_i^{x,j}$ is performed only if it is expected that $gain > 0$.

For example, consider node 10's source-based multicast tree in Figure 1. We consider how node 2 decides to change its parent from node 9, to node 6. We refer to this change event as $Change_2^{9,6}$. To simplify the following explanation, we assume that $K = 1, \alpha = 2, E^T = 0$, and $E^R = 0$. Using Equation (2), node 2 will estimate the change in the energy cost at nodes 2, 9 and 6 if it makes $Change_2^{9,6}$.

First, node 2 will estimate the current energy consumed at nodes 2, 6 and 9: $E_6(T,10) = r_{6,8}^2 = 10.89$, and $E_9(T,10) = r_{9,2}^2 = 22.56$.

Similarly, node 2 can estimate the new energy cost at nodes 9 and 6 (based on $Lemma$ 2, node 2's energy cost will not changed by $Change_2^{9,6}$) after $Change_2^{9,6}$, i.e $E_6(T',10)$ and $E_9(T',10)$ respectively: $E_6(T',10) = r_{6,2}^2 = 12.96$, and $E_9(T',10) = r_{9,3}^2 = 16.0$.

The $gain$ ($g_2^{9,6}$) obtained by switching at node 2 from node 9 to node 6 is:

$$g_2^{9,6} = (E_9(T,10) + E_6(T,10)) - (E_9(T',10) + E_6(T',10))$$
$$= 33.45 - 28.96 = 4.49.$$

Likewise node 2 can compute the gain in energy cost if it switches to node 10 and node 8:

$$g_2^{9,10} = (E_9(T,10)+E_{10}(T,10))-(E_9(T',10)+E_{10}(T',10))$$
$$= 30.12 - 32 = -1.88.$$
$$g_2^{9,8} = (E_9(T,10) + E_8(T,10)) - (E_9(T',10) + E_8(T',10))$$
$$= 22.56 - 30.44 = -7.88.$$

By comparing the gains, node 2 selects a node with the highest positive gain as the new parent which is node 6. Node 2 will disconnect from node 9 and connect to node 6 as its new parent node. So in Figure 1, tree link between nodes 2 and 9 will be deleted, and tree link between nodes 2 and 6 will be added to the multicast tree. Because DR_9 does not need to cover node 2 any more, radius of DR_9 will decrease to $r_{9,3}$. DR_6 should be increased to cover node 2, hence radius of DR_6 will increase to $r_{6,2}$.

B. Local Data Structure and Messages Types

Before describing a node's local data structure and message types used by our distributed protocol, we introduce the following notation. Let d_i' be the second longest link between i and its children. We denote the two-tuple (d_i, d_i'), as l_i. Further, let node j be a neighbor of i, $j \in V_i$. We will use the notation $Data_i$ to denote the data associated with node k:

- $E_i(T,s)$: energy cost (per bit) of node i on the tree T in node s's source-based multicast tree;
- $CTNT_i$: a list of records of the type $(k, l_k), \forall k \in CTN_i$;
- $NCTNT_i$: a list of records of they type $(k, l_k), \forall k \in NCTN_i$.

S-REMiT uses the following message types:

- $TOKEN(i, flag)$: source node s uses Depth-First Search (DFS) to pass token to every node on the multicast tree along the tree branches. Node i is the next hop node in DFS order. $flag$ is a boolean value to represent the refinement was successful or not in the DFS. This message is important and used throughout the second phase of S-REMiT.
- $JOIN\_REQ(i,j)$: sent by node i to node j requesting j to become its parent. This message is used in Step 2 by node i to make $Change_i^{x,j}$.
- $JOIN\_REP(i,j)$: sent by j to reply node i's $JOIN\_REQ(i,j)$. This message is used in Step 2 by node j to make $Change_i^{x,j}$.
- $LEAVE(i,x)$: sent by node i to leave parent node x. This message is used in Step 2 by node i to make $Change_i^{x,j}$ and in Step 5 by node i to leave the tree when i is a leaf node and non-group node.
- $NEIGHBOR\_UPDATE(i,x,j)$: sent by node i to nodes in V_i notifying $Change_i^{x,j}$. This message is used in Step 3 by node i.

S-REMiT needs reliable passing these messages between nodes.

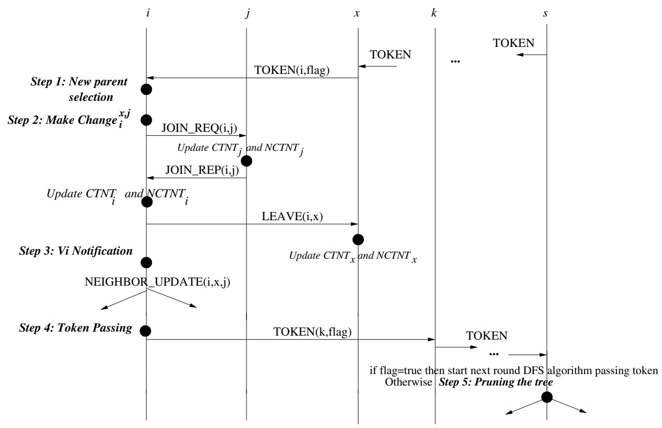

Fig. 2. Second Phase of S-REMiT at node i. Node k is the next hop node of i in DFS algorithm

C. Distributed Algorithm Description

S-REMiT consists of two phases: 1) multicast tree construction and 2) multicast tree refinement. In the **first phase**, if nodes use long range radios, all nodes run a distributed algorithm proposed by Gallager et al. [12] to build a MST tree; if nodes use short range radios, all nodes run a distributed algorithm proposed by Chandy et al. [13] to build a SSSPT tree. We require that at the end of the first phase, node i ($i \in T$, where T is the multicast tree) has all local information l_k, $\forall k \in V_i$. Nodes obtain l_k by hearing k's one-hop local broadcasting within CR_k.

In the **second phase**, the difficulty in this distributed environment is when and how to terminate the refinement. We organize the second phase in rounds. Each round of the second phase is led by the multicast source s. It terminates S-REMiT algorithm when there is no energy $gains$ by switching any node in the multicast tree. In each round, S-REMiT token is passed to the nodes one by one in DFS order. The S-REMiT token gives the permission to a node to do refinement. The node holding the S-REMiT token can do refinement, other nodes only can respond to the node with S-REMiT token.

When i obtains the S-REMiT token, it does the following steps to refine the tree. We use $E_j(T', s)$ and $E_x(T', s)$ to denote the energy cost at j and x after $Change_i^{x,j}$, respectively. $JOIN\_REQ$, $JOIN\_REP$ and $LEAVE$ messages are used by nodes i, x, and j to make $Change_i^{x,j}$. Following are the steps of the second phase in S-REMiT algorithm (see Figure 2 for illustrations of these steps):

1) **New parent selection:** Select a new parent candidate j with the highest positive $gain$ ($g_i^{x,j} := (E_x(T, s) + E_j(T, s)) - (E_x(T', s) + E_j(T', s))$), which will not result in tree disconnection if node i makes $Change_i^{x,j}$. If there is no such node j available, then it constructs token as $TOKEN(-, false)$. 2) **Make** $Change_i^{x,j}$**:** Node i makes $Change_i^{x,j}$ by $JOIN\_REQ$ and $JOIN\_REP$ negotiation with node j. Node j sends $JOIN\_REP$ back to node i. If node i gets $JOIN\_REP$ message, it will change $CTNT_i$ and $NCTNT_i$, send $LEAVE$ message to node x, constructs token as $TOKEN(-, true)$ and go to next step. Otherwise, it will go back to step 1 to select a new parent j. 3) V_i **Notification:** Node i notifies nodes in V_i about the $Change_i^{x,j}$. 4) **Token Passing:** Node i passes the token to next hop node according to DFS algorithm. 5) **Pruning the tree:** If node s gets back the token with $flag = false$, which means that no energy $gains$ in this DFS round, s will request all of the tree node to prune the redundant transmissions that are not needed to reach the members of the multicast group from the tree.

Following is an example to illustrate second phase of S-REMiT algorithm: single refinement at a node.

Example 1: This example illustrates one refinement at one node. In Figure 1, node 2 gets the S-REMiT token, node 2 does the following:

1) Node 2 calculates $gains$ as explained previously in Step 1 and finds out $g_2^{9,6}$ is the highest positive value. 2) Node 2 now sends $JOIN\_REQ(2, 6)$ to node 6. When node 6 responds to node 2 with $JOIN\_REP(2, 6)$ message, node 2 will move node 6 from $NCTNT_2$ to $CTNT_2$ and it will send $LEAVE(2, 9)$ message to node 9. Then node 2 will remove node 9 from $CTNT_2$ to add it to $NCTNT_2$. 3) Node 2 will send $NEIGHBOR\_UPDATE(2, 9, 6)$ to nodes in V_2 ($V_2 = \{6, 9, 10\}$) about $Change_2^{9,6}$. 4) Finally, node 2 will pass the token $TOKEN(9, true)$ to node 9 (Because node 2 passes token using the multicast tree T before $Change_2^{9,6}$) according to the DFS algorithm. □

D. Complexity of S-REMiT algorithm for minimizing source-based multicast tree

The message complexity of each node changing parent is $O(1)$. Hence the message complexity of one round in which each node performs at most one parent changing is $O(N\delta_{max})$, where N is the number of nodes in the tree, and δ_{max} is the maximum number of neighbor any node has in the tree. The computational complexity of one parent changing is $O(\delta_{max})$. Therefore the computational complexity of one round is $O(N\delta_{max})$. The space complexity of S-REMiT for each node is $O(\delta_{max})$ since the size of V is $O(\delta_{max})$.

VI. Performance Evaluation

We used simulations to evaluate the performance of S-REMiT algorithms. We compared our algorithm with BIP/MIP algorithm and EWMA algorithm distributed version (EWMA-Dist). Because EWMA-Dist algorithm is used for building broadcast tree, we extend EWMA-Dist algorithm for multicasting by pruned the redundant transmission from the broadcast tree produced by EWMA-Dist algorithm. The simulations performed using networks of four different sizes: 10, 40, 70, and 100. The distribution of the nodes in the networks are randomly generated. Every node is within the maximum transmission range (r_{max}) of at least one other node in the network. In other words, the network is connected. We use two different E^T values to represent the long range radios and short range radios. Based on the experiment data in [11], we decide to use $E^T = 0$ to represent long range radios and $E^T = 4 * K(r_{max})^2$ to represent short range radios. We ran 100 simulations for each simulation setup consisting of a network of a specified size to obtain average TEC with 95% confidence, the propagation loss exponent α is varied. And the source node s is randomly selected for every network setup.

A. Performance Metric

The performance metric used is TEC. We use TEC of multicast tree to define $Normalized\,TEC$ with algorithm alg is: $\frac{TEC_{alg}}{TEC_{best}}$, where $TEC_{best} = \min\{TEC_{alg}\}, alg \in A, A =$ {S-REMiT, MIP or EWMA-Dist}.

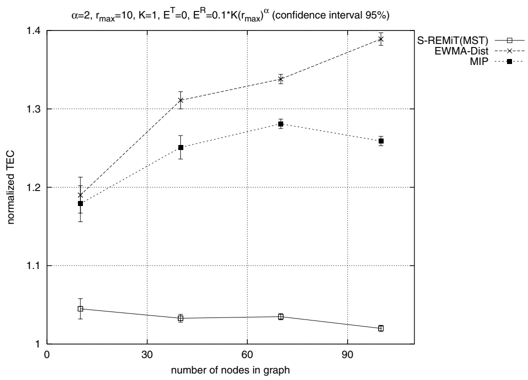

Fig. 3. $Normalized\ TEC$ for long range radios when 50% nodes are in multicast group.

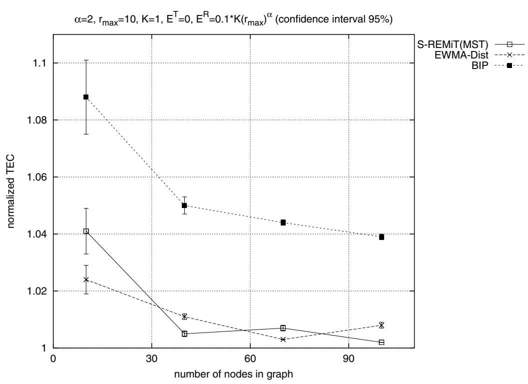

Fig. 4. $Normalized\ TEC$ for long range radios when 100% nodes are in multicast group.

B. Simulation Results

For long range radios, the performance is shown in Figures 3 and 4. We can see the average $normalized\ TEC$ (show on the vertical axis) achieved by the algorithms on networks of different size (the horizontal axis). The figures show that the solutions for multicast tree obtained by S-REMiT have, on the average, lower $normalized\ TEC$ than the solutions of BIP/MIP (BIP for building broadcast tree, MIP for building multicast tree) and EWMA-Dist when 50% of the nodes are group members (This is also true for $\alpha = 3$ and 4). S-REMiT and EWMA-Dist have very close performance, when 100% nodes are group members. In other words, performance difference between S-REMiT and EWMA-Dist becomes larger

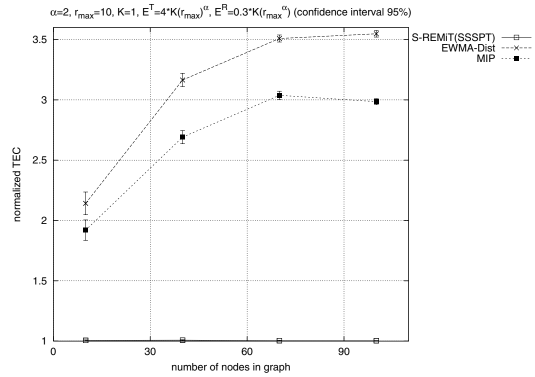

Fig. 5. $Normalized\ TEC$ for short range radios when 50% nodes are in multicast group.

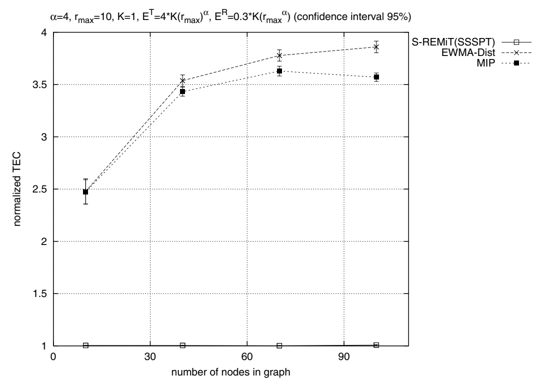

Fig. 6. $Normalized\ TEC$ for short range radios when 50% nodes are in multicast group.

as the group becomes sparse (This is also true for other scenarios). This is because the greedy nature of EWMA-Dist, the algorithm trying to reduce the number of downstream transmitting nodes as many as possible when there is a chance to reduce the total energy consumption of the multicast tree. So EWMA-Dist has more unnecessary coverage to non-group nodes than S-REMiT. Although these non-group nodes which are leaf nodes will be pruned from the multicast tree, the greedy effect can not be reimbursed in EWMA-Dist algorithm. For short range radios, the performance is shown in Figures 5 and 6. In the figures, we can see that the multicast trees produced by S-REMiT algorithm have, on the average, lower $normalized\ TEC$ than those obtained by the BIP/MIP and EWMA-Dist. Because of the space limitation, we do not present all of the results. Our results show that for various scenarios the average $normalized\ TEC$ of BIP/MIP is between 1.0 and 3.6, the average $normalized\ TEC$ of EWMA-Dist is between 1.0 and 3.8, and the average $normalized\ TEC$ of S-REMiT is between 1.0 and 1.1, respectively. Also our simulation results show that energy overhead of S-REMiT is always below 1.5% of total energy cost of the multicast tree when source node send out 1MBytes data to the all of group members.

Based on our simulation results, we find that S-REMiT has better performance than BIP/MIP for various scenarios. S-REMiT performs same as EWMA-Dist for 100% nodes are group nodes. Also S-REMiT performs better than EWMA-Dist when group becomes increasingly sparse, Because the Dist-BIP-A and Dist-BIP-G [2] perform slightly worse than BIP algorithm, S-REMiT should be better than the two distributed version of BIP algorithm.

VII. Difference between S-REMiT and G-REMiT

There are two kinds of multicast trees: *source-based* and *group-shared* multicast tree [14][15]. A source-based multicast tree is rooted at a multicast source node and covers all the other multicast group members who are receivers. As opposed to a source-based tree, a group-shared multicast tree is a common back-bone tree used by all the sources to forward multicast messages to all the receivers in a multicast group. If there is only one multicast source node in the group-shared tree, the group-shared tree will be reduced to source-based tree. In other words, source-based tree can be treated as a special case of group-shared tree, and S-REMiT is a special case of G-REMiT which we proposed in [4]. Following are the two differences between S-REMiT for source-based multicast tree and G-REMiT for group-shared multicast tree:

1) As we discussed in Section IV, the energy consumption (per bit) at a node is decided by the distance between the node and its children nodes in a source-based multicast tree. But in a group-shared multicast tree, the energy consumption (per bit) at a node is not only decided by the tree links attached to node but also decided by where the message is coming from. So we incorporate message generation rates of multicast source nodes into a node metric function in G-REMiT [4]. But in S-REMiT, we do not need message generation rates in node metric function.
2) Based on $Lemma$ 2, nodes j and x are the only nodes whose energy cost are affected by $Change_i^{x,j}$ in a source-based tree. But $Lemma$ 2 is not valid for group-shared tree. We have proved that all of the nodes on tree path $\pi_{i,j}$ may affected by $Change_i^{x,j}$ in a group-shared tree, where tree path $\pi_{i,j}$ is the shortest path between nodes i and j which only includes tree links [4]. So we need explore tree path $\pi_{i,j}$ to obtain the actual energy $gain$ for $Change_i^{x,j}$ in G-REMiT. But we do not need explore tree path $\pi_{i,j}$ for $Change_i^{x,j}$ in S-REMiT.

VIII. Conclusions

In this paper, we proposed a distributed algorithm (S-REMiT) for building an energy-efficient multicast tree in a WANET. Further, S-REMiT employs a more realistic energy consumption model for wireless communication which takes into account the energy losses not only due to radio propagation but also the energy losses in the transceiver electronics. This enables S-REMiT to adapt a given multicast tree to a wide variety of wireless networks irrespective of whether they use long-range radios or short-range radios.

We show that this algorithm outperforms two most famous proposals in the literature, BIP/MIP and Distributed version of EWMA. And we find that the energy consumption overhead of the algorithm itself is very small compared with the total energy consumption of the tree.

For future work, we intend to explore how other mechanisms can be used to further reduce power consumption. We also plan to study the delay constraint and mobility issues in the energy efficiency multicast. Finally, we intend to study the trade-off between minimizing energy consumption and maximizing network lifetime in multicasting.

IX. Acknowledgments

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