An Efficient Multicast Routing in Wireless Multi-hop Mesh Networks

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Abstract—In order that multicast routing characteristics are reflected under wireless environments, multicast routing metric is required for qualifying the multicast tree cost in wireless multi-hop mesh networks. We design a new multicast routing metric called the multicast-tree transmission ratio which quantifies the multicast tree cost, considering the link quality of wireless multicast channels as well as the wireless multicast advantage. The multicast-tree transmission ratio represents the product of the multicast transmission ratios of all nodes in the constructed multicast tree. This paper proposes a wireless multicast routing which constructs the multicast tree by maximizing the multicast-tree transmission ratio in wireless mesh networks. The proposed wireless multicast routing shows a higher delivery ratio and a lower average delay than the multicast routing minimizing the transmission count. In comparison with other multicast routings, simulation results show that the proposed multicast routing maximizing the multicast tree transmission ratio constructs a cost-effective multicast tree in terms of its delivery ratio, average delay, and required network resources.

Index Terms—wireless mesh network; multicast routing; routing metric; tree transmission ratio; wireless multicast advantage

I. INTRODUCTION

Wireless mesh networks are an emerging technology in providing adaptive and flexible wireless Internet connectivity to mobile users [1,2]. Due to such a reason, many network researchers and commercial developers are taking an intensive interest in them for future Internet infrastructure. With the rapid development of communication technologies, multicast communication applications are becoming more widely used in applications such as video on demand, IPTV, video conference, peer-to-peer communications, etc. Although multicast communication in wired infrastructures and mobile ad hoc networks has been studied intensively, the proposed multicast routings have been developed in order to cope with the constraints inherent to wireless multi-hop mesh networks [3]. Several multicast routings have been previously been proposed for constructing the multicast tree between communication members [4-6]. The proposed multicast routings have previously been proposed for constructing the multicast tree between communication members [4-6]. The proposed multicast routing maximizing the multicast tree transmission ratio constructs a cost-effective multicast tree in comparison with other multicast routings.

In wireless mesh networks, wireless nodes handle data packets at the link layer in a different manner in unicast and multicast routing. The nodes for multicast routing use link-layer broadcasts to leverage the wireless multicast advantage. The multicast metrics are designed according to the transmission count of multicast traffic on wireless multicast channels in the multicast tree, considering only the wireless multicast advantage. However, the proposed routings have the limitation that all multicast links are assumed to be of equal quality. Thus a multicast routing metric is required for qualifying the multicast tree cost while considering the wireless multicast advantage in wireless mesh networks.

In order to qualify a multicast tree cost in mesh networks, we design a multicast routing metric called the multicast-tree transmission ratio, considering link quality of wireless multicast channels as well as wireless multicast advantage. For qualifying a multicast routing tree, the designed multicast tree transmission ratio represents the product of the multicast transmission ratios of all nodes in the constructed multicast tree. Then we propose a multicast routing constructing a multicast tree by maximizing the proposed multicast tree transmission ratio in wireless mesh networks. The proposed multicast routing maximizing the multicast tree transmission ratio shows a higher delivery ratio and a lower average delay than the multicast routing minimizing the transmission count. The proposed multicast routing requires less network resources in comparison with multicast routing, constructing the tree by adding paths having the maximum product of transmission ratios from a source to all members. Simulation results show that the proposed multicast routing maximizing the multicast tree transmission ratio constructs a cost-effective multicast tree in comparison with other multicast routings.

The rest of the paper is organized as follows. Section 2 designs the multicast-tree transmission ratio as a multicast routing metric considering link quality metric of wireless multicast channels and wireless multicast advantage. Section 3 proposes a wireless multicast routing heuristic maximizing the multicast-tree transmission ratio and the distributed multicast protocol in wireless mesh networks. Section 4 evaluates our wireless multicast routing by simulation and Section 5 concludes this paper.

II. MULTICAST TREE ROUTING METRIC

In wireless mesh networks, wireless nodes handle data packets at the link layer in a different manner in unicast and multicast routing. The nodes for multicast routing use link-layer broadcasts to leverage the wireless multicast advantage. The
wireless multicast advantage is designed to enable a node to transfer multicast data to all nodes in its propagation area, and enhance the efficiency of data transfer under wireless environments. Thus, a multicast routing metric is required that is distinct from the unicast metric in wireless mesh networks.

At first, the link transmission ratio, \( l_{ij} \), of the wireless link from node \( i \) to its 1-hop neighbor node \( j \) is defined as link quality metric of a wireless multicast link.

**Definition 1** The multicast-node transmission ratio, \( r_i \), of node \( i \)'s wireless link in a multicast tree is defined as follows:

\[
     r_i = \min_{k \in \text{children}(i)} l_{ik},
\]

where node \( k \) is a child in the multicast tree.

The multicast-node transmission ratio of node \( i \)'s, \( r_i \), is expressed as the minimum transmission ratio from node \( i \) to its all child nodes via the multicast links in the multicast tree. This is because node \( i \) in the multicast tree should transfer multicast packets until the neighbor node with the minimum transmission ratio can successfully receive them, even though other nodes can already do so. Hence, the multicast-node transmission ratio considers the wireless multicast advantage.

We design a multicast-tree transmission ratio as a tree cost metric from Definition 1 for qualifying the multicast tree constructed by multicast routing.

**Definition 2** The multicast-tree transmission ratio, \( R_T \), of a multicast tree is defined as follows:

\[
     R_T = \prod_{i \in \text{tree}} r_i,
\]

where node \( i \) is in the multicast tree excepting leaf nodes.

The multicast-tree transmission ratio, \( R_T \), of the multicast tree is expressed as the product of the multicast-node transmission ratios of node \( i \)'s wireless links excepting the leaf nodes. The leaf nodes have no multicast-node transmission ratio, because they need not transfer data to any node in the multicast tree. Hence, the multicast-tree transmission ratio reflects the link quality of the wireless multicast channels in the multicast tree.

### III. PROPOSED MULTICAST ROUTING

Algorithm 1 describes a multicast routing heuristic constructing a multicast tree \( T = (V_T, E_T) \) by maximizing the proposed multicast-tree transmission ratio. The wireless mesh networks is denoted by \( G = (V, E) \) as a directed graph, where \( D \) is a set of multicast members, and \( s \) is the source. In the proposed heuristic, multicast members are individually added to the multicast tree. Initially, all distinct multicast trees are constructed by adding a distinct path to the already generated tree \( T \). Then, the multicast-tree transmission ratios are computed (See Definition 2) for all distinct multicast trees, respectively. The path is chosen that maximizes the multicast-tree transmission ratio \( R_T \). Nodes and links along the chosen path are added to the multicast tree \( T \).

#### Algorithm 1: Wireless Multicast Routing Heuristic

Given \( G = (V, E), D = \{d_1, ..., d_m\}, s, T = (V_T, E_T) \)

for \( i = 1 \) to \( n \) do

while there exist a distinct path to \( T \) do

    Construct a temporary tree \( T_{temp} \) by adding the path

    Compute the multicast tree transmission ratio, \( R_{T_{temp}} \) for the temporary tree \( T_{temp} \)

end while

Find the path \( p \) with maximum \( R_{T_{temp}} \)

\( V_T \leftarrow V_T \cup \{k \mid \forall k \in p\} \)

\( E_T \leftarrow E_T \cup \{(i,j) \mid \forall (i,j) \in p\} \)

end for

In Figure 1, the multicast tree depicted by the solid line is constructed using the proposed multicast routing heuristic, where the multicast source is node \( S \) and the members are node \( R1 \) and \( R2 \). The multicast tree transmission ratio of the multicast tree is 0.56 where \( m_s = 1.0, m_A = 0.7 = \min \{0.7, 0.9\} \), and \( m_c = 0.8 \).

![Figure 1. Example of proposed multicast routing heuristic](image)

Thereafter, if node \( R3 \) wants to join multicast communication, three different multicast trees are used. The first tree is the multicast tree adding the blue dotted path (\( S'!B'!R3 \)). This has a multicast-tree transmission ratio of 0.448. The second tree is the tree adding the red dotted path (\( C'!R3 \)). This has a multicast-tree transmission ratio of 0.498. The other tree is the multicast tree adding the green dotted path (\( R2'!R3 \)). This has a multicast-tree transmission ratio of 0.448. Therefore, the proposed multicast routing heuristic constructs a multicast tree by adding the red dotted one, since this path maximizes the multicast-tree transmission ratio.

However, the path maximizing the product of transmission ratios from the multicast source \( S \) to node \( R3 \) is the blue dotted path, since the product of transmission ratios of the blue dotted path is 0.64, that of the path along \( S, A, C, R3 \) is 0.63, and that of the path along \( S, A, C, R2, R3 \) is 0.576. Therefore, the proposed multicast routing heuristic constructs a multicast tree in a different manner than a multicast routing by adding paths having the maximum product of transmission ratios from the source to all members.

### IV. PERFORMANCE EVALUATIONS

The multicast routing heuristic maximizing the proposed multicast tree transmission ratio is implemented in NS2 [8].

To evaluate the multicast routing, the simulation parameters for the wireless mesh networks are shown in Table I.

In the simulations, 50 fixed nodes are located in areas of dimension 1,500m \times 900m. One multicast source generates

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traffic at a CBR (Constant Bit Rate), with a packet size of 256 bytes. The packets are generated every 0.5, 0.05 and 0.005 seconds. From the total nodes, 20 are randomly selected and send a join request packet to the multicast group every second.

<table>
<thead>
<tr>
<th>Parameters in Our Simulation Scenario</th>
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<tbody>
<tr>
<td>MAC Type</td>
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<tr>
<td>Interface Queue Type</td>
</tr>
<tr>
<td>Interface Queue Length</td>
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<tr>
<td>Antenna Type</td>
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<tr>
<td>Propagation Type</td>
</tr>
<tr>
<td>Topology Instance</td>
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<tr>
<td>Transmission Range</td>
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<tr>
<td>Traffic</td>
</tr>
</tbody>
</table>

In comparison to the proposed multicast routing heuristic which constructs a multicast tree by maximizing the proposed multicast tree transmission ratio, two other multicast routings are considered. One multicast routing [6] constructs the multicast tree by minimizing the transmission count of multicast traffic, where all links are assumed to be of equal quality. The other constructs the tree by adding the paths having the maximum product of transmission ratios from a source to all members, as addressed in Section III.

### A. Delivery Ratio

The delivery ratio is the ratio of the number of data packets received to the number of data packets sent from a source, defined as follows:

\[ P_{\text{delivery}} = \frac{N_{\text{received}}}{N_{\text{sent}}} \]

where \( N_{\text{sent}} \) and \( N_{\text{received}} \) denote the total numbers of packets sent and successfully delivered, respectively.

As shown in Figure 2, the delivery ratio of our multicast routing heuristic is much higher than that of the multicast routing minimizing the transmission count in [6], and is lower than that of the multicast routing adding paths having the maximum product of transmission ratios from the source to all members.

### B. Average Delay

The delay of the multicast tree is measured according to the maximum delay from the source to the members, which includes the queuing delay, retransmission delay, propagation delay, and transmission delay. In Figure 3, the y-axis represents the simulation time unit while multicast traffic is transmitted in the multicast tree from the source to the members.

### C. Cost of Multicast Tree

The cost of the multicast tree indicates how many nodes are involved in forwarding the multicast packet from the source to all members.

As shown in Figure 3, the average delay of the proposed routing multicast heuristic maximizing the proposed multicast tree transmission ratio is much less in comparison with that of the multicast routing minimizing the transmission count. Also, the average delay of our proposed multicast routing heuristic is very close to that of the routing adding paths having the maximum product of transmission ratios.

In Figure 4, the proposed routing heuristic maximizing the multicast tree transmission ratio constructs a multicast tree having more forwarding nodes than the multicast routing minimizing the transmission count. However, the number of forwarding nodes required by our routing heuristic is much less than that required for the routing adding paths with the maximum product of transmission ratios from the source to all members.
V. CONCLUSIONS

In this paper, a multicast metric is designed for qualifying a multicast tree cost in wireless multi-hop mesh networks. The multicast-tree transmission ratio product considers the link quality of the wireless multicast channels as well as wireless multicast advantage. We propose a wireless multicast routing which constructs a multicast tree by maximizing the multicast-tree transmission ratio in wireless mesh networks. The proposed wireless multicast routing maximizing the multicast tree transmission ratio shows a higher delivery ratio and a lower average delay in comparison with the multicast routing minimizing the transmission count. In comparison with other multicast routings, simulation results show that the multicast routing maximizing the multicast tree transmission ratio constructs a cost-effective multicast tree in terms of its delivery ratio, average delay, and required network resources.

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