Network Coding-based Bridge Routing in Wireless Mesh Network

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***Abstract*—We propose bridge routing based on network coding for wireless mesh network. Our bridge routing offers the solution to exploit the network coding to minimize the usage of time slot. We present feasible and practical ways to study the performance of routing with network coding, as compared to the conventional shortest path algorithms. Bridge routing consists of two procedures, node coordination procedure which builds *bridge* and routing procedure, and it works in a decentralized way. Simulation results show that our bridge routing is more efficient than the shortest path algorithm, which its performance depends on the network connectivity.**

***Index Terms*—Wireless mesh network, network coding, routing algorithm, the shortest path algorithm**

I. Introduction

These days wireless mesh network is very popular and, keeping up with the demands of consumers, researchers have found room for improvement in wireless mesh network. Wireless mesh network usually have a bunch of nodes which want to communicate each other in a multi-hop process. Since each node usually transmits packets via intermediate nodes, how to find an efficient path, routing problem, is the most important issue in wireless mesh network.

So far various routing algorithms ([2]-[6]) in wireless mesh network have been proposed. These conventional works choose the next hop along the shortest path from the source to the destination. However, in large network, the conventional works are hard to maintain routing tables. GPS equipments enable geometric routing algorithms ([1], [7]) by sensing the locations of relative nodes.

Above mentioned routing algorithms basically try to find the shortest path to the destination. However, the attempt to minimize the hop length in each path cannot guarantee to enhance network performance without consideration of packet transmission in wireless mesh network. We exploit on network coding schemes ([9]-[13]) to resolve the foundational problem of the shortest path algorithms. Network coding is one of the most promising technologies, which has great advantages on packet transmission in wireless mesh network. It effectively reduces the number of transmission while enduring a weakness such as topology dependency.

In this paper, we propose bridge routing based on network coding. Bridge routing consists of two procedures, node coordination and routing. In node coordination procedure, three nodes (one core and two branches) build *bridge* in a decentralized way, and each node routes packets along the bridge in routing procedure. In the bridge, the core executes network coding process and network performance is enhanced even though routing paths are not the shortest paths. To get stochastic results, we simulate 5000 times, and simulation results show that finding the shortest path is not optimal to enhance network performance.

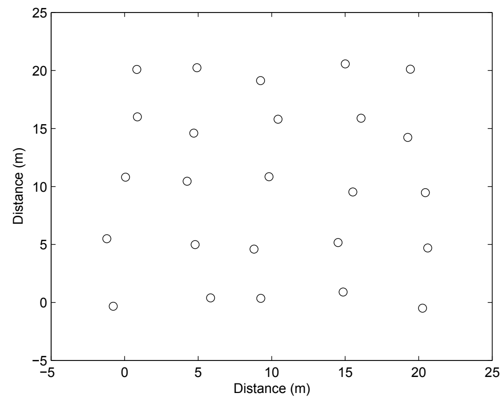

Fig. 1: Wireless mesh network (ex: 25 nodes are uniformly distributed in $25m^2$).

The rest of the paper is organized as follows: Section II describes system model and key idea of the proposed algorithm. Bridge routing is proposed in Section III and node coordination procedure and routing procedure are also discussed. In Section IV, we evaluate the effectiveness of our approach compared with the shortest path algorithm with simulation results. Finally, discussion and future works are described in Section V.

II. System Model and Key Idea

In this section, system model and key idea of bridge routing will be described.

A. System Model

We suppose wireless mesh network where a bunch of nodes is uniformly distributed within a restricted area (Fig. 1). All nodes have the same transmission range that packets can be transmitted without packet loss and GPS equipments informing their geometric locations. With GPS equipments, each node knows its own and its neighbor nodes' locations and source node knows the location of its own destination. The source node wants to communicate one destination node which means unicast transmission,

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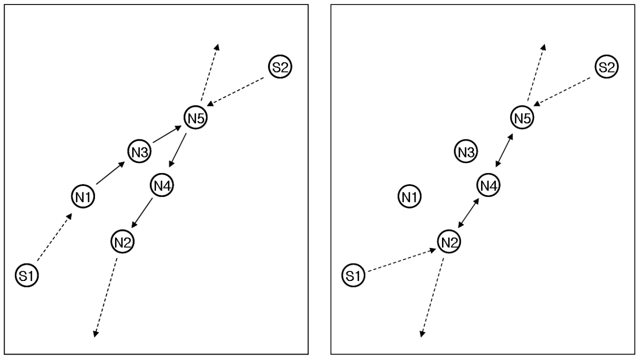

Fig. 2: The shortest path algorithm (left) and the Key idea of bridge routing (right).

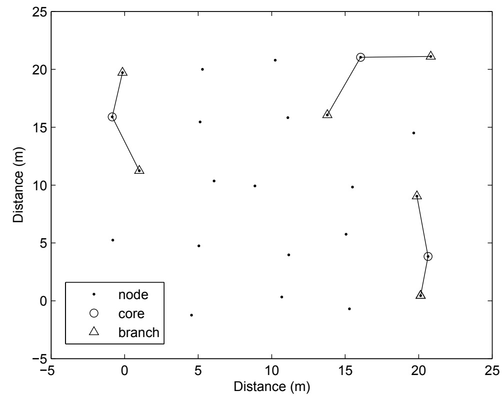

Fig. 3: The example of the bridges (25 nodes in $25m^2$, transmission range is 7m and N is 3).

and packets only flow from the source to the destination. Time-slotted CSMA/CA [8] is assumed, in which only one node transmits one packet at a time in the same transmission range.

In these circumstances, all source nodes have the same amount of packets to transmit, and the proposed algorithm tries to minimize global time slot usage. Global time slot usage means the amount of time slot necessity until entire network finishes packet transmission and it is a very important measure to evaluate network performance.

B. Key Idea

To minimize global time slot usage, the conventional works ([1]-[7]) tried to find the shortest path to the destinations. This actually works to minimize the hop length from the source to the destination. However, it would not be enough to minimize global time slot usage, and we focus on network coding scheme which effectively reduces the number of transmission.

For example, S1 and S2 individually transmit packets to their own destinations in Fig. 2. When each packet arrives at N1 from S1 and N5 from S2, the packets should be transmitted to N5 and N2 respectively in the shortest path algorithm. Because of wireless channel property, only one node among N1, N2, N3 and N4 is allowed to transmit packets and it is the same to the group of nodes (N3, N4 and N5). With time-slotted CSMA/CA [8], four wireless transmissions would be needed to complete packet transmission (N1 $\rightarrow$ N3, N3 $\rightarrow$ N5, N5 $\rightarrow$ N4 and N4 $\rightarrow$ N2). However, if network itself coordinates the routing path of S1 making N4 execute network coding process, the number of transmission would be three from four (N2 $\rightarrow$ N4, N5 $\rightarrow$ N4 and N2 $\leftarrow$ N4 $\rightarrow$ N5). Although the routing paths is not the shortest, global time slot usage would decrease by taking advantage of network coding scheme. The proposed algorithm comes from this key idea.

III. Bridge Routing

Bridge routing consists of two procedures, node coordination and routing. In node coordination procedure, each node builds a network coding-based routing region, so-called *bridge*. The bridge consists of one core and two branches (for example, N4 is the core and N2 and N5 are the branches in Fig. 2 (right)), and the core and branch execute additional tasks in routing procedure.

A. Node Coordination Procedure

In this procedure, network builds the bridges in a decentralized way. Node i who has the geometric location (n_i) and the transmission range (R) generates the neighbor node set (S_i):

$$S_i = \{j \mid \; i \neq j \; and \; \mid n_i - n_j \mid \leq R\}.$$

Node i who fulfill two following conditions can be a core candidate.

Condition 1) $\mid S_i \mid \leq N$.

Condition 2) $\mid n_{j_i^*} - n_{j_i^{**}} \mid > R$,
where $j_i^* = argmax_j \mid n_i - n_j \mid, \quad j \in S_i$ and $j_i^{**} = argmax_j \mid n_i - n_j \mid, \quad j \in S_i', \, S_i' = S_i - \{j_i^*\}$.

j_i^* and j_i^{**} would be branches of node i, and node i, j_i^* and j_i^{**} form the bridge. N is neighbor cost and predetermined. We will discuss the impact of neighbor cost (N) in Section IV.

After core candidates are determined, two problems occur. 1) Branch sharing is the problem which one branch joins two or more bridges. According to the proposed routing algorithm, connecting two or more bridges will increase the hop length severely from the source to the destination. 2) Duplicated core means two or more cores locate within the same transmission range. It offers various paths in a certain region and the chance of executing network coding process would decrease. Avoiding discussed problems, the nearby bridges should communicate each other and select the one who has lower $\mid S_i \mid$ and higher $\mid n_{j_i^*} - n_{j_i^{**}} \mid$.

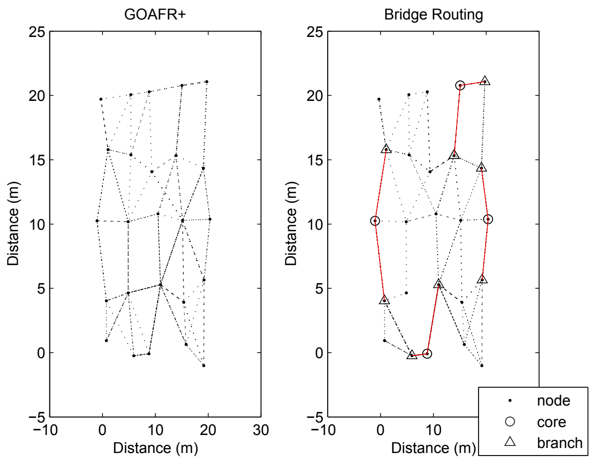

Fig. 4: The comparison between GOAFR+ and bridge routing paths (25 nodes in $25m^2$, transmission range is 7m and N is 3).

Fig. 3 is the example of the bridges. According to node coordination process, the bridges are scattered along the network boundary.

B. Routing Procedure

Our bridge routing employs the greedy routing mode and the face routing mode of GOAFR+ [1] as baseline routing schemes. Greedy routing mode finds the next node taking advantage of the shortest path algorithm. If a node executing greedy routing mode cannot find the shortest path, it would carry out face routing mode. In face routing mode, a node finds the next node in clockwise direction, and forwards packets.

Bridge routing divides nodes into three kinds, public (all nodes which do not participate the bridges are public), core and branch. 1) The public executes greedy routing and face routing as like GOAFR+. 2) The core just forwards packets to the branch which is nearer from the destination. 3) The branch compares its own and the core's location. If the core is nearer from the destination, it selects the core as the next node. Otherwise, it executes greedy routing and face routing. For example, we plot all of the routing paths passing by the bridges in Fig. 4 to compare the routing algorithms of GOAFR+ and bridge routing. The dotted lines are routing paths and the red lines are the bridges. As the number of routing paths passing a certain route increases, the dotted lines are thicker. In GOAFR+, routing paths are scattered all over the network, but bridge routing tends to bring together routing paths (the dotted lines) along the bridges executing network coding process.

In packet transmission, all nodes except the core transmit packets along the routing paths, and the core just executes network coding process to packets come from the branches.

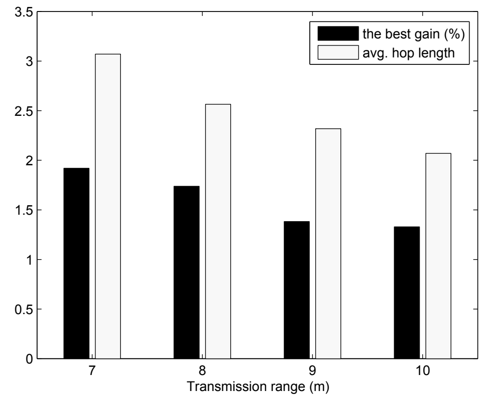

Fig. 5: The transmission range vs. the best gain and average hop length.

IV. Evaluation

Wireless mesh network where 25 nodes are uniformly distributed in $25m^2$ is assumed (Fig. 1). There are 300 source-destination pairs which have 5 packets to transmit. With time-slotted CSMA/CA [8], we measure global time slot usage until entire network finishes packet transmission. As a representative of the shortest path algorithm, GOAFR+ [1] also using GPS equipments is selected, and we simulate 5000 times to get statistical results.

Table I shows the relation between neighbor cost (N) in Section III and the gain (G) of bridge routing according to the transmission range. If global time slot usage of GOAFR+ is T_{GOAFR+} and that of bridge routing is T_B, then the gain of bridge routing is

$$G = 100 * \frac{T_{GOAFR+} - T_B}{T_{GOAFR+}} \quad (\%).$$

Table I describes that there is adaptive neighbor cost (N) which maximizes the gain (G) of bridge routing in each transmission range. When the transmission range increases, the node density of unit transmission range also increases. Since this change directly affects neighbor cost, adaptive neighbor cost increases with the transmission range (for example, neighbor cost 3 is the best in 7m and 6 is the best in 10m).

Fig. 5 represents the transmission range versus the best gain of bridge routing and average hop length. As the transmission range increases, average hop length of routing algorithm decreases. It means that relatively network is

TABLE I: The relation between neighbor cost (N) and the gain (G) of bridge routing.

	Transmission range: 7m			Transmission range: 8m		
N	2	3	4	4	5	6
G	1.4234	1.92	1.8113	1.5596	1.7383	1.391

	Transmission range: 9m			Transmission range: 10m		
N	4	5	6	5	6	7
G	0.6088	1.3831	1.2342	0.9713	1.3292	1.1506

getting smaller and the chance to build bridges is also decreasing. Therefore, maintaining network connectivity, bridge routing is more efficient in large network since the gain is the highest, about 2% in 7m.

V. Discussion and Future Works

This paper concerns the general issue of wireless mesh network. To evaluate network performance, the concept of global time slot usage is adopted. While the conventional works tried to reduce the hop length of routing algorithm, bridge routing directly decreases global time slot usage by taking advantage of network coding scheme. Bridge routing is about 2% more efficient than the shortest path algorithm, however, it turns out that the gain of bridge routing depends on the transmission range. In the future, we will formulate the proposed issue of wireless mesh network and, based on the formulation, find room for improvement in bridge routing.

Acknowledgment

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