A Proposal of Routing Algorithm under Practical Conditions for Wireless Internet-Access Mesh Networks

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***Abstract*-- A Wireless Internet-access Mesh NETwork (WIMNET) can provide an expandable Internet-access network by flexibly adopting multiple Access-Points (APs) that have wireless connections in the field. Previously, we proposed a routing algorithm for generating an optimal routing path between the hosts and one Internet Gateway (GW). However, in practical situations, multiple GWs are usually necessary for scalability. Beside, in the high-speed IEEE802.11ac protocol, the link speed drastically decreases as the distance increases due to the lowered receiving signal quality. Furthermore, commercial APs implementing them have the limitation on the number of hops between a GW and a host. In this paper, we propose a routing algorithm to consider these practical conditions for large-scale WIMNET. We verify the effectiveness through simulating three topologies using the WIMNET simulator.**

I. INTRODUCTION

As a scalable Internet-access network, we have studied **Wireless Internet-access Mesh NETwork (WIMNET)**. WIMNET adopts multiple **Access-Points (APs)** that are connected through wireless links [1]. These APs are communicated with each other mainly on the MAC layer using the **Wireless Distribution System (WDS)** [2]. At least one AP acts as a **Gateway (GW)** to the Internet. Any host connects to the Internet through a GW after multihop communications between APs [3].

Previously, we proposed a routing tree algorithm for the WIMNET hosting only one GW to generate an optimal routing path that connects the hosts and this GW such that the transmission delay to the farthest AP can be minimized [4]. However, in practical situations, multiple GWs are usually necessary for large-size WIMNET. Beside, in the high-speed **IEEE 802.11ac** protocol that has been popular [5], the link speed drastically decreases when the received signal quality decreases as the distance increases [6]. Furthermore, commercial APs implementing them have the limitation on the number of hops (hop count) between a GW and a host.

In this paper, we first present the formulation of the routing problem considering these practical conditions in WIMNET. Here, as the new input, we add the information of multiple GWs. As the new constraint, we introduce the **hop count constraint** such that the hop count between any host and the GW must be within a given limit. Also, as an objective function, we define the minimization of the total transmission time of the routing tree for the bottleneck GW. We note that the output of the problem is a set of routing trees or a **routing forest** where each root node is a GW.

Then, we propose the heuristic algorithm by introducing the **routing graph** that describes any possible link for the routing forest. Using this graph, we extract the routing forest that satisfies the constraints and optimizes the objective in the problem through two stages. The initial stage generates a routing forest by sequentially selecting the shortest path to one GW for any host, where communication loads may become unbalanced between GWs. Then, the improvement stage iteratively improves this load balance by a local search method. We verify the effectiveness of the proposed algorithm through simulations in three topologies.

II. FEATURE of IEEE 802.11ac protocol

IEEE802.11ac protocol is a new high-speed wireless communication protocol to realize the maximum of 6.93Gbps using 5GHz band. It adopts **MIMO** (Multiple-Input-Multiple-Output) with the maximum of eight antennas, **multi-user MIMO**, **channel bonding** with the maximum of 160MHz, and 256QAM (256 Quadrature Amplitude Modulation).

IEEE802.11ac may suffer from larger performance degradations due to the received power decrease and the interference/noise increase because the maximum throughput is far higher than conventional IEEE802.11b/g. Thus, we measured throughputs using devices implementing this protocol (Buffalo, WZR-1750DHP) in our campus when the link distance increased from 0m to 100m. Figure 1 shows the result where approximated throughputs with a third-order linear equation of the link distance are also shown. This device allows the maximum of two hops between a GW and a host. Thus, for WIMNET using this device, the hop count must be two or smaller.

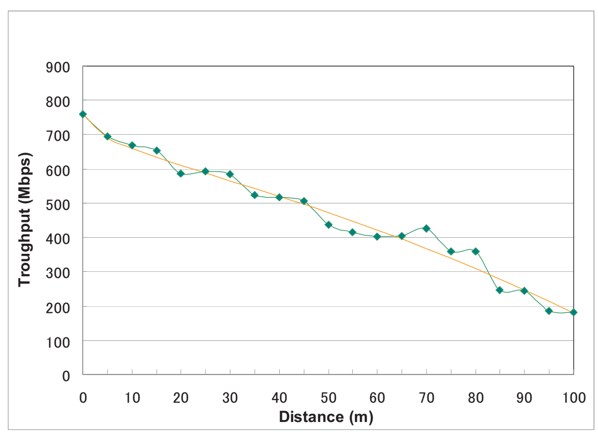

Figure 1 Measured link speed change by distance.

III. ROUTING ALGORITHM

In this algorithm, we consider two things: 1) multiple GWs, 2) the link speed change in IEEE802.11ac, and 3) the hop count limit. To simply estimate the link speed from the distance, we newly add the coordinate information of each node in the input to the algorithm, although the link speed should be measured in real situations.

A. Inputs:

- Network topology: G = (V, E)
  - set of nodes: V
  - node type: GW, relay-AP (AP), host
  - node location coordinate: (x, y)
  - set of links between nodes: E
  - IEEE802.11ac link speed estimation equation
  - link speed threshold for interferences between links

B. Constraints:

- Every host must be connected with a GW in the forest (host covering constraint).
- The hop count between a GW and a host must not exceed its limit (two in this paper) (hop count constraint).
- For any node, either of the following nodes must be selected for the downstream connection (node type connection constraint):
  – for GW: AP or host
  – for AP: host
  – for host: none (any host must be a leaf).
- For any node, only one upstream node must exist (unique routing constraint).

C. Cost Function

The cost function $\boldsymbol{E}$ representing the maximum total transmission time of the links in a GW tree (the bottleneck tree) in the routing forest should be minimized:

$$E = \max_{m}\left[\sum_{k \in T_m}\left(\sum_{ij \in Pk}\frac{r_k}{s_{ij}}\right)\right] \quad (1)$$

where T_m represents the tree for the m-th GW in the routing forest, s_{ij} does the link speed (throughput) for link ij, r_k does the traffic of host k, P_k does the routing path between the GW and host k.

D. Algorithm Procedure

1. Routing graph generation

To describe the feasible links in the routing forest, we generate the **routing graph**. Each vertex represents a node in V, and each edge represents a link that can be selected in the forest. To satisfy the hop count constraint and the node type connection constraint, an edge can exist only between the following pair of vertices in this graph:

- GW and replay-AP
- GW and host
- relay-AP and host.

Then, the inverse of the link speed is assigned to each edge weight as the link delay.

2. Initial routing forest generation with shortest path

An initial routing forest is greedily constructed as a collection of the shortest path in terms of the link delay for each host, where 1) the selection of the shortest path among the unselected hosts and 2) the removal of the infeasible links from the routing graph to satisfy the unique routing constraint are repeated until every host is selected.

3. Routing forest improvement by local search

Then, the routing forest is improved by iteratively changing the path to another GW in the bottleneck tree by:

1) Select one unselected host in the bottleneck tree.
2) Find the shortest path to a different GW.
3) If the cost function $\boldsymbol{E}$ is reduced by adopting the new path in 2), keep it in the memory.
4) If every host is selected in 1), find the best change that minimizes $\boldsymbol{E}$ among 3), update the routing forest and $\boldsymbol{E}$, and go to 1). Otherwise, terminate the procedure.

IV. EVALUATION BY SIMULATIONS

In simulations, three topologies with three GWs and two relay-APs are considered. To evaluate the performance of a routing forest found by the algorithm (Proposal) through comparisons, we compare it with the initial routing forest by the algorithm. Figure 2 illustrates the initial and final routing forests by the algorithm for topology 2. Then, we calculate throughputs using the WIMNET simulator [1] for each tree. Table I shows the throughput results. The tree by our algorithm (Proposal) improves the throughput by 30-50% from the shortest path one by averaging the load among the GW routing trees while keeping the short path. It supports the effectiveness of our modified algorithm.

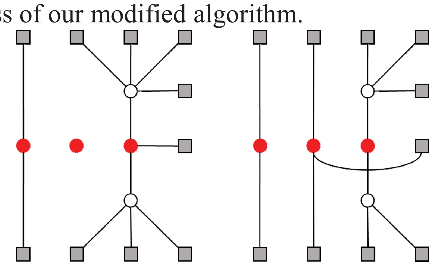

Figure 2 Routing forests by shortest path and algorithm.

Table I Throughput results (Mbps).

topology	AP	host	proposal	shortest path
1	5	3	635.66	496.78
2	5	10	658.47	436.80
3	5	15	650.85	501.76

V. CONCLUSION

This paper presented a two-phase routing algorithm using a routing graph for WIMNET under practical conditions: 1) multiple GWs, 2) link speed change, and 3) hop count limit. The effectiveness was verified through simulations.

References

[1] N. Funabiki edited, Wireless Mesh Networks, InTech-Open Access Publisher, 2011.
[2] M. S. Gast, 802.11 wireless networks - the definitive guide, 2nd ed., O'Reilly, 2005.
[3] I. F. Akyildiz, X. Wang and W. Wang, "Wireless mesh networks: a survey," Comput. Network, vol. 47, no. 4 pp.445-487, 2005.
[4] N. Funabiki, K. Uemura, T. Nakanishi, and W. Hassan, "A minimum delay routing tree algorithm for access-point communications in wireless mesh networks," Proc. RIVF 2008, pp. 161-166, July 2008.
[5] M. S. Gast, 802.11ac: a survival guide, O'Reilly, 2013.