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Efficient Load Balancing Routing in Wireless Mesh Networks

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ABSTRACT

In a Wireless Mesh Network (WMN), the traffic load is disseminated unevenly over the network. A load aware routing scheme is introduced to balance the load in the network, and accordingly improve the overall capacity of network. The load aware routing scheme is designed to maximize the utility by using dual decomposition technique. In the proposed scheme, a WMN is divided into multiple clusters to control the load in the network. Cluster has number of nodes, i.e., routers. One node acts as a cluster head. Cluster head estimates the traffic load in its cluster. As the estimated load gets higher, the cluster head increases the routing metrics of the routes passing through the cluster. Based on the routing metrics, user traffic takes a detour to avoid overloaded areas and, as a result , the WMN achieves global load balancing.

***INDEX TERMS**—Wireless mesh network, load-aware routing, utility, dual decomposition.*

I. INTRODUCTION

Mesh networking is a type of networking where in each node in the network may act as an independent router, regardless of whether it is connected to another network or not. It allows for continuous connections and reconfiguration around broken or blocked paths by "hopping" from node to node until the destination is reached. A Wireless Mesh Network (WMN) has many advantages over conventional wired networks, such as low installation cost, wide coverage and robustness, etc. In the WMN users communicate with in the network and communicate with outside network via wired gateways. The gateway is used to connect the different WMN. In this situation links around the gateways are likely to be a overloaded in the network. If the routing algorithm does not control the traffic load on these links, some gateways may be overloaded while others may not. This load imbalance can be resolved by introducing a load-aware routing scheme that adopts the routing metric with load factor.

In this paper, we propose a load-aware routing scheme, which maximizes the total utility of the users in the WMN. The utility is a value which quantifies how satisfied a user is with the network. Since the degree of user satisfaction depends on the network performance, the utility can be given as a function of the user throughput. Generally, the utility function is concave to reflect the law of diminishing marginal utility. To design the scheme, we use the dual decomposition method for utility maximization. Using this method, we can incorporate not only the load-aware routing scheme but also congestion control and fair rate allocation mechanisms into the WMN.

In the proposed routing scheme, a WMN is divided into multiple overlapping clusters. A cluster head takes role of controlling the traffic load on the wireless links in its cluster. The cluster head periodically estimates the total traffic load on the cluster, and increases the "link costs" of the links in the cluster, if the estimated load is too high. In this scheme, each user chooses the route that has the minimum sum of the link costs on it. Thus, a user can circumvent overloaded areas in the network, and therefore, the network-wide load balance can be achieved.

The major advantages of the proposed load-aware routing scheme can be summarized as follows.

• Designed by the dual decomposition method, the proposed load-aware routing scheme maximizes the system-wide performance.

• The proposed scheme is scalable, has low control and computation overheads, and can be easily im- plemented by means of the existing ad hoc routing protocols.

II. RELATED WORKS

In WMN, a number of routing metrics and algorithm have been proposed to take advantage of stationary topology. the routing metrics are expected number of transmissions(ETX), minimum loss(ML), minimum time metric(MTM), expected transmission time (ETT), weighted cumulative extended transmission time (WCETT), the intra-flow interference (MIC), interference aware (iAWARE), modified extended number of transmissions (mETX). These routing metrics contain the standard deviation of the link quality in addition to the average link quality. The blacklist forwarding algorithm (BFA), ExOR algorithm ,resilent opportunistic mesh routing (ROMER) have been proposed.

The load aware routing protocols incorporate the load factor into their routing metrics. Compared to these load-aware routing protocols, the proposed routing scheme has three major advantages. First, the proposed scheme is designed to maximize the system capacity by considering all necessary elements for load balancing, e.g., the interference between flows, link capacity, etc. Second, the proposed scheme can guarantee fairness between users. Third, the proposed scheme can provide routes stable over time.

We have used dual decomposition method to design the proposed load-aware routing scheme to maximize the network utility. To use this method, we should formulate the optimization problem under the constraints. After the constraints are relaxed by the Lagrange multipliers, the whole problem can be decomposed into small sub problems which are solved by the different network layers in the different nodes. Therefore, the dual decomposition method provides the systematical way to design a distributed algorithm which finds the global optimal solution.

III. SYSTEM MODEL

A Mesh network structure

Each wireless router in the network is static in their location. The WMN does not change frequently and the channel quality is static. In Figure 1, we illustrate an example of WMN. In this figure, a node stands for a wireless router, which do not only delivers data for its own users but also relays data traffic for the other routers in the network. Among nodes, there are some gateway nodes that are connected to the wired backhaul network. User can send or receive data traffic from outside networks via wired gateway nodes. If node n transmits data to node m directly, there exists a link from node n to node m. In this paper we define link as unidirectional. The WMN under consideration provides a connection-oriented service, where connections are managed in the unit of flow. A flow is a unidirectional.

Data traffic on a flow is conveyed to the destination node through a multi-hop route. We only consider the acyclic routes. Thus, a route can be determined by the set of all intermediate links that the route takes. For a flow there are a number of routes that connect the source and destination. We assume that a flow can utilize multiple routes simultaneously by dividing its data traffic into these routes. Here limit the possible data rate to control the amount of traffic injected to the WMN. The flow data rate, which is defined as the maximum data rate at which the flow f can send data traffic on the route. We can define flow data rate vector. The sum of all components in a flow data rate vector is limited to the “maximum flow data rate”. We will call flow data rate vector the “multipath flow date rate vector” if it has morethan one route. Otherwise we will refer as “single path flow data rate vector” only for one active route. In case all flows have the single path flow data rate vector, we can denote the “active route vector”.

B Physical and medium access control layer model

The proposed scheme can be implemented on top of various physical (PHY) and medium access control (MAC) layer protocols. The effective transmission of the link is defined as the number of actually transmitted bits divided by the time spent for the data transmission, calculated in consideration of retransmissions due to errors. We define the “air time ratio” of the link l. The air time ratio of the link l is defined as the sum of the data rates on the link l divided by the effective transmission rate of the link l.

Roughly, we consider that a fixed portion of the time can be used for data transmission, while the remainder section is used for the purpose of the control, e.g., control message exchange and random back-off. Let β denote the ratio of the time for data transmission to the whole time. The sum of the links in a cluster cannot exceed β.

C Utility and delay penalty as optimization target

The flow longer distance consumes generally more airtime to convey the same amount of time. Therefore, if maximizing system throughput is the optimization target in the WMN, the flows with short distance are likely `with long distance. The utility is a highly desirable performance measure since the user satisfaction is the ultimate goal of the network design.

The utility function defines the mapping between the data rate of a flow and the utility of that flow. Since the utility function quantifies the network performance perceived by users when a data rate is given, it can only be estimated by a subjective survey, not by theoretical development. The marginal utility of a flow is the amount of the utility that the system can obtain by assigning a unit data rate to the flow.

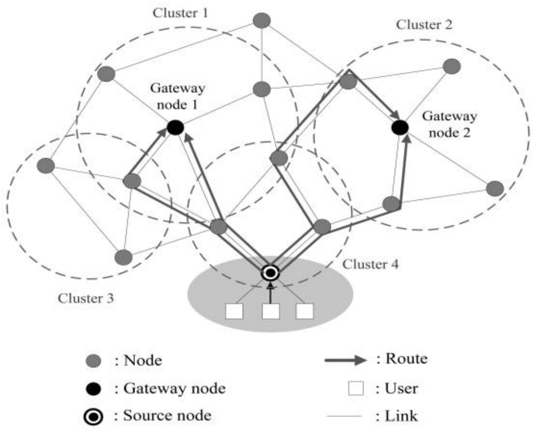

Figure.1. Example mesh network

The delay is also of great importance in the practical WMN, we incorporate the delay term into objective function. To do this, we define the "delay penalty function" for each flow, which penalizes the objective function foe selecting the route with long end to end delay.

IV. PROPOSED LOAD-AWARE ROUTING SCHEME

In this section, we design the routing seheme by using the dual decomposition method. We first formulate the optimization problem from the objective function and constraints introduced in the previous section, and derive the dual problem. Next, we explain how to calculate the flow data rate vector for the given Lagrange multipliers, and suggest the subgradient method to iteratively calculate the optimal Lagrange multipliers. Finally we propose the dampening algorithm to alleviate the route flapping problem.

A. Problem formulation

We formulate the optimization problem from air time ratio, β and mergerd objective function. We solve the optimization problem by converting it to the dual problem according to the Lagrangian method. From the Lagrangian, we define the dual function. From the dual function, we define the dual problem. We can find optimal solution from this problem

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B. Flow data rate calculation for given lagrange multipliers

We calculate the flow data rates that maximizes the Lagrangian for given Lagrange multipliers.

Proposition 1: The set of flow data rate vector contains at least one single path flow data rate vector.

Proof: consider the any flow data rate. Let flow data rate be the flow data rate vector such that for the active route that minimizes link cost. This means there exists a single path floe data rate vector.

C. Lagrange multiplier update

We will find the solution of the dual problem. The constraint in the dual problem can be incorporated into the dual function. We define the modified dual function where satisfies the constraint for given Lagrange multiplier.

D. Convergence of flow data rate

We will take the flow data rate vector as the estimation of the optimal flow data rate vector at jth iteration. We will discuss the convergence of this flow data rate vector. Since the optimization problem is strictly feasible and the objective and constraint functions are concave, the strong duality holds from slater's constraint qualification.

V. DISTRIBUTED IMPLEMENTATION

For implementation, one node with in a cluster is designated as the head of the cluster. The head of the cluster is assumed to be able to communicate with the transmitter nodes of the links in its cluster. The proposed scheme takes the following steps at the jth iteration of the sungradient method. Fig. 2 illustrates an example of control information exchange for this operation.

By the below steps, not only the routing but also the link cost control and the flow control are performed. That is,

- Each cluster head estimates the traffic load with in cluster and the nodes with in the cluster adjust the link costs of its outgoing links, on the basis of estimated loads as in first 5 steps (i.e., link cost control).

- Based on the link costs, the active route for each flow is updated in the steps 6-8 (i.e., routing).

- The flow date is calculated in the step 9.

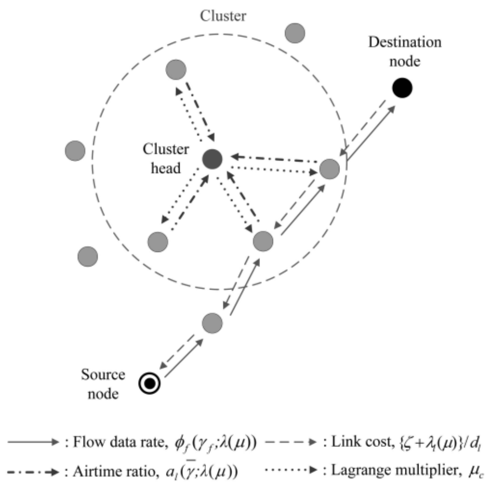

Figure.2. Control information exchange for distributed implementation

1) The source node of flow f sends a message containing flow data rate on the active route to the nodes on the active route.
2) Each node calculates the air time ratios for its all outgoing links from and broadcasts them to the heads of the clusters to which the links belong.
3) The cluster head receives air time ratios for all links in its cluster and updates the Lagrange multipliers.
4) The cluster head broadcasts updated Lagrange multiplier to the transmitter nodes of the links in its cluster.
5) Each node calculates updated Lagrange multiplier and derives the link cost for its all outgoing links.
6) The source node of flow f finds the optimal route.
7) The source node of flow f is informed of the link costs on the active route and the new optimal route.
8) The source node of flow f sets active route to optimal route if it increase certain margin, if not the active route is not changed.
9) The source node of flow f calculates the flow data rate

VI. NUMERICAL RESULTS

The numerical results presented below show that the proposed routing scheme effectively balances traffic load, consequently outperforms the routing algorithm using the ETT as a routing metric. We consider two scenarios, i.e., with and without gateway. To model the load imbalance situation, we introduce the load skewness denoted σ.

A. Gateway scenario

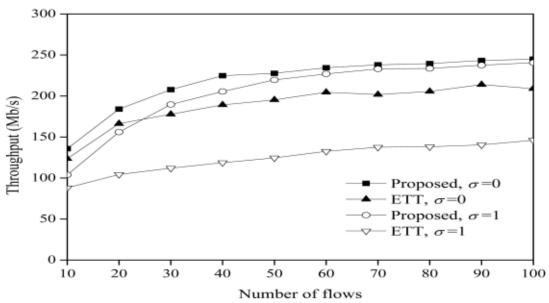

Fig.4. System throughput according to the number of flows in the gateway scenario.

B No gateway scenario

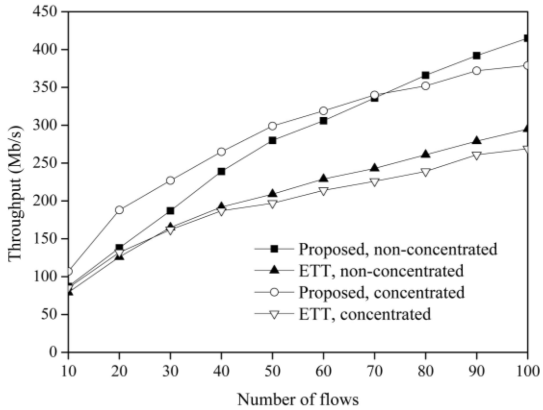

Fig.6. System throughput according to the number of flows in the no gateway scenario.

VII. CONCLUSIONS

In this paper, we have developed a load aware routing scheme for the WMN. We have formulated the routing problem as an optimization problem, and have solved it by using the dual decomposition method. The dual decomposition method makes it possible to design a distributed routing scheme. However, there could be a route flapping problem in the distributed scheme. To tackle this problem, we have suggested a dampening algorithm and have analyzed the performance of the algorithm. The numerical results show the proposed scheme with a dampening algorithm well converges to a stable state, and achieves much higher throughput than the ETT-based scheme does owing to its load-balancing capacity.

FUTURE ENHANCEMENT

The proposed scheme can be applied to various single band PHY/MAC layer protocols. In future work, we can extend the proposed scheme so that we can applied to the multiband protocols, which can provide larger band width to the WMN.

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