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An Effective Implementation of Multi-Path Routing Protocol in Wireless Mesh Networks

Mr. V. Ramesh
Associate Professor,
Department of CSE,
Sree Vidyanikethan Engg. College,

T.Rajasekhar Reddy, T.Swarna Latha
Department of CSE,
Sree Vidyanikethan Engg. College,
tiyyagurarajasekhar@yahoo.in

Abstract*— This paper's contribution is a multi-path routing protocols that emphasize different aspects of multi-path routing. Multi-path protocols, which can provide larger bandwidth to the WMN. The network performance (end-to-end delay and packet loss ratio) compares favorably to the single-path DSR protocol, though as might be expected there is a trade-off against control packet overhead. In a WMN, the traffic load tends to be unevenly distributed over the network. We design a routing scheme which maximizes the utility, i.e., the degree of user satisfaction, by using the dual decomposition method. The goal of the metric is to choose a high-throughput path between a source and a destination. Our metric assigns weights to individual links based on the Expected Transmission Time (ETT) of a packet over the link. The proposed routing scheme in a fully distributed way. With the proposed scheme, a WMN[1] is divided into multiple clusters for load control. A cluster head estimates traffic load in its 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.

Keywords— *Wireless Mesh Networks, Load-Aware Routing, Clustering.*

I. INTRODUCTION

Wireless mesh networks (WMNs) typically consist of mesh routers and mesh clients with each node having the capability of operating not only as a host but also as a router.. Mesh routers are used to form a multi-hop and multi-path wireless relay backbone capable of communicating with gateways and clients. Mesh clients can form a self organized ad hoc networks which can access services by relaying requests to wireless backbone network..

Wireless mesh networks have been drawing significant attention in recent years due to their flexibility in providing extensive wireless backbone for wired backbone. The potential applications include wireless broadband services, community networking, instant surveillance systems, high speed metropolitan area networks, and back-haul service for large-scale wireless sensor networks. Some of the technical challenges in WMNs are load balancing, optimal routing, fairness, network auto configuration and mobility management. Our focus in this paper is routing and load balancing. Existing solutions in mobile ad hoc and sensor networks cannot be directly applied to WMNs due to the difference in traffic patterns, mobility scenarios, gateway functionalities and bandwidth requirements.

Since most users in WMN are primarily interested in accessing the Internet or other commercial servers, the traffic in WMNs is routed either toward the Internet Gateways (IGWs) or from the IGWs to clients . Thus, if multiple edge mesh routers choose the best throughput path toward a gateway, the traffic loads on certain paths and mesh routers increases tremendously thereby significantly decreasing the overall performance of the network.

The main contributions of this paper are:

(1) We propose a routing metric that provides load balancing at mesh router and;

(2) We introduce a dynamic traffic splitting algorithm to balance load distribution among mesh routers.

The recent advance of wireless communication technologies has prompted a flourish of a new kind of multi-hop wireless network architecture, called wireless mesh networks (WMNs). WMNs typically comprise a number of static wireless routers that are attached to reliable sources of energy.

Some of the routers are directly connected to a fixed infrastructure (i.e., a wired network like the Internet) and serve as gateways for other wireless routers. This load imbalance can be resolved by introducing a load-aware routing scheme that adopts the routing metric with load factor. To design the scheme, we use the dual decomposition method for utility maximization [7], [8]. 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. Most notably, we can implement the load-aware routing scheme in a distributed way owing to the structure of the dual decomposition method.

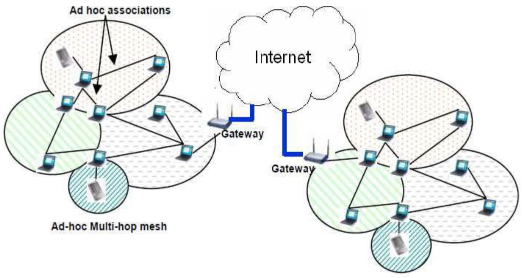

Figure1:Ad-hoc Mesh network with multi-hop connections to gateway

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:

- Maximizes the system-wide performance.
- The proposed scheme is scalable, has low control and computation overheads.

2. RELATED WORK:

Management of wireless multi-hop networks has been an active research area and numerous routing algorithms have been proposed. Comprehensive surveys on WMNs and routing in multi-hop wireless networks can be found. Most of the routing schemes for multi-hop wireless networks aim at such environments as battlefield ad-hoc networks, and the typical objective is to maintain the communication links between mobile stations.Several routing schemes have been proposed for WMNs. Here, we mention only those studies that are directly relevant to our work. In [9], De couto et al. introduce the ''expected transmission count'' (ETX) metric that enables existing routing algorithms to find high performance paths between source–destination pairs where a single radio channel is used. Draves et al. propose in [2] a new path metric, called ''weighted cumulative expected transmission time'' (WCETT), that explicitly accounts for the interference among links using the same channel. Then, they incorporate the WCETT metric into a source-route link-state-like routing that exploits the advantage of the multiple radios.

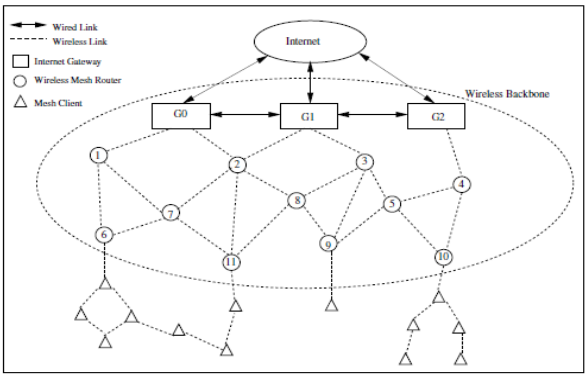

Figure 2. A three-layer wireless mesh network architecture

In this section we will briefly discuss recently proposed routing metrics and multi-path routing schemes for WMNs. Routing metrics are very critical for determining the performance of the networks. Multi-path routing protocols can be used to provide load balancing in wireless networks [2,10]. In order to achieve load-balancing, each node needs to maintain multiple paths from itself to the IGWs.

If the current best to the second best path efficiently. In [10], authors proposed a multi-path routing protocol for balancing traffic over multiple paths and improving the overall network performance. The proposed multi-path protocol establishes paths at each node to IGWs by selecting maximal disjoint paths.

3. SYSTEM MODEL:

3.1 Mesh Network Structure

Each wireless router in a WMN is fixed at a location. Thus, the WMN topology does not change frequently and the channel quality is quasi-static. In addition, each wireless router serves so many subscribers (i.e., users) in general that the characteristic of the aggregated traffic is stable over time. Therefore, we design the routing scheme under the system model of which topology and user configuration are stable. The WMN under consideration provides a connection oriented service, where connections are managed in the unit of a flow. A flow is also unidirectional. A user can communicate with the other user or the gateway node after setting up a flow connecting them. Since a user is connected to a unique node, the flow between a pair of users can also be specified by the corresponding node pair.

The node where a flow starts (ends) will be called the source (destination) node of the flow.

3.2 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 that utilize a limited bandwidth and divide the time for multiple access, for example, such as the carrier sense multiple access/collision avoidance (CSMA/CA), the time division multiple access (TDMA), and the reservation ALOHA (R-ALOHA). The effective transmission rate of a link is defined as the number of actually transmitted bits divided by the time spent for data transmission, calculated in consideration of retransmissions due to errors. That is, the effective transmission rate can be calculated as the PHY layer transmission rate times the probability of successful transmission.

The PHY layer transmission rate can be fixed, or can be adaptively adjusted according to the channel quality by means of rate control schemes such as the receiver-based auto rate (RBAR).

4. DUAL DECOMPOSITION METHOD:

If all flows convey data traffic through each route at their flow data rates, the sum of the data rates of traffic passing through link l is calculated as, $\sum_{r \varepsilon \mathcal{H}_1} \sum_{f \varepsilon Qr} pf, r$, where Hl is defined as the set of the indices of all routes passing through the link l i.e., $\mathcal{H}_\ell := \{r : \ell \in \mathcal{D}_r\}$ and Q_r is the indices of all flows that use the route r, i.e., $Q_r := \{f : r \in \mathcal{G}_f\}$. We define the "airtime ratio" of the link l, denoted by a_l, as the ratio of the time taken up by the transmission to the total time of link l. The airtime ratio of the link l can be calculated as the sum of the data rates on the link l divided by the effective transmission rate of the link l. That is,

$$a_l = \sum_{r \in \mathcal{H}_l} \sum_{f \in Q_r}^{\frac{pf,r}{d_l}} \qquad (1)$$

Roughly, we assume that a fixed portion of the time can be used for data transmission, while the remainder is used for the purpose of 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. Since only a link can convey data traffic at a time within a cluster, the sum of the airtime ratios of the links in a cluster cannot exceed β. Therefore, we have the following constraint:

$$\sum_{l \in \mathcal{M}_c} a_l \leq \beta, \qquad for\ all \in C \qquad (2)$$

Since we have two different objectives (i.e., the utility and the delay penalty), we should find a Pareto optimal solution such that no other solution can improve any objective without worsening the other objective. To calculate a Pareto optimal solution, we use the scalarization technique [28, pp. 178-180] that merges multiple objectives into a single objective by taking the weighted sum of the objectives. We introduce the merged objective function as follows:

$$O(\bar{p}) := \sum_{f \in \mathcal{F}} u_f \left(\sum_{r \in G_f} pf, r \right) - \varsigma . \sum_{f \in \mathcal{F}} \sum_{r \in G_f} pf, r \sum_{l \in D_r} \tfrac{1}{d_l} \qquad (3)$$

Where $\bar{p} := (pf, r)_{f \in \mathcal{F}, r \in \mathcal{G}_f}$ and ς is the "delay penalty parameter" that controls the relative importance of the delay penalty to the utility. We can reduce the end-to-end delay at the expense of the utility by increasing the delay penalty parameter. We will demonstrate the impact of the delay penalty parameter in Section 6.

4.1 Problem Formulation

We formulate the optimization problem from (1), (2), and (6) as follows:

$$max \sum_{f \in \mathcal{F}} u_f \left(\sum_{r \in G_f} pf, r \right) - \varsigma . \sum_{f \in \mathcal{F}} \sum_{r \in \mathcal{G}_f} pf, r \sum_{l \in D_r} \tfrac{1}{d_1} \qquad (4)$$

$$s.t\ a_1 = \sum_{r \in \mathcal{H}_\ell} \sum_{f \in Q_r} \tfrac{pf,r}{d_1} \quad for\ all\ l \in \mathcal{L}, \qquad (5)$$

$$\sum_{l \in M_c} a_l \leq \beta, \ \ for\ all\ c \in C, \qquad (6)$$

Where pf, r ≥ 0 and $\sum_{r \in \mathcal{G}_f} pf$, r $\leq$ p_{max} for all f and r .

This optimization problem is feasible and convex. Let $p^*_{f,r}$ be any optimal solution of this optimization problem. We also define the optimal flow data rate vector $p^*_{f,r} := (p^*_{f,r})_{r \in \mathcal{G}_f}$

We solve the optimization problem by converting it to the dual problem according to the Lagrangian method in [29]. The Lagrangian is given as follows:

$$\begin{aligned} È(\bar{p}, a; w) := & \sum_{r \in \mathcal{G}_f} u_f \left(\sum_{r \in \mathcal{G}_f} pf, r \right) - \varsigma . \sum_{f \in \mathcal{F}} \sum_{r \in \mathcal{G}_f} pf, r \sum_{l \in \mathcal{D}_r} \tfrac{1}{d_\ell} \\ & + \sum_{l \in \mathcal{L}} \lambda_\ell \left\{ a_l - \sum_{r \in \mathcal{H}_\ell} \sum_{f \in Q_r} \tfrac{pf,r}{d_l} \right\} \\ & + \sum_{c \in C} \mu_c \left\{ \beta - \sum_{l \in \mathcal{L}} a_\ell \right\} \qquad (7) \\ = & \sum_{f \in \mathcal{F}} \left\{ u_f \left(\sum_{r \in \mathcal{G}_f} pf, r \right) - \sum_{r \in \mathcal{G}_f} pf, r \sum_{l \in \mathcal{D}_r} \tfrac{\varsigma + \lambda_1}{d_1} \right\} + \sum_{l \in \mathcal{L}} \left\{ \lambda_l - \sum_{c \in v_1} \mu_c \right\}, \end{aligned}$$

Where a:= $(a_1)_{l \in \mathcal{L}}$ and $\mathcal{V}_\ell$ denotes the set of the indices of all clusters that the link ℓ belongs to (i.e., $\mathcal{V}_\ell := \{c : l \in M_c\}$). It is noted that we have

$$\sum_{l \in \mathcal{L}} \lambda_\ell \sum_{r \in \mathcal{H}_\ell} \sum_{f \in Q_r} \tfrac{pf,r}{d_l} = \sum_{f \in \mathcal{F}} \sum_{r \in \mathcal{G}_f} pf, r \sum_{l \in \mathcal{D}_r} \tfrac{\lambda_l}{\mathcal{D}_l}$$

and $\sum_{c \in C} \sum_{\ell \in \mathcal{M}_c} a_l = \sum_{l \in \mathcal{L}} a_l \sum_{c \in v_1} \mu_c$ Then ,the dual function is given as follows:

$$g(w) = \sum_{f \in \mathcal{F}} \sum_{r \in \mathcal{G}_f} pf, r + \beta \sum_{c \in C} \mu_c \qquad (8)$$

From the dual function, we define the following dual problem:

$$\text{Min } g(w), \qquad (9)$$

$$\lambda_l - \sum_{c \in v_\ell} \mu_c = 0 \ \ for\ \ all\, 1\, L \qquad (10)$$

$\mu_c \geq 0$, for all $c \in C$ (11)

Let $w^*:=(\lambda^*,\mu^*)$ be any optimal solution of this dual problem

4.2. Distributed Implementation:

The proposed routing scheme can be implemented in a distributed way which improves the scalabity of the wmn's. By using flow data rate vector[1]. In order to improve the convergence speed, in practice, different network entities (i.e., cluster heads, nodes in each cluster, and source nodes) carry out these operations asynchronously, by using currently available information. . In the following, we describe three operations in more detail when they are implemented asynchronously.

- **Link cost control**: For link cost control, the cluster head c gathers the information on the total load in the cluster c and adjusts μc to control the load on the cluster c.
- **Routing**: The link cost of link l is calculated . Since d_L is the effective transmission rate reflecting the PHY transmission rate as well as the packet error probability
- **Flow/congestion** control: the source node periodically recalculates the flow data rate by using the link costs on the active route .

By the above three operations, network-wide load balance can be achieved.

ETX Metric Design

This section describes the design of the ETX metric. The metric's overall goal is to choose routes with high end-to-end throughput. the metric suggests following issues

- The wide range of link loss ratios.
- The existence of links with asymmetric loss ratios.
- The interference between successive hops of multi-hop paths.

ETX has several important characteristics:

- ETX is based on delivery ratios, which directly affect throughput.
- ETX detects and appropriately handles asymmetry by incorporating loss ratios in each direction.
- ETX can use precise link loss ratio measurements to make fine-grained decisions between routes.
- ETX penalizes routes with more hops, which have lower throughput due to interference between different hops of the same path .
- ETX tends to minimize spectrum use, which should maximize overall system capacity.

4.3. DSR Implementation

DSR is a reactive routing protocol, in which a node issues a *route request* only when it has data to send. Route requests are flooded through the network, each node appending its own address to each request it receives, and then re-broadcasting it. Each new request includes a unique ID, which forwarders use to ensure they only forward each request once. The request originator issues new requests for the same destination after an exponentially increasing back-off time. Route requests are issued with increasing time-to-live (TTL) values, to minimize the range and cost of flooding. The destination issues a *route reply* in response to every forwarded request it receives. Each reply, which includes the route which was accumulated as the request was forwarded through the network, is source-routed back to the originator along the reverse route.

The source node chooses a route using information from the route replies it receives, and source-routes data along this route. A node runs Dijkstra's shortest-path algorithm on its link cache to find the best route to a destination. DSR uses feedback from the link layer to react to link failures. The DSR specification describes optimizations in which nodes update their link caches using data from packets they forward or "overhear".

5. CONCLUSION:

This paper introduces a new metric for multi-hop wireless networks, 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. ETX finds routes with significantly higher throughputs than a minimum hop-count metric, particularly for paths with two or more hops. The proposed scheme is a practical single-path routing scheme, unlike other multipath routing schemes which are designed by using the optimization theory. Also, the proposed scheme can easily be implemented in a distributed way by means of the existing routing algorithms.

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