A Routing Metric for Load-Balancing in Wireless Mesh Networks

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Abstract

This paper proposes a routing metric known as Weighted Cumulative Expected Transmission Time with Load Balancing (WCETT-LB) for wireless mesh networks. WCETTT-LB enhances the basic Weighted Cumulative Expected Transmission Time (WCETT) by incorporating load balancing into the routing metric. Unlike other existing schemes proposed for load balancing for wireless mesh networks, WCETT-LB implements load balancing at mesh routers. WCETT-LB provides a congestion aware routing and traffic splitting mechanism to achieve global load balancing in the network. The preliminary qualitative and quantitative analyses show the significance of the proposed scheme.

1 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. Based on the functionality of the nodes, WMNs can be classified into three categories: Infrastructure backbone, client backbone and hybrid [1, 9]. 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. The hybrid mesh network architecture is a combination of infrastructure and client meshing and is expected to be the best choice in the next generation WMNs.

Wireless mesh networks have been drawing significant attention in recent years due to their flexibility in providing extensive wireless backbone for wired backbone [6]. 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 routing algorithm therefore needs to determine routes between each traffic access point in a way that balances the load on the entire mesh network. Efficient load balancing mechanism can help in avoiding congestion and can increase the efficiency of the network resource utilization.

In order to achieve load balancing in WMNs, a suitable routing protocols should be designed. Existing schemes for load balancing in wireless mesh networks consider load balancing at the Internet gateways [8, 9, 10, 11]. This paper proposes load-balancing at mesh routers and also introduces a traffic splitting algorithm to divide the traffic among mesh routers. 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. Our proposed scheme also provides a mechanism for handling inter-flow and inter-flow interference in the network.

The rest of this paper is organized as follows: Section 2 discusses existing related work. Section 3 presents the proposed routing metric and traffic splitting algorithm. The architecture of the wireless mesh network was also presented. Section 4, presents the analysis and discussion of the simulation results. Both qualitative and quantitative results were presented. Finally, Section 5 presents conclusions and some ongoing experimental work related to the proposed scheme with the indication of future research direction.

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2 Related Work

Due to the existence of many interacting parameters such as network load, link transmission rate, intra-flow and inter-flow interferences and link dynamics, the realization of efficient routing in wireless mesh networks is a challenging problem. Load balancing in WMNs can be achieved through path-based load balancing, gateway-based load balancing or mesh router-based load balancing [5, 8, 9]. In path-based load balancing, the traffic is distributed across multiple paths. In gateway-based load balancing, the load is balanced either at all Internet gateways or at some selected gateways. Load balancing can also be carried out at the mesh routers over the wireless backbone.

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. A good metric should contain sufficient information about the link or the routing path. Each node in the network chooses the best path in terms of all the properties contained in routing metric. Recently proposed routing metrics for mesh networks include hop count, Expected Transmission count (ETX), Expected Transmission Time (ETT), Weighted Cumulative ETT (WCETT) and Metric of Interference and Channel-switching (MIC) [3, 4, 12, 13].

The hop count metric reflects only the effects of path lengths in the network. The routing metric ETX captures both the packet loss ratios and path length by counting number of MAC layer transmissions for successfully delivering a packet through a wireless link. ETT considers the differences in link transmission rate for different links in wireless mesh networks. It enhances ETX by integrating the data transmission rate of each particular link into the routing metric. WCETT is a routing metric which considers both the difference in link bandwidth and diversity of channel assignment.

WCETT enables nodes in the network to setup the best path of channel diversity and link bandwidth to IGWs. MIC [13] improves WCETT by catching both intra-flow interference within a path and inter-flow interference between adjacent paths. It considers both the channels used in the current link and in the previous link within a path. If the current link is using the same channel as its previous link, then MIC will assign a larger parameter value to the current link in order to capture the intra-flow interference within each path. In order to capture inter-flow interference, MIC also catches the set of neighbors that the transmission on each current link interferes with. Hence, packets can be routed through routers with less traffic concentration. However, all of these routing metrics do not consider load-balancing.

Multi-path routing protocols can be used to provide load balancing in wireless networks [2, 8]. In order to achieve load-balancing, each node needs to maintain multiple paths from itself to the IGWs. If the current best path is heavily loaded or congested, the node can switch to the second best path efficiently. In [8], 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. However, the scheme does not consider load balancing at mesh routers.

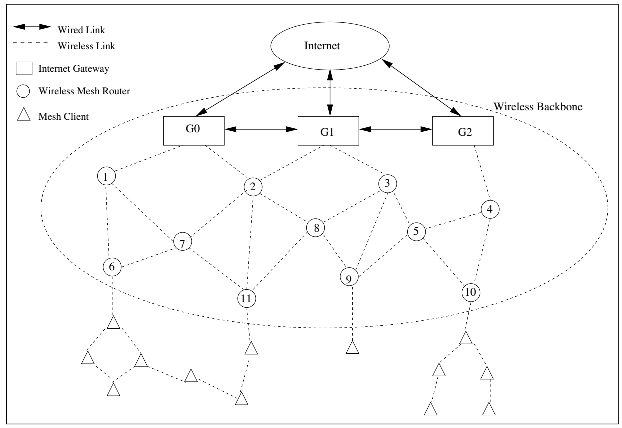

Figure 1. *A three-layer wireless mesh network architecture*

$$\sum_{node i \in p} \frac{QL_i}{b_i} \tag{1}$$

3 The Proposed Load Balancing Scheme

In this paper, we propose a routing metric and a traffic splitting algorithm to provide load balancing in WMNs. The proposed routing metric known as Weighted Cumulative Expected Transmission Time with Load Balancing (WCETT-LB) is based on the WCETT routing metric. WCETT-LB introduces load balancing feature at the mesh routers and supports global load-aware routing. The integration of a load-balancing metric to WCETT and the global congestion aware routing scheme can provide performance improvement in the entire network. Our proposed load-balancing scheme is based on the architecture shown in Figure 1. In this architecture, the upper layer is the wired Internet with the IGWs. The middle layer consists of wireless mesh routers connected to both the IGWs and entities in the third layer (mesh clients). Mesh routers connect to IGWs with wireless links. The mesh routers automatically form a wireless backbone network to provide Internet connectivity for all mesh clients. In the client layer, mesh clients can request Internet services by relaying their requests to the wireless backbone. Mesh clients can be connected

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Notation	Description
σ	Congestion level threshold for mesh routers.
δ	Load-balancing threshold for path switching in a mesh network.
N_i	Set of children nodes using node i as their next hop in paths.
G_i	Internet Gateway i in the network.
$WCETT - LB^i_{current}$	WCETT-LB of current path that node i chose to IGW.
$WCETT - LB^i_{best}$	WCETT-LB of current best path in terms of traffic load and throughput from node i to IGW.

Table 1. *Notations used in the paper*

to wireless backbone through a single hop or multi-hop routing scheme. The notations in Table 1 are defined to simplify the presentation of the protocol.

3.1 WCETT-Load Balancing Metric

In the proposed approach, we integrate load-balancing component into WCETT metric. The load-balancing component consists of two parts: congestion level and traffic concentration level at each node in a particular path. The congestion level at each node is evaluated by considering the average queue length at each nodes in a particular path. If the average queue length is higher than a threshold, then the path is heavily loaded. So, we can monitor the loads on all paths by evaluating their nodes congestion level as follows.

where QL_i is the average queue length at a node in a particular path and b_i is the transmission rate at a node. We take the fraction of the average queue length over the transmission rate to get the actual time needed for transmission. We consider the traffic concentration of each node by using N_i. So, if more children nodes choose i as their next-hop to transmit packets, the traffic at the node increases. Therefore, such a node has higher probability to become congested in the network. We normalize the value so that we can integrate the component to WCETT. This can be achieved as follows.

$$\sum_{node i \in p} \min(ETT) N_i \qquad (2)$$

The quantity $\min(ETT)$ is the smallest ETT in the network. The higher value of $\min(ETT)N_i$ indicates more traffic concentration at node N_i. We add the values of all nodes to capture the traffic concentration level in a path. Hence, this model tends to make source node choose the more independent paths in the network. Now, we formulate our routing metric for load-balancing as follow:

$$WCETT - LB(p) = WCETT(p) + L(p) \qquad (3)$$

where

$$L(p) = \sum_{node i \in p} \frac{QL_i}{b_i} + \min(ETT) N_i$$

Thus, in addition to all the features of WCETT, WCETT-LB considers the traffic concentration and congestion level at all nodes in path p. If a particular path is heavily loaded, WCETT-LB can captures this situation. It can be further combined with our global congestion aware routing to balance the load at all mesh routers in the network.

3.2 Global Congestion Aware Routing

Previous work on traffic splitting algorithm only balance the load between paths based on the neighbors' congestion level in the network. So, since the load balancing is done locally at each mesh router, packets may still be routed to highly congested nodes located further in the path. We propose a global congestion aware routing scheme to make sure that each node can be aware of the congestion level along all its paths to IGWs. Nodes can choose the best paths to balance the traffic based on the received information.

3.2.1 Congestion Aware Routing

We introduced a congestion level threshold σ to determines whether a particular node in the network is congested or not. A mesh router is said to be congested if its congestion level $\frac{QL_i}{b_i} \geq \sigma$. We use threshold σ to reduce periodic broadcasting of congestion information to the neighbors since if a node is not congested, communication with neighbors periodically results in wasting network bandwidth. The proposed algorithm let the node determine its congestion level itself reducing communication overhead. Basically, a node i will compute its own $\frac{QL_i}{b_i}$ periodically. If $\frac{QL_i}{b_i} < \sigma$, then we assume that the load is balanced at node i. But if its congestion level is greater than the σ threshold, then the node will update this information by re-computing WCETT-LB. We can achieve this by letting each node remember the old WCETT-LB from itself to IGWs during the path establishment phase. After re-computed WCETT-LB, this congested node will multicast the updated WCETT-LB routing metric to all the nodes in N_i. So, all the neighbors which are currently using node i as their next hop

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can be aware of congestion occurs in the path by receiving this information. All the nodes in N_i will further multicast this congestion information in the same fashion until this congestion information is received by edge mesh routers.

Algorithm 1 shows the congestion aware process at each mesh router. Each node determines its own congestion level by computing $\frac{QL_i}{b_i}$ periodically.

Algorithm 1

At each mesh router i:
Compute $\frac{QL_i}{b_i}$ periodically;
If($\frac{QL_i}{b_i} \geq \sigma$ at node i)
then re-compute WCETT-LB;
multicast WCETT-LB to N_i;
Else
Load is balanced at mesh router i;

As shown in algorithm 1, each mesh router has two states: congested and load-balanced. If $\frac{QL_i}{b_i} \geq \sigma$ at node i, then this mesh router is in congested state. If the average queue length of this mesh router is back to normal load level, then the mesh router will notify its recovery to all its previous child nodes.

3.2.2 Load Balancing

Each time an edge mesh router receives updated WCETT-LB from its neighbor, it knows that congestion occurs in its path toward IGW. The global congestion awareness routing allows the mesh router to balance the load along all its paths. The mesh router can either choose to stay on current path or switch to other path that have better performance. Algorithm 2 shows the path switching process at each mesh router and it is used to determine the network load. Each node compares $WCETTLB^i_{current}$ with $WCETTLB^i_{best}$ after it receives updated WCETT-LB. If $(WCETTLB^i_{current} - WCETTLB^i_{best}) \geq \delta$, then the mesh router will switch from the current path to the new best path. Otherwise, the mesh router can chose to stay on the current path.

Algorithm 2

At each edge mesh router i:
If i received updated WCETT-LB
and $(WCETTLB^i_{current} - WCETTLB^i_{best}) \geq \delta$
then switching is made
Else
Load is balanced in all the paths at mesh router i;

There are two main advantages of the control parameter δ. It prevents mesh routers from frequently switching paths back and forth. If the mesh router switches paths each time when it receives WCETT-LB, then the mesh router will be in a situation that keep switching between paths at all time when the load slightly oscillates. This will decrease network performance dramatically. Furthermore, δ prevents pulling all the traffic away from the congested nodes. If all edge mesh routers choose to switch to other paths then, there may be no traffic through the congested node. This is not a desirable load balancing approach. Hence, by using the parameter δ, some of the edge mesh routers can switch to other path if the new path is better than the current path.

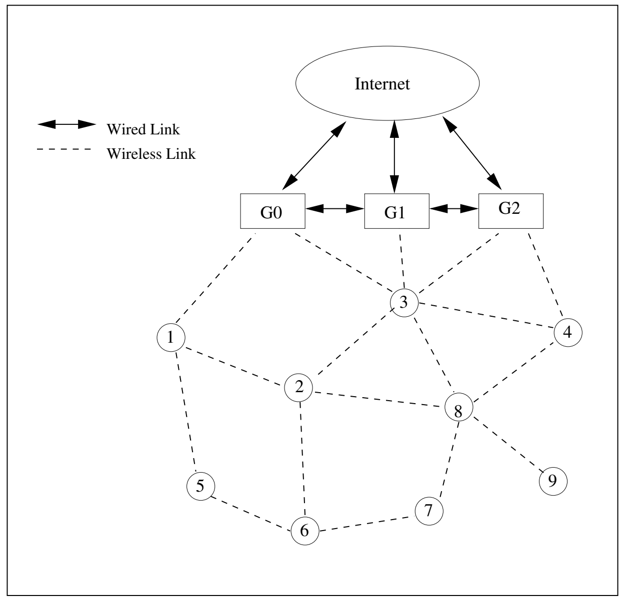

Figure 2. *An example wireless mesh network.*

We now illustrate the operation of our protocol using an example. Consider a wireless mesh network architecture in Figure 2. The network consists of three gateways G0, G1 and G2 and nine mesh routers 1-9. Mesh router 1 and mesh router 3 are connected to G0. Mesh router 3 is also connected to G1. Mesh router 3 and mesh router 4 are connected to G2. Instead of using other routing metric, we use our WCETT-LB to setup paths. So, mesh router 8 will choose mesh router 4 as its next-hop, since mesh router 2 and mesh router 3 may have more concentrated incoming traffic and they have higher probability of congestion.

After path establishment phase, mesh router 6 has two paths to IGWs, 6-2-3 and 6-5-1 where and 6-2-3 is the default path. Mesh router 9 has two paths to IGWs, 9-8-3 and 9-8-4 where 9-8-3 is the default path. Now, if we assume that mesh router 3 is congested. Then, mesh router 3 will re-compute WCETT-LB and multicast the

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Routing Metrics	LB	Inter-FTI	Intra-FTI
ETT	No	No	No
WCETT	No	No	Yes
MIC	No	Yes	Yes
WCETT-LB	Yes	Yes	Yes

Table 2. *Comparison of existing routing metrics.*

routing information to mesh router 2 and Mesh router 8. Mesh router 2 and mesh router 8 will further pass this information to mesh router 6 and mesh router 9. mesh router 6 and mesh router 9 will decide to stay on the current path or switch to another path by comparing the congested path with the second best path. In this case, mesh router 6 may choose to stay on the current path and mesh router 9 may choose to switch to the path path 9-8-4 if the difference is greater to the threshold.

If mesh router 5 and mesh router 2 are also congested in future time, then mesh router 6 can choose the best path based on global congestion awareness. It will select the least congested path, since the path 6-2-3 could be highly congested. Therefore, load balancing can be achieved in the network.

4 The analysis and discussion of simulation results

Since our load-balancing routing metric WCETT-LB integrates load-balancing component into traditional WCETT, we preserve all the features and properties of WCETT. The load-balancing component enhances the performance of WCETT by considering traffic congestion. Our global congestion aware routing also enhances several features of congestion aware routing protocol proposed in [8]. In our scheme each node receives the congestion information along all its paths to IGWs. Introducing the load-balancing threshold δ in our algorithm can prevent mesh routers from frequently switching paths back and forth (i.e. ping-pong effect). Another advantage is that our algorithm allows each node to determine its congestion level instead of periodically sending the average queue length to its neighbors. This can greatly reduce traffic overhead in the network and improve the network performance.

We compared our load-balancing routing metric with the other three existing metric through a qualitative measures as shown in Table 2. Four routing metrics and three parameters namely, load-balancing (LB), Inter-flow interference (Inter-FTI), intra-flow traffic (Intra-FTI) were used. Among all these routing metrics, only WCETT-LB considers load-balancing in the network. The rest of the metrics do not consider load in each path which is an important parameter for network performance. It can be noted that only MIC and WCETT-LB metrics capture the inter-flow interferences between paths in the

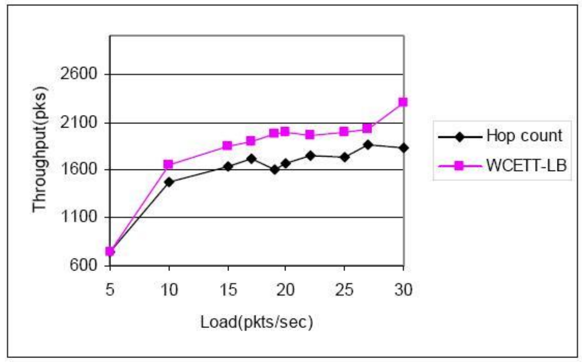

Figure 3. *Total network throughput*

network. Although WCETT-LB does not directly consider the inter-flow interference, it can be easily adapted to catch the interference between nodes. Furthermore, for intra-flow interferences WCETT, MIC and WCETT-LB metrics perform well. They consider the interference within each path. The other possible parameter is isotonic property of each routing metric. Only ETT is isotonic, but it performs poor with respect to other parameters. MIC is not directly isotonic, but it has been shown to be isotonic by introducing virtual nodes. Our load-balancing metric is isotonic, so it can be integrated with other isotonic routing metric. Overall results show that our WCETT-LB is the only metric that addresses all the metrics load-balancing, inter-flow interference and intra-flow interferences.

We have also performed preliminary quantitative experiments. To this end, the performance of our proposed routing metric was evaluated using NS2 [7] simulation tool. Two performance metrics namely, total network throughput and average end-to-end delay were used in the experiments. In this paper we present the experimental results that compare WCETT-LB with hop count. The simulation environment consisted of three IGWs, 80 nodes with 10 traffic flow sources. The simulation was conducted in an area of 1500 X 1500 square units. Due to the nature of wireless mesh network traffic, all traffic flows were intended to or from the IGWs. The Constant Bit Rate (CBR) traffic source were used. We set the CBR packet size to 512 bytes. The transmission range was 250m with 550m carrier sensing range.

Each data point in the graphical results was based on 10 simulations each with load varied between 5 packets per second and 30 packets per second. Figure 3 shows the total network throughput as a function of network load. Hop count has a dramatic drop of packets when hop spots occur in the network while WCETT-LB shows a steady increasing in the network throughput. The throughput gain looks better at higher network

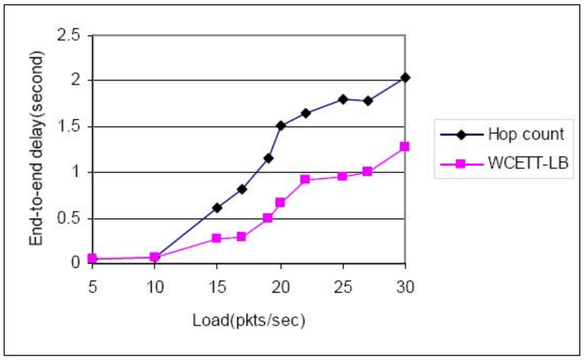

Figure 4. *Average end-to-end delay*

load. However, further experiment is needed to confirm and validate the results. Figure 4 shows the simulation results for experiments on end-to-end delay. The results confirm that WCETT-LB has much lower end-to-end delay to IGWs than hop count. The performance gain increases with increase in the network load which suggests its suitability for providing a scalable solution.

5 Conclusions and Future Work

In this paper, we proposed a routing metric for load balancing over multiple paths in wireless mesh networks. We also proposed a traffic splitting algorithm to divide the traffic among mesh routers. The basic features of the proposed scheme were described and compared with existing similar schemes qualitatively and qualitatively. The quantitative evaluation was carried out in a simulation settings using NS2 simulation tool. Further experimental evaluation is being carried out to compare WCETT-LB with all other similar metrics. We are also investigating the effect of the values of the thresholds for the parameters σ and δ on the over all network performance. Future work includes the extension of the proposed scheme for load balancing in the presence of the inter-domain mobility and in multi-radio and multi-channel network environment.

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