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LAmETx: The New Routing Metric with Load Balancing in WMNs

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Abstract: Wireless Mesh Network (WMN) is a multi-hop mesh network that consists of mesh routers and mesh clients, where mesh routers are static and form the backbone of the mesh network. The static nature of mesh nodes imposes requirements for designing routing metrics that support high throughput and low packet delay. This paper provides a comprehensive survey of various routing metrics that have been proposed for wireless mesh networks and a new routing metrics have been proposed. The literal of this metric is to route the traffic through congestion free areas and balance the load amongst the network nodes. We integrate this new metric in the well known OLSR routing protocol and study the performance of LAmETx through simulations. We show that the proposed metric is able to adapt to changes in load balancing traffic better than existing link metrics such as ETX. We also demonstrate that our metric delivers high-throughput and low delay. Avoidance of congestion at nodes, high throughput, low levels of interference, isotonicity, efficient utilization of channel capacity, minimal transmission delay are some of the desired characteristics of a good routing metric for wireless mesh networks.

Key words: Wireless mesh network · IEEE 802.11s · Deployment design · Performance of metric and Multipath

INTRODUCTION

Wireless Mesh Networks (WMNs) [1-4] have emerged recently as a promising technology for next-generation wireless networking to provide better services. A WMN consists of two types of nodes: mesh routers and mesh clients. Mesh routers form the backbone and they have minimal mobility which guarantees high connectivity, robustness, etc. The mesh client nodes can be stationary or mobile. A simple example of Wireless Mesh Network is presented in Fig. 1. Like ad hoc networks, each node operates not only as host but also as router, forwarding packets to and from an Internet- connected gateway in a multi-hop fashion. Wireless Mesh Networks are considered as a type of ad hoc networks.

But, because the aim of WMN is to diversify the capabilities of the ad hoc network, more sophisticated algorithms and design principles are required for the realization of WMNs. Some of the differences between WMNs and ad hoc networks are outlined below (1). The mesh routers in WMN form the backbone which provides large coverage, connectivity and robustness. But in ad hoc networks, the connectivity depends on the individual contribution of end-users. (2) The gateway and bridging functionalities in mesh routers provide the integration of WMN's with other networks such as Internet, cellular, IEEE 802.11, IEEE 802.15, IEEE 802.16 and sensor networks. Unlike ad hoc networks, the routing and configuration functionalities of the mesh routers reduces the load on end- user devices. (3) The mesh routers can be equipped with multiple radios to perform routing and access functionalities which improves the capacity of the network. On the other hand, ad hoc networks use same channel for routing, network access, etc.which result in poor performance. (4) Unlike in WMNs, we run into several challenges with routing protocols, network configuration and deployment in ad hoc networks because its topology depends on the movement of users.

The mesh network is dynamically self-organizing and self configuring, with the nodes in the network automatically establishing and maintaining connectivity among themselves. These features provide many advantages for WMN's like good reliability, market coverage, scalability and low upfront cost. WMN gained significant attention because of the numerous

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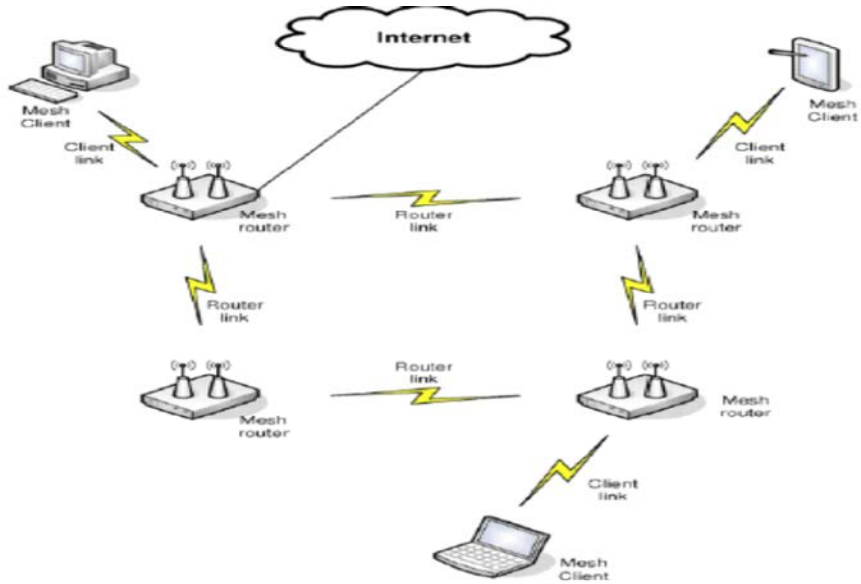

Fig. 1: Wireless Mesh Network with mesh routers and mesh clients. Mesh routers are static and form the backbone of the network whereas mesh clients can be static or mobile. Mesh clients rely on mesh routers to forward the data to destination.

applications it supports, e.g. broadband home networking, community and neighborhood networks, delivering video, building automation, in entertainment and sporting venues, etc.

Research Contributions: In wireless mesh networks, each mesh node is equipped with multiple radio interfaces and a subset of nodes serve as Internet gateways, wherein, we'll treat the problem of interference aware routing in multi-radio infrastructure mesh networks. We concentrate on the centre node load balancing and investigate a way to obtain the centre node load balancing using a routing metric.

We present our new routing metric" LAmETx" that aids in finding for reducing the load balancing. We integrate this metric and new support for multi-radio networks in OLSR routing protocol to design an enhanced LAmETx-OLSR routing protocol.

Outline of the Paper: In our paper, we specify a good routing metric for routing protocols in WMNs. Rest of our document is organized as follows: i. we draft the characteristics of a good routing metric ii. A survey of routing protocols used in WMNs iii.We summarizes the performance of the metric iv. Overview report on each of the routing metric we have studied and we present our new routing metrics we have proposed in this paper. v. Section 5 describes the simulation setup and the performance results. vi.Section 6 results and discussions vii.Finally, we cover conclusion and scope for future work.

Characteristics of Routing Metrics

Interference: Interference in a mesh network can be of three types: Intra-Flow Interference, Inter-Flow Interference and External interference.

Locality of Information: Some metrics require information such as channels used on previous hops of a path, or other metrics observed on other nodes of the networks, such as packet delivery rate or noise levels. This non-local information can be part of routing metric and can be used to make more optimal routing decisions.

Load Balancing: The ability of a metric to balance load and provide fairer usage of the networks distributed resources.

Agility: The agility of a metric refers to its ability to respond quickly and efficiently to changes in the network in terms of topology or load. In order for a metric to be considered agile, the rate at which measurements are taken should be higher than the rate of change in the network.

Isotonicity: The isotonic property of a routing metric means that a metric should ensure that the order of weights of two paths is preserved if they are appended or prefixed by a common third path.

Throughput: In general, a metric should be able to select routes with greater throughput consistently.

Routing Protocols Using for Wireless Mesh Networks: Destination Source-Routing Protocol (DSR) [5]: Is an on-demand routing protocol that is based on concept of source routing. In source routing algorithm, each data packet contains complete routing information to reach its destination. Nodes are required to maintain route caches that contain source routes of which the node is aware. There are two major phases in DSR; the route discovery and route maintenance. For route discovery, the source node broadcasts a route request message which contains the address of the destination, along with source nodes address and a unique identification number. Every node which receives this packet checks if it has route information to destination. If not, it appends its own address to route record of the packet and forwards the packet to its neighbors.

Destination Sequence Distance Vector Routing Protocol (DSDV) [6]: Is a proactive unicast routing protocol based on classical Bellman-Ford routing mechanism. Every node in the network has a routing table which contains information on all possible destinations within the network. Sequence numbers are used to distinguish stale routes from fresh ones. To maintain consistency, routing table updates are periodically transmitted throughout the network. If two updates have same sequence number, the path with smaller metric is used in order to optimize the path. DSDV protocol only supports bi- directional links.

Ad-hoc On-Demand Distance Vector Routing Protocol (Aodv) [7]: Is a reactive on- demand routing protocol which builds on both DSR and DSDV. AODV is an improvement on DSDV as it minimizes the number of required broadcasts by creating routes on demand basis. It is also an improvement on DSR as a node only needs to maintain routing information about the source and destination as well as next hop, thereby largely cuts back the traffic overhead. The process of route discovery is similar to DSR. Route request (RREQ) packets are broadcasted for route discovery while route reply (RREP) packets are used when active routes towards destination are found. HELLO messages are broadcasted periodically from each node to its neighbors, informing them about their existence.

Performance Metric: In this section, we use the performance metrics which are Average multicast packet delivery ratio, average throughput, average end-to-end delay, average jitter, Average unicast packet delivery ratio, Average path length and Number of forwarding nodes in the simulation to measure the performance of a multicast routing protocol. We show the explanation of these performance metrics as follows.

Average Multicast Packet Delivery Ratio: The packet delivery ratio (PDR) of a receiver is the number of data packets actually delivered to the receiver versus the number of data packets supposed to be received. The average PDR of a multicast group is the average of the PDRs of all the receivers in the group.

Average End-to-end Delay: The end-to-end delay of every packet received at every receiver is recorded; the average over all the packets received is then computed.

Average Throughput: The throughput is defined as the total amount of data a receiver actually receives divided by the time between receiving the first packet and the last packet. The average taken over all the receivers is the average throughput of the multicast group, assuming that each group has one sender.

Average Delay Jitter: Delay jitter is the variation (difference) of the inter-arrival intervals from one packet received to the next packet received. The per-receiver delay jitter at a receiver is the sum of all the absolute values of delay jitters from the first packet received to the last packet received divided by the total number of packets received. The average delay jitter is the average of the per-receiver delay jitters taken over all the receivers.

Average Unicast Packet Delivery Ratio: To measure the impacts of multicast data traffic on the PDRs of unicast flows in a network, we recorded the PDR of every unicast flow and then took the average over all the unicast flows.

Average Path Length: The path length (or the hop count) is an indirect indicator of performance: in general, the longer a path, the higher the packet loss rate of a flow and the longer the end-to-end delay. The average path length is the average of the lengths of all source-to-destination paths in a multicast tree.

Number of Forwarding Nodes: The number of forwarding nodes in a multicast tree is also an indirect indicator of performance: the lower the number, the less network bandwidth consumed by the multicast group (i.e. the wireless broadcast advantage). This affects the packet delivery ratios of the multicast group as well as of other flows in the network.

Conception for Our New Routing Metric LamETx: In order to have a better understanding of the routing metrics, in this section, we describe the different routing metrics which are incorporated in wireless mesh networks to find best possible paths.

Need for a New Routing Metric: Routing protocol provides one or more network paths over which packets can be routed to the destination. The routing protocol computes such paths to meet criteria such as minimum delay, maximum data rate, minimum path length etc. The design of routing metrics for wireless mesh networks is stimulating due to following three unique characteristics of wireless links:

Time Varying Channels and Resulting Variable Packet Loss: The wireless links suffer from short term and long term fading and result in varying packet loss over different time scales. When the distance between the communicating nodes is large or if environment is obstacle rich and causes fading, the loss ratio of the link can be high. A routing metric should accurately capture this time varying packet loss.

Packet Transmission Rate: The packet transmission rate (or data rate) may vary depending upon the underlying physical layer technology. For example, 802.11a links have high data rate compared to 802.11b links. The data rate may also vary depending on the link loss characteristics when auto-rate control algorithms are used.

Interference: Wireless links operating in unlicensed spectrum suffer from two kinds of interference:

Uncontrolled Interference: Results from non-cooperating entities external to the network that use the same frequency band but do not participate in the MAC protocol used by network nodes. For example, microwave ovens, Bluetooth devices operating in 2.4GHz ISM bands interfere with 802.11b/g networks in the same band.

Controlled Interference: This kind of interference results from broadcast nature of wireless links where a transmission in one link in the network interferes with the transmissions in neighboring links. The interference of this kind depends on factors such as the topology of the network, traffic on neighboring links etc. It is well known that interference seriously affects the capacity of wireless networks in a multi-hop setting. It is important for a routing metric to capture the potential interference experienced by the links to find paths that suffer less interference and improve the overall network capacity. Interference can be intra-path, wherein transmissions on different links in a path interfere or inter-path interference or inter-path wherein, transmissions on links in separate paths interfere. A more channel diverse multi-hop path has less intra-flow interference which increases the throughput along the path as more links can operate simultaneously if they operate on different orthogonal channels.

A good routing metric should find paths with component links that have low loss ratio, high data rate and experience low levels of interference. In the following, we give an overview of the various routing metrics proposed for multi-hop wireless mesh networks in the literature and discuss their limitations.

Hop Count: Hop count is the traditional routing metric used in most of the common routing protocols (AODV, DSR and DSDV) designed for multi-hop wireless networks. This metric treats all links in the network to be alike and finds paths with the shortest number of hops. It also does not account for data rate and interference experienced by the links. This can often result in paths which have high loss ratio and therefore, poor performance.

Expected Transmission Count (ETX) [8, 9, 10]: Is a metric to estimate the expected number of MAC layer transmissions for the wireless links and measure the packet loss rate which is proposed by De Couto *et al*.

$$P = (1 - pf) \times (1 - pr) \tag{1}$$

Where pf is the probability of successful forwarded packets and pr denotes the probability of successful received packets. The advantages of ETX are the reduced probing overhead and non self-interference as the delay is not measured.

Expected Transmission Time (ETT) [11, 12]: Measures the MAC layer transmission time of a packet over a link l. It considers the impact of link transmission rate and packet size so as to improve the performance of ETX. The relation between ETT and ETX is formulated as follows:

$$ETTl = \frac{(ETTl \times s)}{bl} \tag{2}$$

Where

S: is the packet size
Bl: is the bandwidth of link l.

Weighted Cumulative ETT (WCETT) [11]: Is also proposed by Draves *et al*. and it considers the multi-radio nature of the WMNs in two components: the total transmission time along all hops in the WMN and the channel diversity in the path.

The WCETT of a path p is:

$$WCETT(r) = (1 - p)ETTl + p\max_{1 \le j \le k} Xj \tag{3}$$

Where:

Xj is the number of times that channel j used by path r.
p is a parameter as 0 =p =1.

$$WCETT(r) = (1 - p)ETTl + p\max_{1 \le j \le k} Xj \tag{4}$$

In [6], the authors propose MIC which improves upon WCETT by considering inter-flow interference. MIC for a path p is defined as follows:

$$MIC = \frac{1}{N}\min(ETT)\sum_{linkl \in p} IRUl + \sum_{nodei \in p} CSi \tag{5}$$

Where

N is the total number of nodes in the network.
The two components IRU and CSC are defined as follows:

$$IRUl = ETTl \times Nl \tag{6}$$

$$CSCi = \begin{cases} \omega 1 \text{ if } CH(prev(i)) \ne CH(i) \\ \omega 2 \text{ if } CH(prev(i)) = CH(i) \end{cases} \tag{7}$$

$$0 \le \omega 1 < \omega 2 \tag{8}$$

Where

- Nl is the set of neighbors that interfere with the transmissions on link l.
- CH(i) represents the channel assigned for node is transmission. prev (i) represents the previous hop of node i along s the path p.

Our New Routing Metric: LAmETx is a new metric which is based on the existing routing metrics such as ETx. The path metric of LAmETx is defined as follows:

$$LAmETx = \exp\left[\frac{ETX + \frac{\mu}{2}}{1000}\right] + nb\,L(P) \tag{9}$$

Where,

ETX: Expected Transmission Count metric
µ: Estimated average packet loss ratio of a link.
nb L (P): is the number of traffic load.

Explanation:

- In LAmETx metric, we first calculate the ETX values of all the links in the path.
- This ETX value considers the link quality, remaining capacity and packet size into consideration.
- For any link in the path, the ETX value of the link is summation of all the ETX values of links which are in the interference set (IS) of this link.

Performance and Evaluation: The proposed metric was incorporated in the OLSR implementation in ns2 [14]. The performance of the proposed LAmETx is compared with ETX and The OLSR standard using ns2. The performance is evaluated in terms of network throughput, average delay, packet loss rate, sensitivity of metric to varying interfering traffic and routing overhead. In the case of Wireless Mesh Networks energy constraint is not an issue [1] and hence we have not discussed it in this article.

Simulations Environments: Our proposal is experienced under network simulator NS2 [14] (Network Simulator) 2.35 version in which we have integrated a standard version of OLSR (UM-OLSR-1.0 [15, 16]), which is developed by MASIMUM (MANET Simulation and Implementation at the University of Murcia).

Simulation Setup: Our simulation parameters are as follow. For all simulations, our network is consisted of a maximum number of mobile nodes (60) whose radio scoop is 250 m, moving in an area of 1000 × 1000m2. Each node moves according to the RWP (Random Waypoint) mobility model [17] with pause time fixed to 0 second and maximum speed that varies between 5 and 30 meter/second with step of 5 and a fixed CBR traffic in the first scenario and maximum CBR traffic that varies between 5 and 20 XX with step of 5 and a fixed speed.

The scenario that defines the nodes movement is regenerated at the beginning of each simulation. To generate traffic in the network, in each simulation, 1/5 of nodes are randomly selected to be a source of CBR (Constant Bit Rate) traffic. We set the CBR packet size to 512 bytes. And these selected nodes use UDP (User Datagram Protocol) connections to send Packets with 1024 bytes of size such that one packet every 2.5 second is sent. Table 1 summarizes all the parameters used during simulations.

Table 1: Simulation Parameters

Simulation environment	Option and parameter
Flat size	1000mx1000m
Maxim number of nodes	60 nodes
Radio scope	250 m
Mac layer	IEEE.802.11. peer mode Transport layer
Transport layer	User Datagram Protocol (UDP)
Traffic model used	CBR
Package size	1024 bytes
Rate	0.4
The number of connections	1/5 of the number of nodes
Mobility model	RWP (Random Waypoint)
Pause time	0 second
Maximum speed of nodes	5,10,15,20,25,30
Maximum CBR traffic of nodes	5,10,15,20
Simulations time	250sec

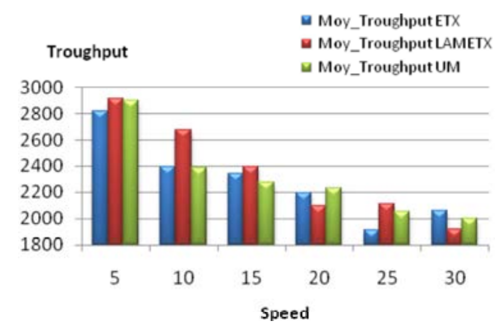

Fig. 2a: Avg- Throughput CBR=5 varied Speed

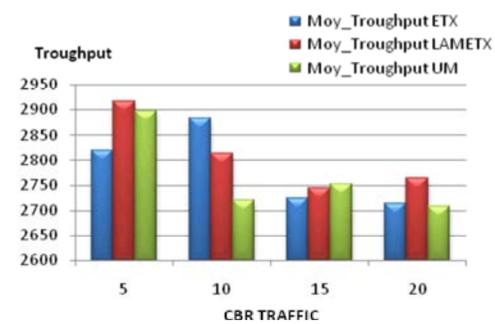

Fig. 2b: Avg-Throughput Speed=5 varied CBR

RESULTS AND DISCUSSIONS

We compare the performance of LAmETx, metrics implemented in OLSR with ETX and UM OLSR. All measurements are presented with 100% confidence intervals represented in the figures by vertical bars. Through a qualitative measures as shown in Table 1. Three 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 LAmETx 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 LAmETx metric capture the inter-flow interferences between paths in the network. Three performances metrics namely, total network Throughput, average end-to-end Delay and Packet Delivery Rate were used in the experiments.

Figures 2.a. and 2.b. plot the average Moy-Throughput for each metric that show that the LAmETx has the higher throughput with 99%. This metric is designed to select the higher throughput better than ETX and UM -OLSR.

Figures 3.a. and 3.b. plot the average-Delay for each metric. These figures show that LAmETx metric have a lower delay than ETX and UM-OLSR.

Figures 4 plot the average Packet Delivery Rate for each metric. The Packet Delivery Rate produced with the LAmETx metric is the lowest among the ETX and UM-OLSR. Although such fact results in a higher number of medium accesses, the route links have better quality and send packets using higher physical rates. This explains the lower Packet Delivery Rate for LAMETX metric. As the packet size increases, the Packet Delivery Rate also increases.

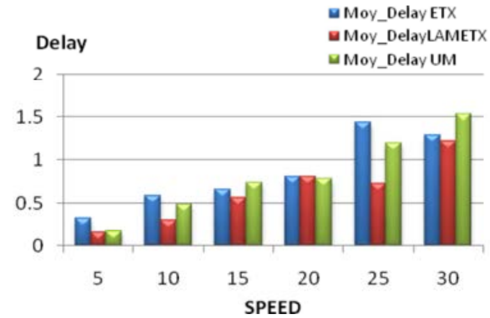

Fig. 3 a: Avg- Delay CBR=5 varied Speed

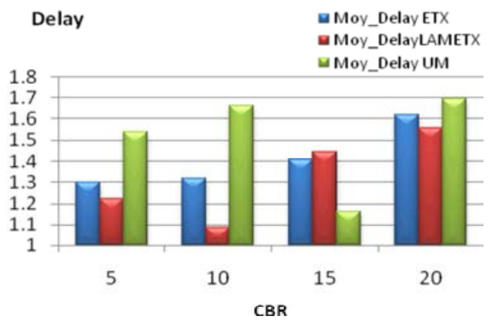

Fig. 3 b: Avg-Delay Speed=30 varied CBR

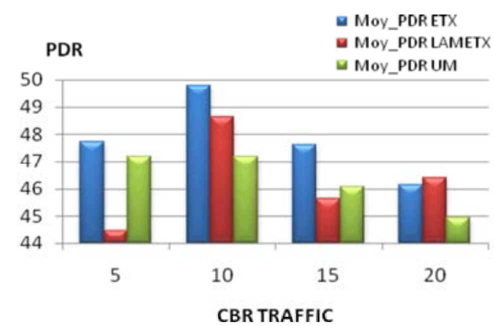

Fig. 4: Avg-PDR Speed=30 varied CBR

Conclusions and Future Works: We presented a new Routing Metric with Interference Aware (LAmETx) that ensures the high throughput, lower packet delivery ratio and aids in finding paths that are better in terms of reduced inter-flow and intra-flow interference.

We integrated this metric and new support for multi-radio networks in the well known OLSR routing protocol to design an enhanced OLSR-LAmETx routing protocol.

As future work, we propose to implement LAmETx in OLSR routing protocol with varied number of nodes and we trait the problem of throughput, delay, load-balancing (LB), Inter-flow interference (Inter-FTI) and intra-flow traffic (Intra-FTI) in multi radio infrastructure mesh networks wherein each mesh node well equipped with multiple radio interfaces.

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