Comparison of Routing Metrics for Wireless Mesh Networks

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Abstract-A number of routing metrics exist in wireless networks. These routing metrics were originally designed for mobile ad hoc networks (MANETs). When Wireless Mesh Networks (WMNs) came into being, an idea of introducing and using these routing metrics for WMNs was considered. The problem that arises is that these routing metrics have not been proven whether they work best in WMNs. These routing metrics have to be compared before they can be used in WMNs, so as to choose the best routing metric for WMNs among existing routing metrics before designing new one. There are works in the literature that compare the routing metrics, but the comparisons are not done a consistent manner. The main aim of this paper is to compare the routing metrics in a consistent manner. This paper simulates four routing metrics in NS2, with Ad hoc On Demand Vector (AODV) protocol as a routing protocol. After the routing metrics have been simulated, the results of the simulation are compared to see which routing metric performed best. From the evaluation, design criteria for an ideal routing metric for WMNs are recommended.

Index Terms — WMNs, AODV, routing protocol, routing metric, node.

I. INTRODUCTION

Wireless mesh networks are dynamically self-organized and self-configured; with the nodes in the network automatically establishing an ad hoc network and maintaining the mesh connectivity, they are usually comprised of three types of nodes: mesh clients, mesh routers, and gateway (see Figure 1) [1]. Nodes do not operate only as hosts but can also operate as mesh routers, mesh clients, or a gateway. An assumption that is made in WMNs is that not all nodes can directly communicate with any other node; relay nodes are used to pass packets across the network [2].

WMNs can be used in community networks, enterprise networks, home networks, and local area networks (LAN) for hotels, parks and trains. They can be used as well in metropolitan area networks. WMNs can also be used in ad hoc deployment of LAN such as public safety, rescue and recovery operation. There are challenges that still face WMNs.

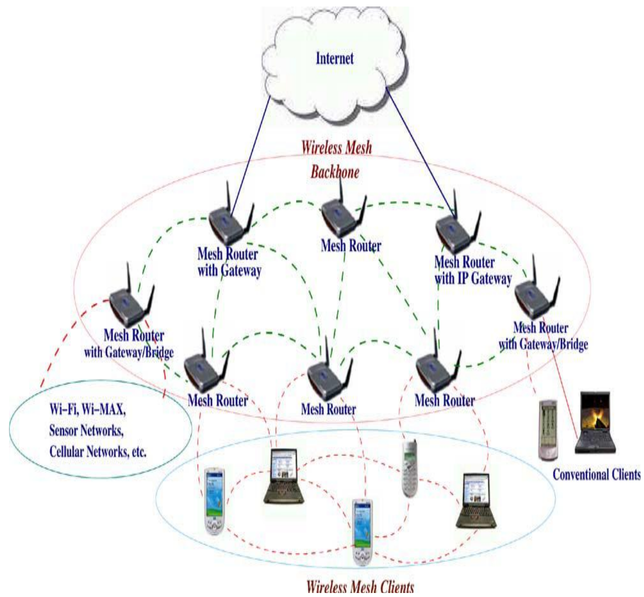

Figure 1: A typical example of WMNs [1]

One of the challenges is the provision of Quality of Service (QoS) functionalities to the network. QoS is the collective effect of service performance which determines the degree of satisfaction of a user of the service [3]. The process of selecting the optimal path through which to send a packet is called routing. Routing is performed in each and every relay node so as to find the next hop for the packet. A routing metric is simply a measure used for selecting the best path, used by a routing protocol. Figure 2 shows the relationship between a routing protocol and the routing metric in fulfilling the process of routing. There is a need to find out which routing metric is best for WMN among the existing routing metrics.

The existing routing metrics have not been compared with QoS parameters, therefore they need to be compared and find out if they can work in WMNs, if so which one works best. If they can work in WMNs, they will solve the problem of routing in WMNs. If these routing metrics do not work for WMNs, there will still be a need for a new routing metric that will work best in WMNs.

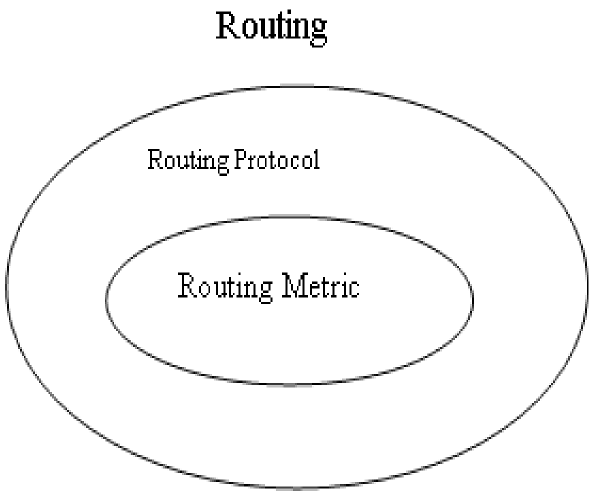

Figure 2: The relationship between routing protocol and a routing metric

We simulated four routing metrics in NS2 simulation tool. Setting up a network is more expensive than using NS2 simulation because there is a need to buy wireless nodes while NS2 is open source, hence free to download and install. It is not easy to extend the network when using the test bed because the space might be limited to the size of the room if it is deployed inside a room while simulations in NS2 are scalable enough since they do not depend on the size of the room and there are no costs of buying the nodes.

The remainder of this paper is organized as follows. Section II discusses four routing metrics that were compared in this paper. Section III presents and discusses work done by other scholars in comparing the routing metrics for WMNs. Section IV describes NS2 simulation environment and setup. Section V discusses the results of the simulation and comparisons of routing metrics, while section VI presents the proposed design criteria for an ideal routing metric for WMNs. The future enhancements of this work are presented in section VII while section VIII concludes this paper.

II. BACKGROUND

In this paper, we reviewed up to twenty routing metrics, but only the four selected routing metrics were discussed in this paper (sees Table 1). Routing metrics were firstly grouped into four groups: shortest path-based, packet loss ratio-based, delay-based, and interference. Only one routing metric was selected to represent each group, since we could not simulate all the twenty routing metrics. The selection of a routing metric in a group was based on its QoS-awareness level. The routing metrics that considered QoS the most were selected from each group. This section discusses the four routing metrics that were compared in this paper, which are: hop count (HOP), expected transmission count (ETX), per hop round trip time (RTT), and exclusive expected transmission time (EETT).

Shortest Path	Packet Loss Rate	Delay	Interference
HOP	ETX	PktPair	WCETT
	mETX	RTT	MIC
	ENT	ETT	iAWARE
	iETT	MCR	EETT
	MM	PPTT	ILA
	Routing metric for BATMAN	AETD	
		Airtime link metric	
		WCETT-LB	

Table 1: Group of existing routing metrics [4]

The routing metrics were firstly analyzed and compared among themselves in a group (see table 1) so as to come up with one routing metric from every group. The first group only had one routing metric (hop count), it there for gained automatic selection.

A. Hop Count (HOP)

Hop Count [5] is a legendary routing metric that has been used by traditional routing protocols. It uses the shortest path to select the best route to send packets. The link quality for HOP is a binary concept; it is either the link exists or it does not exist. The obvious advantage of this metric is its simplicity. The disadvantage is that it does not take packet loss and bandwidth into account [6]. Research has proven [7] that the route that uses HOP does not necessary maximize throughput of a flow. It worked for wired networks, but has been criticized in wireless networks.

B. Expected Transmission Count (ETX)

ETX [6] estimates the number of transmissions (including retransmissions) needed to send unicast packets by measuring the loss rate of broadcast packets between pairs of neighboring nodes. It improves from HOP count by taking packet loss rate into consideration. One of the disadvantages of this routing metric is that it still does not directly cater for link load or data rate [7].

C. Per-hop Round Trip Time (RTT)

RTT [8] measures the round trip delay seen by unicast probes between neighboring nodes. The RTT metric measures several facets of link quality. The RTT metric is designed to avoid highly loaded or loss links. Since RTT is a load-dependent metric, it can lead to route instability. This metric has disadvantages as well. First, there is the overhead of measuring the round trip time. Finally, this measurement technique requires that every pair of neighboring nodes probe each other.

D. Exclusive Expected Transmission Time (EETT)

EETT [9] is used to give a better evaluation of a multi-channel path. EETT of a link l represents the busy degree of the channel used by link l. path with a larger EETT indicates that, it has a more severe interference and needs more time to finish the transmission over all links within the path.

Section III presents the literature survey on the existing comparisons of routing metrics for wireless mesh networks. Two works discussed from the literature. The two works are worth looking at because they compare a number of routing metrics, which is similar to what is done in this paper.

III. LITERATURE REVIEW

This section discusses two works that have compared the routing metrics for WMNs from the literature. The first work [10] discussed five existing routing metrics; HOP, ETX, ETT, WCETT, and MIC. Out of the five routing metrics that were discussed, only results of four routing metrics were shown, it is not clear whether ETX was simulated since its results are not there. It was not clear whether one routing protocol was used for all the simulations that were conducted in this work.

Same performance metrics (maximum channel utilization, network throughput, end-to-end packet delay) were used to measure the performance of all the routing metrics that were considered. Authors in this work randomly generated 10 networks with 100 nodes and 10 networks with 160 for the experiments, and we feel that they should have varied the network size rather than using only two network sizes (100 and 160). MIC outperformed all the other routing metrics that it was simulated with, while HOP was the worst performer.

Work by [11] started off by classifying ten different routing metrics that were designed for diverse quality of service (QoS) parameters in WMNs into three groups. The authors did not provide any results from the experiments to back their theoretical analysis of the routing metrics. Our own work compares four different routing metrics in a consistent manner by using the same routing protocol (AODV) [12], same performance metrics, same simulation environment, and same network sizes for all routing metrics that were simulated for comparison.

Section IV presents the actual simulation of the four routing metrics that were compared in this paper. The routing metrics were simulated in the wireless mesh network setup.

IV. SIMULATION

We simulated our routing metrics in ns2 version 2.34 simulation tool, run on ubuntu version 9.04. In our simulations, we checked the effect of network size on the three performance metrics (delay, delay jitter, and packet loss rate) that we use for our evaluation. We also checked the effect of time on throughput as the fourth performance metric. We used AODV as our routing protocol, while we use HOP, ETX, RTT, and EETT as our routing metrics for our simulation. A square grid topology was used to place the nodes while all the nodes were kept stationary as we were simulating the topology of a WMN which uses stationary nodes.

A square grid topology provided a consistent comparison because each node was at the same position for all the simulations, unlike if the topology is random, the positioning of the nodes changes. The main aim of this work is to compare routing metrics in a consistent manner; the square grid helps us achieve this goal since the positioning of the nodes is exactly the same for all the simulation of different routing metrics. The network size was varied from 9 up to 196 as shown in table 2. The network is kept at 1500m x 1500m for the duration of all simulations. Section V presents the graphical presentation and discussion of the results from the simulation of the four routing metrics discussed in section II. Our simulation measured four performance metrics: delay, delay jitter, packet loss ratio, and throughput. This performance metrics are the most used performance metrics when evaluating the performance of routing metrics in WMNs, this is the reason we also measured them in our evaluation.

V. RESULTS DISCUSSION

Figure 3 presents the graphical representation of the effect of network size on the average network delay. The best routing metric among the four routing metrics that are compared, must have the lowest average delay, while the worst routing metrics have the highest average delay. RTT outperformed all the four routing metrics that were compared in this work, while the second best routing metric was the ETX. EETT performed worse when compared to both RTT and ETX, but it performed better than the hop count, which is the worst performer.

Parameter(s)	Value(s)
Number of nodes	9, 16, 25, 36, 49, 64, 81, 100, 121, 144, 169, 196
Area	1500m X 1500m
Network topology	Square grid
Simulation time	1000 seconds
Routing protocol	AODV
Routing metrics	HOP, RTT, ETX, EETT
Recorded parameters	Delay, delay jitter, packet loss ratio, throughput

Table 2: Simulation parameters

Figure 4 shows the effect of network size on the average delay jitter of the network. The best routing metric among the four routing metrics that are compared must have the lowest average delay, while the opposite is true for the worst routing metric. It can be seen from figure 4 that ETX performed better than the four routing metrics compared in this paper, while EETT was the worst performer.

The results showing the effect of network size on packet loss ratio are depicted in figure 5. An optimal routing metric for WMNs must have a very low packet loss ratio, while a routing metric with high packet loss ratio results in low network performance. Expected transmission count routing metrics outperformed all the routing metrics that were compared in this work, while HOP was the worst performing routing metric. RTT was the second best routing metric, while EETT only performed better than HOP.

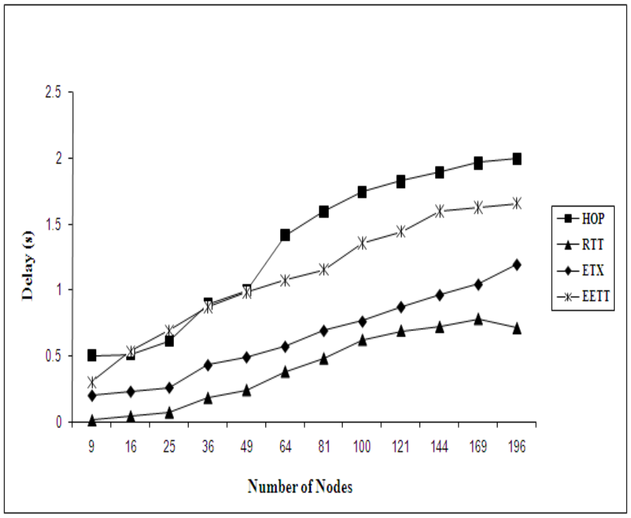

Figure 3: Effect of number of nodes on delay

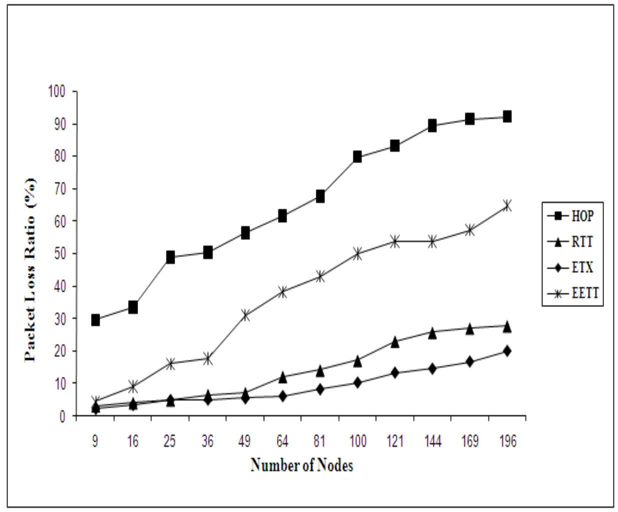

Figure 5: Effect of number nodes on packet loss ratio

Figure 6 depicts a graphical representation of the effect of time on the throughput of the network. For high network performance, an optimal routing metric is expected to have high throughput. It can be seen from figure 6 that ETX outperformed all the routing metrics it was compared to, while HOP was the worst performer of all the routing metrics compared. EETT was the second best routing metric, while RTT only performed better than HOP.

Overall, ETX outperformed all the other routing metrics compared, while HOP was the worst performing routing metric. RTT was the second best routing metric overall, while EETT only performed better than HOP, but worse compared to the other two routing metric.

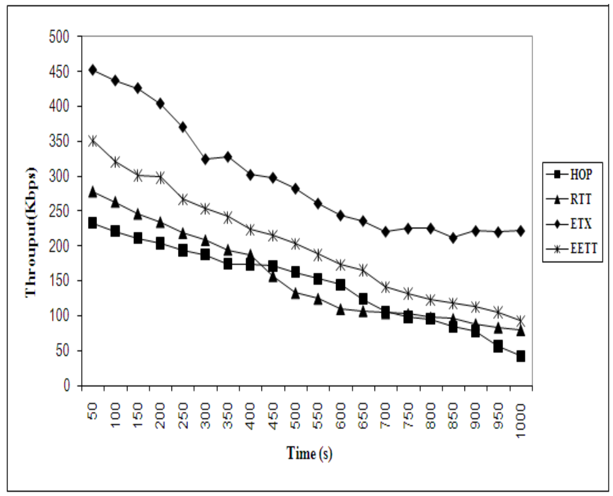

Figure 6: Effect of number of nodes on throughput

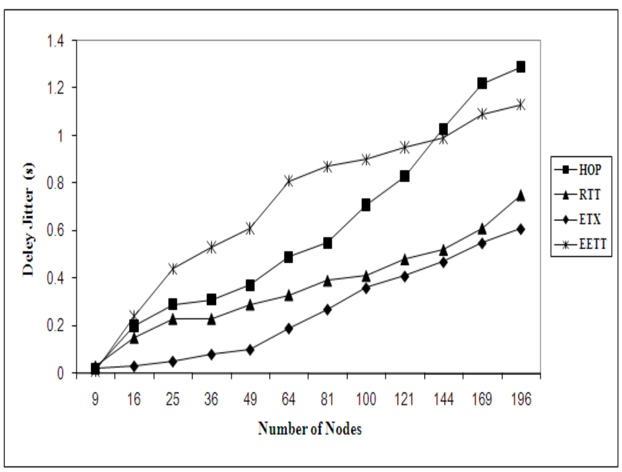

Figure 4: Effect of number of nodes on delay jitter

Routing metrics are assigned scores from 1 (worst performer) up to 4 (best performer). The last row on table 3 shows the overall score of the performance of the routing metrics that were compared in this paper. It can be seen from table 3 that overall ETX outperforms the other three routing metrics, while HOP performed worse than all the other three routing metrics that were compared. ETX outperforms all the routing metrics that were simulated when delay jitter in the entire network was measured.

VI. RECOMMENDATION OF DESIGN CRETERIA

A. Weight path-awareness

The main goal of every routing protocol is to send packets through minimum weight paths in terms of a particular routing metric that it is using. To make sure that there is an effective utilization of wireless mesh networks resources, the minimum weight paths selected by a particular routing protocol must have good performance inform of high throughput, low packet loss and low delay. The results from our simulations have shown low throughput, high packet loss ratio, and high delay on achieved by the four simulated routing metrics.

B. Efficient weight path algorithm design

Each and every routing protocol uses a certain efficient algorithm to compute minimum weight paths. It can not be guaranteed that routing protocol can have good performance if there is no efficient algorithm to calculate the minimum weight paths based on a particular routing metric. The results of the experiments have shown the hop count routing metric as the worse performer amongst all the simulated routing metrics, this can be attributed to the fact that it uses an algorithm that is not very efficient since it does not consider the quality of a link, but only chooses a path that have a less number of hops among the available paths.

C. Quality of Service-awareness

Quality of Service has a potential to improve performance of a wireless mesh network. A routing metric like hop count does not consider the quality of the link through which it is intending sending packets. The fact that hop count does not consider link quality degrades network performance by having high packet loss ratio and low throughput (see Figure 4 and 5). An optimal routing metric for WMN need to make QoS one of its priorities. Hop count routing metric does not take the quality of the link into consideration when choosing a route to use for sending packets.

D. Network scalability

Most of experiments conducted in section IV of this paper have shown that the performance of the network (i.e. throughput, packet delivery ratio) degrades when the network size increases. Figure 4 shows that throughput of the network degrades as the network size is increased for all routing metrics that were simulated. Figure 5 showed that packet loss ratio decreases when the network size increases, leading to poor performance of the entire network.

Delay is also one of the causes of performance degradation; hence it increases as the network size increases, leading to poor throughput. An optimal routing metric for wireless mesh network needs to take network scalability into consideration. A routing metric should try to maximize network performance despite the number of nodes the network has. Figure 3 has shown that network delay increased as more nodes were added in the network, while figure has shown that the delay jitter increased as well when more nodes were added. As more nodes were added, packet loss ratio increased as it can be seen in Figure 5.

VII. FUTURE WORK

This section presents the limitations and future enhancements of this study. Simulation results might not reflect real world results since they do not consider external interference, therefore, conducting the same experiments on a wireless test bed still needs to be considered to further validate results presented in this paper. This study needed a fairly large number of wireless nodes to test network scalability; this would not have been possible with the test bed that is running in the wireless mesh lab at the University of Zululand, because it contains only fourteen nodes. Test bed implementation was not possible because of time and financial constrains. As future work, this study should consider using a test bed which will reflect real world results. The results from the test bed should be compared with results from simulation.

One routing protocol (AODV) was used in all the experiments that were conducted in this study, another routing protocol could be used to also run the very same experiments. AODV was chosen because it has been used with a majority of routing metrics that were simulated in this paper; AODV is suitable since the focus of this study was on the routing metrics rather than a routing protocol. The use of two routing protocols instead of one should be considered as future enhancement of this work. The use of two routing protocols will help to further validate simulation results, since the performance of routing metrics will then be judged on two different routing protocols. Hybrid wireless mesh protocol is a routing protocol for WMNs, it should be considered as the second routing protocol to use in this study.

In this study, only one routing metric was chosen for simulation from each group. Only one routing metric could be simulated from each group because of time constrains, since the code for the other three routing metrics (RTT, ETX, and EETT) had to be hard coded before they could be used, which took a lot of time to achieve. Selecting more than one routing metric from each group was going to take even more time.

Experience	HOP	RTT	ETX	EETT
Delay	1	4	3	2
Delay jitter	2	3	4	1
Packet loss ratio	1	3	4	2
Throughput	1	2	4	3
Overall	**5**	**12**	**15**	**8**

Table 3: Summary of results

As future enhancement to this study, two routing metrics should be simulated from each group to improve this study. The results of this paper should be compared to the results of the work that will simulate two routing metrics from each group.

VIII. CONCLUSION

This paper presented the successful comparison of the routing metrics for wireless mesh networks. Four different routing metrics were compared: HOP, RTT, ETX, and EETT and four performance metrics were measured: delay, delay jitter, packet loss ratio, and throughput. The four routing metrics were compared in a consistent manner. ETX performed better than all the other routing metrics that were compared while the hop count routing metric was the worst performer of all the routing metrics that were simulated. RTT was the second best performing routing metric after the ETX. EETT performed worse that both ETX and RTT, but better when it was compared to the hop count routing metric.

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