Performance Evaluation of Routing Metrics for Community Wireless Mesh Networks

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***Abstract*—With the growth of different types of Internet traffic, there is a compelling need to provide better quality of service especially over the increasing number of wireless networks. Expected Transmission Count (ETX) is a high throughput route selection metric developed for routing protocols used in Wireless Mesh Networks (WMNs). Using the minimum hop count to find the shortest path has been shown to be inadequate for WMNs as the selected routes often include the weakest links. This paper presents a performance evaluation comparing hop count and ETX when used with the Optimized Link State Routing (OLSR) protocol. This study is based on the wireless mesh network topology of a suburban residential area in New Zealand, and analyses the performance of three common Internet traffic types in terms of throughput, end-to-end delay and packet loss ratio, and presents findings that are closer to the perspective of what an end user experiences.**

***Index Terms*—Wireless Mesh Networks, OLSRv2, ETX, hop count, VoIP, FTP, HTTP**

I. Introduction

Wireless Mesh Networks (WMNs) have been an emerging technology in recent years due to their attributes such as self-configuration, flexibility, high robustness and bandwidth efficiency. Owing to these attributes, WMNs are widely regarded as an attractive solution for wireless community networks. In WMNs, nodes are classified as mesh routers and mesh clients, and each node can function both as a host and a router. The connections between mesh nodes can be set up and maintained dynamically making a WMN a dynamic self-organized and self-healing network [1]. In WMNs, mesh routers can be stationary or have minimal mobility, and they make up the backbone of a WMN and provide access for mesh clients.

To improve the performance of wireless clients and increase network capacity, routing protocols play an important role in WMNs. Routing protocols [2][3][4] designed for Mobile Ad Hoc Networks (MANETs) have been widely implemented in WMN and their performance studied. Most of the current ad hoc routing protocols use hop count as their route selection metric to find the shortest path between source and destination nodes. However, hop count, as the basic routing metric is insensitive to packet loss, data rates, link capacity, link quality, channel diversity, interference or various other routing requirements. A good routing metric should address the issues related to the key characteristics, discussed in [5], such as, interference, isotonicity and throughput. Researchers have proposed many routing metrics to replace hop count in order to improve the performance of WMNs. Expected Transmission Count (ETX) [6] is one such metric that aims to provide high throughput, by measuring the packet delivery ratio of the link between neighboring nodes.

With the growth of the Internet, Voice over Internet Protocol (VoIP), File Transfer Protocol (FTP) and Hypertext Transfer Protocol (HTTP) constitute a signification portion of the Internet traffic. Users of applications that rely on these protocols expect at least the same quality level as in wired networks, and consequently, these protocols require higher quality of service (QoS) support over wireless links than what shortest path routing can provide. While shortest path routing has worked well for the wired Internet, when used in wireless networks, the selected routes often (if not always) include the weakest links. Consequently, any link quality fluctuation will result in re-computation of routes, incurring delays, packet loss and throughput degradation. To evaluate what benefits ETX can bring to such traffic types, we evaluate ETX and hop count in terms of four characteristics of performance namely end-to-end delay, jitter, throughput and packet loss. We have identified these performance metrics as they have a significant impact on the common Internet traffic types considered in our study.

In the Greater Wellington region of New Zealand, the Porirua VillageNets Project has worked with Porirua Chamber of Commerce to carry out market research to identify target businesses and high value subscribers. They need to ensure that network coverage is provided to core subscriber centres as effectively as possible. We use a part of their deployment area, in the Whitby Area, as the basis of our simulations; the network consists of 126 nodes deployed in a suburban residential area.

This paper is organized as follows. In the next section, we present the related research on the Optimized Link State Routing version 2 (OLSRv2) protocol, and the hop count and ETX metrics. We then present the simulation results of three different traffic types, namely, VoIP, FTP and HTTP, which dominate the traffic carried by the present day Internet. This is followed by discussion on how the ETX metric can benefit these traffic types through the selection of routes comprising better quality links.

II. Related Work

In this section we present related research on the hop count and ETX metrics, and a specific routing protocol, OLSR version 2.

A. Optimized Link State Routing version 2 (OLSRv2) protocol

Routing protocols take the responsibility for route discovery and creation as well as maintenance of network topology. According to the time at which the routes are calculated, routing protocols for WMNs are classified into two categories: reactive routing and proactive routing.

OLSR [4] is a proactive routing protocol, which means each node in the network maintains a routing table and periodically updates routing information on every other node in the network.

OLSRv2, proposed in [7], is an updated version that retains the same basic functions and algorithms as OLSR, while additionally providing much simplified messages and a flexible signaling framework.

Normally, link state protocols use a flooding mechanism to exchange link state information, which causes massive overheads as every node will receive repeated link state information, resulting in low network efficiency. OLSR and OLSRv2 use Multipoint Relays (MPRs) to reduce control overheads and redundancy during the route creation and update processes. Only the nodes selected as MPRs assume the responsibility of forwarding control messages to the entire network. This mechanism reduces the overheads caused by control messages and improves flooding efficiency thereby decreasing the number of retransmission messages.

OLSRv2 mainly uses two basic types of control messages: Hello message and Topology Control (TC) message. The Hello message serves to discover link information, 1-hop and 2-hop neighbors. It is also involved in the MPR selection process. These Hello messages are broadcast periodically, thereby enabling every node to keep track of immediate changes in their local neighborhood. TC messages are used to propagate topology information. They advertise the link information into the entire network, so that every node can use this information to calculate the shortest path to a desired destination. TC messages are broadcast periodically, but only nodes selected as MPRs can generate a TC message keeping overhead to a minimum. Every node in its 1-hop neighborhood selects the smallest set of MPRs to cover all its 2-hop neighbors. Thereafter, MPRs will announce to the network their reachability to the nodes that have selected it as an MPR.

B. Routing Metrics

Routing metrics play an important role as they have a direct impact on the efficiency and robustness of routing protocols. Different routing metrics will provide different performances to routing protocols when used to compute weight of paths. In this paper two metrics, hop count and ETX are studied and their performances in selecting routes to support various types of Internet traffic are studied using simulations.

1) Hop Count: Hop count is the basic and most common metric used by routing protocols in networks. OLSRv2 uses it as its basic routing metric. Hop count evaluates the suitability of a route/path based purely on the path length. It is simple and provides a high level of stability, and its isotonicity property allows it to find minimum weighted paths efficiently.

However, hop count is not without limitations and these include ignoring packet loss ratios, data rates, link capacity, throughput, channel diversity, interference and various other routing requirements to assign weights. For example, a route with good link quality and link capacity can provide better throughput and flow performance than a route with fewer hops (i.e. lower hop count) and a high loss ratio.

2) Expected Transmission Count (ETX): The ETX metric measures link quality by estimating the number of transmissions and retransmissions needed to send a data packet over a link. To get the ETX value, every node broadcasts a probe packet periodically to neighboring nodes.The formula to calculate ETX is as given in (1).

$$ETX = \frac{1}{d_f \times d_r} \tag{1}$$

Where, the forward delivery ratio, d_f, denotes the probability that a packet will be successfully delivered in the forward direction, and the reverse delivery ratio d_r denotes the probability of receiving the corresponding acknowledgement packet. Therefore, ETX involves the delivery ratio and the number of transmissions in both directions over a link. Since the two probabilities are independent, $d_f \times d_r$ can be understood as the expected probability of a successful transmission, which includes acknowledgement. $d_f \times d_r$ is also equal to $(1 - P_f) \times (1 - P_r)$, where P_f and P_r are the forward and reverse packet loss ratios.

Link ETX uses probe measurement for the calculation of delivery ratios. Each node broadcasts small link probes (134 bytes) once every second. As broadcast packets are not retransmitted nor acknowledged at the IEEE 802.11 Medium Access Control (MAC) layer, a node remembers the probes it receives from its neighbors during a sliding window of duration of ω seconds (usually ω=10). They also send the record during the same sliding time window to their neighbors, so that at any given time a node can calculate the delivery ratio in both directions. To avoid the possible synchronization of periodically broadcast probe packets, which could lead to the large-scale collision, a random jitter is used for every probe packet. The jitter value is usually $\pm 0.1\omega$.

Since the value of the ETX metric is based on the delivery ratio, it directly affects throughput and packet loss ratio in both directions of a given link. This will imply that a path with low ETX value has low congestion, low packet loss ratio, and hence high throughput. ETX uses broadcasting instead of unicasting thereby reducing probing overheads.

The main disadvantages of ETX lie in the way it broadcasts small probe packets to detect data delivery ratio, and that probe packets are sent at a lower data rate. This estimation may not reflect the real packet loss ratio, because actual packets are usually larger and sent at higher data rates. Additionally, ETX does not take link data rates into account. The same packet loss ratio may be associated with different data rates and link delays. For this reason, ETX is more suitable for single-rate networks.

III. Evaluation

A. Simulation Setup

Qualnet [8] is used as the simulation tool. The network topology used in our study, as shown in Figure 1, is the Whitby Area deployment by Porirua VillageNets. There are 126 static nodes deployed in a 2000m×2000m suburban residential area, and every node is placed atop a house. The transmitting power of each node is equivalent to 15dB, and the channel frequency is 2.4GHz. Each node uses one 802.11b radio channel. As all the nodes are static, Constant Shadowing and Two Ray path loss models are used in the simulation. The routing protocol OLSRv2 with ETX is developed by Niigata University OLSR research group [9].

In every application scenario, we vary the traffic load in the network from 10 to 50 connections. We also use a single connection as the baseline for comparing the performance of hop count and ETX. The reason for configuring the number of flows is to analyze the metrics' performance under different traffic loads for audio, bulk file transfer and web streams.

For every scenario, more than twenty simulations were performed using different seeds to get the average results. Each simulation was run for 300 seconds.

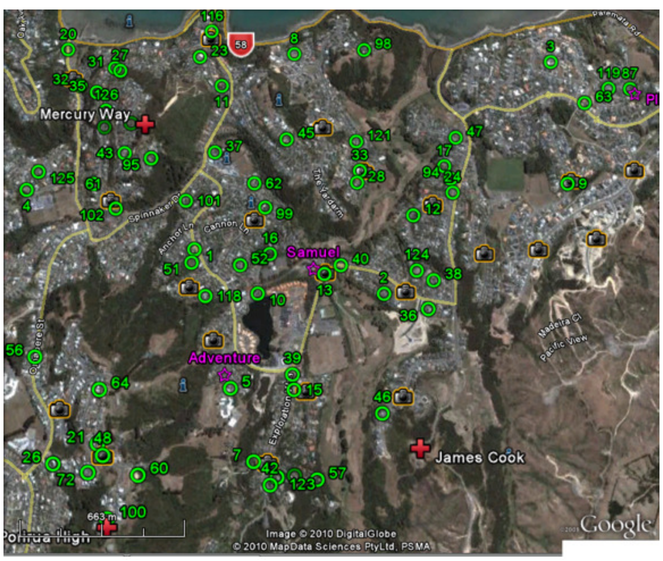

Fig. 1. Whitby Area Network Topology

B. Simulation Results

1) Voice over Internet Protocol (VoIP) Traffic: To ensure the quality of VoIP traffic, the key QoS parameters are delay, jitter and packet loss ratio. We examined OLSRv2 using the ETX and hop count metrics with regard to these parameters.

For signaling and control, we used H.323 [10] and Real-time Transport Protocol [11]. As VoIP data is small, the UDP flow rate is maintained at 8Kb/s, packet size at 32 bytes (RTP + UDP + Payload) and packetisation interval at 20ms to closely emulate the G.729 codec [12]. We randomly selected pairs of VoIP communicating nodes from the nodes in the network.

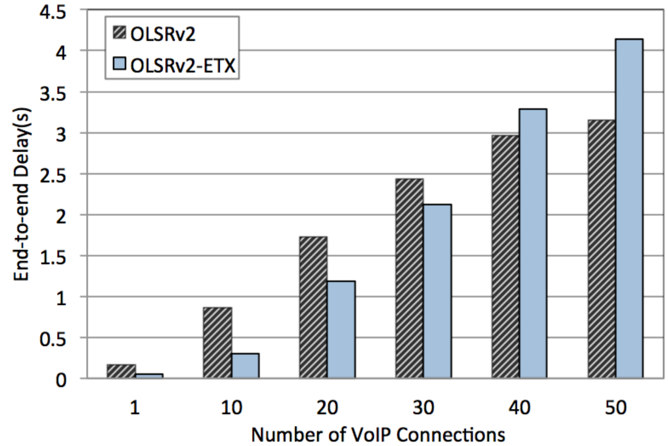

Fig. 2. Average End-to-end Delay

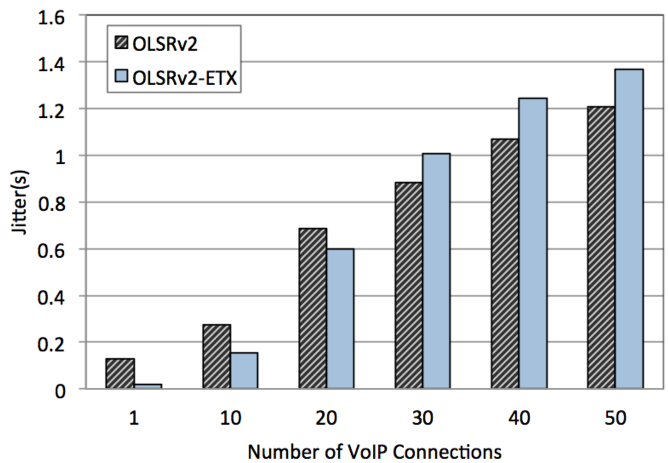

Fig. 3. Average Jitter

In Figure 2, we plot the average end-to-end delay experienced by the VoIP packets. It is obvious that ETX reduces end-to-end delay when the traffic load is low. When 10 VoIP connections exist, which means twenty nodes are communicating at the same time, the ETX metric experiences almost 50% less delay than using hop count. When the traffic load increases, the end-to-end delay of both ETX and hop count increase rapidly. From 1 connection to 30 connections, the delay is consistent between ETX and hop count. When the numbers of connections exceed 40, the hop count metric is able to achieve lower end-to-end delay compared to the ETX metric. When using hop count, as the traffic load increases, the propagation delay and queue delay increase leading to higher end-to-end delay. The hop count metric is not sensitive to these intermediate and sudden increases in delays and still tries to establish the shortest path. This will lead to higher packet losses, as shown in Figure 4.

The ETX metric tends to choose a low packet loss path to avoid congestion; in other words, the ETX metric will choose a longer path than hop count. When the traffic load is high enough, ETX will choose a much longer path, resulting in higher end-to-end delay as compared to the hop count metric. On the other hand, when hop count is used, fewer packets reach the destination but those that do have lower delays, and thus, the average delay and jitter are lower than those for ETX.

Figure 3 presents the jitter results for VoIP calls. The results are consistent with the end-to-end delay. At low traffic loads, ETX experiences lower jitter compared to hop count. As the traffic load increases, to avoid congestion ETX may change routes, as and when a new route with lower ETX value than existing routes is discovered. This can lead to a number of route changes resulting in higher jitter than using the hop count metric.

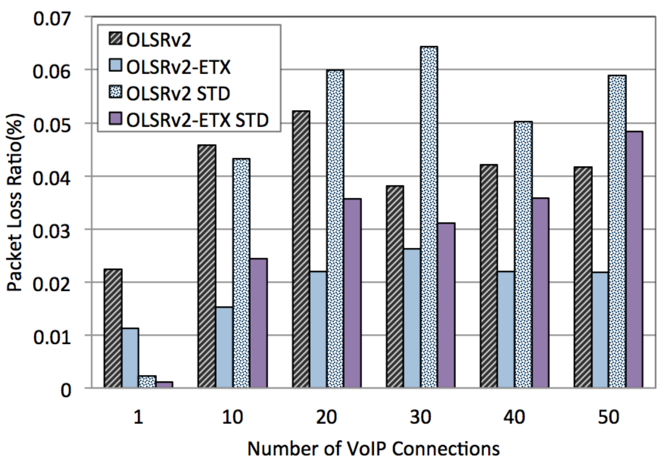

Fig. 4. Average Packet Loss Ratio

Figure 4 shows the packet loss ratio of the hop count and ETX metrics. Irrespective of whether the traffic load is low or high, it is observed that, the ETX metric, which takes packet loss ratio into account, ensures much lower packet loss than the hop count metric. Hop count being indifferent to packet losses caused by aggravated congestion and interference along the shortest routes invariably results in high packet loss ratio. Although the ETX metric chooses a route with more hops, it keeps the packet loss probability within an acceptable threshold. This is significant for VoIP users, as low loss ratio results in better quality of calls.

The standard deviation of the packet loss ratio is also shown in Figure 4. The lower standard deviation achieved by ETX shows that the network traffic is distributed across the network, unlike using hop count which tends to concentrate traffic along the direct paths between communicating nodes. However, when the traffic load is high, the network becomes congested and route selection based on either approach experience high performance variations. In general, the standard deviation is lower when ETX is used as compared to hop count, since ETX spreads the traffic and avoids the congested routes.

Like any routing protocol, OLSRv2 also incurs overheads due to broadcast control messages. In OLSRv2, TC messages cause much larger overheads than Hello messages. Figure 5 presents the average number of control messages broadcast by every node. It can be seen that ETX generates more control messages than the hop count metric, which will result in significant overheads. The reason is that when using ETX as its routing metric, OLSRv2 has to select more MPRs to cover links of acceptable ETX values in order to calculate the smallest weighted path. As more MPRs are selected by the ETX metric, more control messages are broadcast across the entire network.

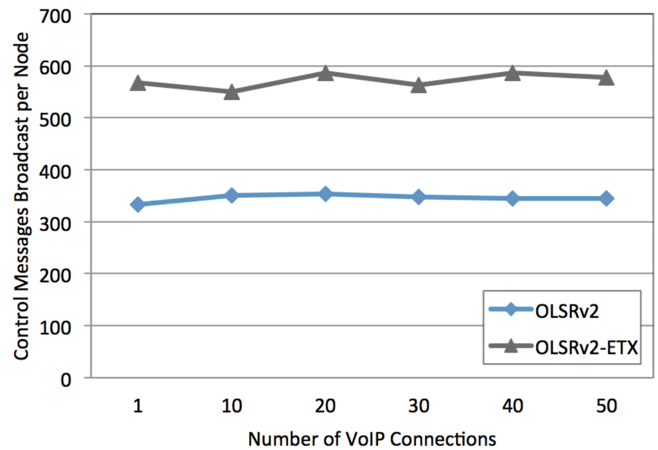

Fig. 5. Number of control messages broadcast per node

2) File Transfer Protocol (FTP) Traffic: To model FTP traffic, we randomly assigned nodes as FTP servers and clients and set up connections ranging from 1 to 50. Each FTP flow carries 100 file items with an average size of 1460 bytes and lasts for at least two minutes.

For each simulation, we calculate the average throughput of all the connections. Figure 6 shows the throughput performance of the two metrics. The results show that the ETX metric gives better throughput than the hop count metric by almost 20%. As expected ETX establishes routes with low loss probability resulting in connections that can support more data transfer than the hop count metric.

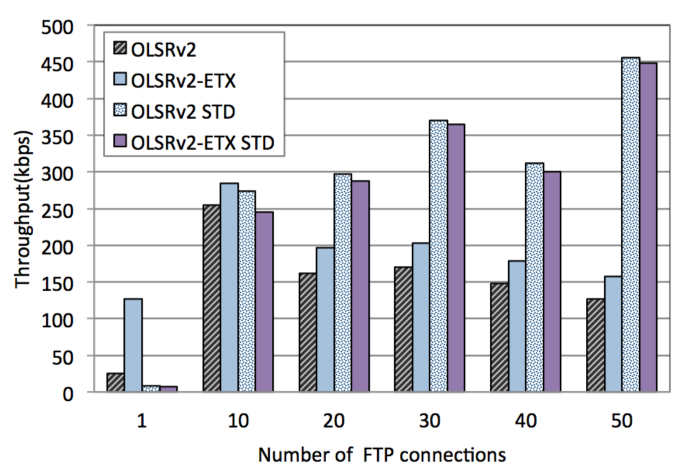

Fig. 6. Throughput with number of FTP connections

For the single connection case, we chose a path with more hops to set up the connection. From Figure 6, we can see the ETX metric provides much better results than the hop count metric. Normally longer paths suffer from higher loss probability and lower throughput, but ETX achieves higher throughput by avoiding these low throughput paths. As the number of connections increases from 10 to 50, the overall throughput of both the ETX and hop count metrics reduces. The reason is that links start interfering with one another, especially when the traffic load is high. With high load traffic, the number of poor quality links (lossy or slow) increases. The hop count metric, using Dijkstra's algorithm, still chooses these links to form the shortest path, which significantly reduces the throughput. Even when high load leads to route instability and the overall throughput is considerably lowered, ETX provides comparatively better throughput than hop count.

3) Hypertext Transfer Protocol (HTTP) Traffic: To perform web traffic analysis, each client is modeled as a single user running HTTP. It simulates single-TCP connections between web servers and clients. The web traffic was generated using Mah's model [13]. HTTP requests are the only data sent from the client to server and are about 320 bytes, with a median size of 240 bytes. HTTP server replies, on the other hand, are larger, with median file size around 1.5-2.0 KB. Each user fetched over 40 files from HTTP servers in a session that ran for at least two minutes.

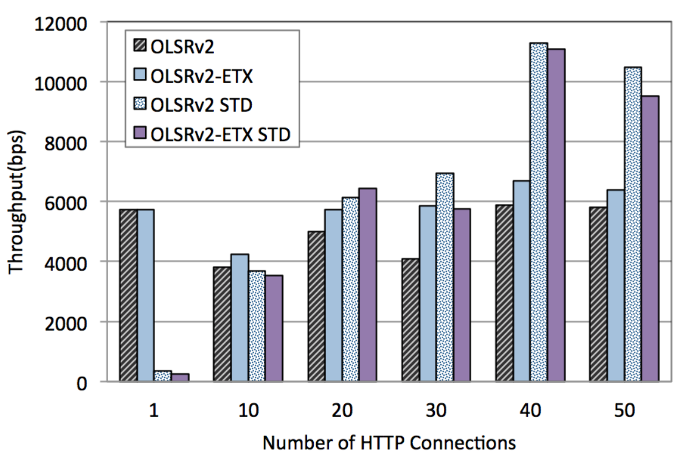

Fig. 7. Throughput with number of HTTP connections

In Figure 7, we plot the average throughout experienced by each web client which shows that, no matter how much the traffic load increases, using ETX can still provide higher throughput than using hop count. This is consistent as ETX is ideal for HTTP traffic as it is a high throughput routing metric. For the single HTTP connection, we set a path only two hops away. The throughput achieved using the ETX metric then was almost the same as using hop count. For the shorter paths, ETX does not perform better than hop count. However, contrary to what has been observed about the FTP traffic analyzed earlier, the overall throughput of HTTP does not degrade with the increase in traffic load. One possible reason is that the HTTP servers keep sending web pages to clients, which keep the throughput high.

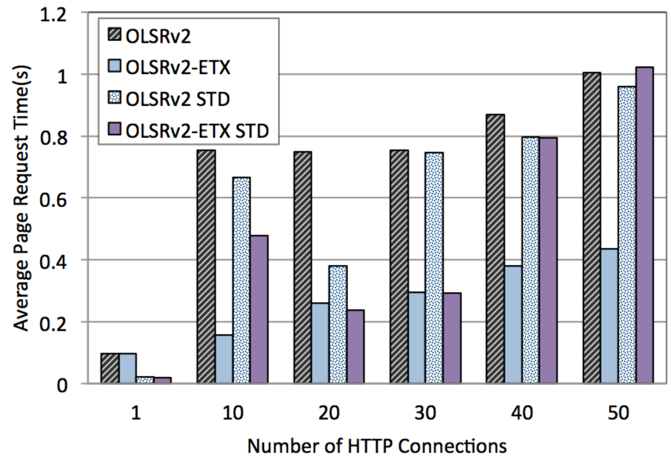

Fig. 8. Average page request time

Figure 8 presents the average page request time by each web client. The overall request time of ETX and hop count increase with the increase in traffic load, but the ETX metric provides at least 50% lower average request time than hop count. When using a single connection, the result is consistent with that of throughput; ETX does not show better performance than hop count along a shorter path. As the request packet is small, ETX reduces the delay of small transfers by a significant proportion. The request data sent from the client to the server can fit inside a single TCP packet. The standard deviations in Figures 7 and 8 show that ETX performs better than hop count, especially when the network is not under extremely high loads. Not only is the HTTP request time lower when ETX is used, the variations are lesser as shown by the lower standard deviations. This translates to more consistent response times to the endusers.

IV. Conclusion

In this paper, we evaluated the performance of the hop count and ETX metrics when used with the OLSRv2 routing protocol to support three different types of Internet traffic in a network topology based on a real deployment scenario. The simulation results show that using the ETX metric in place of the hop count metric improves the overall performance of OLSRv2 protocol, especially in the case of throughputs. With increasing traffic loads, performances of both ETX and hop count reduce rapidly when supporting VoIP traffic. One reason is that VoIP uses UDP as a transport layer protocol. Another is high traffic load means more interferences which neither ETX nor hop count metrics can handle. For FTP and HTTP traffic, ETX guarantees higher throughput because ETX considers packet loss probability in both directions of a link thereby establishing routes with significantly higher throughput than hop count, particularly for a path with higher hops.

On the other hand, when OLSRv2 uses ETX as its routing metric, it will result in more MPRs and more control messages.

The network overheads will increase and significantly reduce the performance of networks. While adopting ETX as its routing metric is a good choice for OLSRv2, we still need to consider the traffic load, overheads and the traffic profile. We also note that the standard deviation is always lower when ETX is used, as compared to hop count, under low to moderate traffic conditions for all three types of traffic. When using ETX as the routing metric, routes that avoid the congested parts in the network are selected; under high traffic loads where the network is generally congested throughout, there are far fewer alternative routes to choose from to get any additional benefits from using ETX. From this perspective, the ETX metric is able to provide better traffic equalization than hop count.

Our simulation still has some limitations that we intend to overcome as part of our future work. One such limitation is the use of Hello message in OLSRv2; the probes used by ETX cannot accurately determine the real data loss ratio because the Hello message is quite small compared to the actual data being transmitted. While QualNet provides many propagation models, it is still not entirely possible to model a real deployed network, with the actual buildings' locations, trees, hills or any other reflectors in the line of sight between nodes. Future research should address and implement these shortcomings.

ACKNOWLEDGMENT

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