Performance Evaluation of Scalable Routing Protocols using Routing Metrics for Wireless Mesh Networks under different Network Scenarios

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Abstract:

Wireless Mesh Networks has been considered as an important solution to the next generation wireless networks which offer broadband connectivity to rural community. This is possible because of its extendibility in coverage and scalable deployment in various geographical terrains. There are still research issues needs to be addressed in terms of its performance degradation due to unexpected behavior of routing protocols under different network scenarios. In this paper, after thorough investigation, suitable routing protocol is suggested with the help of appropriate measurement using routing metrics. Even though IEEE task group has adopted IEEE 802.11s as standard for integrated mesh networking as also suggested default routing protocol and default routing metrics, it is very much needed to investigate the performance of different categories of routing protocols under different network scenarios. The performance evaluation of ad hoc on demand distance vector (AODV), optimized link state routing Protocol (OLSR) and hybrid wireless mesh protocol (HWMP) are considered as popular protocols in each category under different network scenarios. The considered metrics include airtime, EXT, ETT and WCETT. The impacts of varying traffic loads, number of sources, network size and real time and non real time applications on Wireless Mesh Networks using metrics have been invested through simulation. Simulation results shows that HWMP-Airtime outperforms other Routing Protocol and Routing Metrics combination for real time applications and significantly HWMP-EXT has a clear advantage over others in terms of maximizing the packet delivery ratio minimizing routing overhead and end-to-end delay.

Keywords: Wireless Mesh Networks, Routing Protocols, Routing Metrics, Performance, AODV, OLSR, HWMP.

I.INTRODUCTION

In past recent years, most of the routing protocols for Wireless Mesh Networks have an increased in popularity due to their properties of self configuration, self healing, and scalable. The motivation behind it is due to mesh network's network hardware cost is relatively low. The advantage of low cost of mesh networks hardware provided opportunity to allow routers to include two or more radio interfaces on a single node in order to increase throughput and also to handle the problems of co-channel interference in large dense networks. The capacity of the mesh router can be significantly increased by considering the radio interfaces on orthogonal channels and also overcomes the limitation of half duplex operation of single radio nodes. In addition to this, there is a requirement of designing routing protocols which takes the advantage of the availability of multiple interfaces efficiently. Wireless Mesh Networks have been revolution to tackle the major limitations of the traditional wireless networks. This special type of multi-hop wireless networks consists of Mesh Routers and Mesh Clients form high bandwidth connectivity networks [1]. In most of the times mesh routers are static and power enable and mesh clients are mobile and they access the network via mesh routers or directly by forming a mesh with each other. Mesh routers are power enabled and form a wireless backbone for the WMNs while connected with the wired networks to provide multi-hop wireless internet connectivity to mesh clients.

The existing 802.11 based networks depend on wireless networks on wired infrastructure to carry the traffic and thus make wired infrastructures expensive and rigid as WLAN does cover beyond some particular point of time. With the help of mesh concept, the WLANs capability of coverage can be extended. However the performance of the WMNs is mainly depend on the design of routing protocols and the linked routing metrics. The best path between the source and destination is selected by routing protocol based on the routing metrics adopted. The current routing protocol in WMNs depend mainly on the network layer and use hop count to enable multi-hop communication and does not provide appropriate right solution in selecting best path between source and destination. This problem is addressed by IEEE task group called IEEE 802.11s [2] to design and develop an integrated mesh networking solution. Finally the task group has identified hybrid wireless mesh protocol [3] as default routing protocol and air time [4] metric as default routing metrics. But, this cannot be right away accepted for different network scenarios and applications traffic. In [5] the performance study of HWMP protocol for IEEE 802.11s for WMNs was carried for different applications traffic considering only airtime as default metric. The WMN routing protocols can be classified as proactive, reactive and hybrid in general. In case of proactive protocols, the routes to all destinations are maintained regardless of whether these routes are needed or not. Thus, this may waste the bandwidth because of unnecessary transmission of control messages when there is no data traffic. Reactive routing protocols only set up a route between a source and its destination when required. While, hybrid routing protocols combine both reactive and proactive routing to increase the overall scalability in the networks. In this paper, protocol from each category are taken OLSR (proactive), ADOV (reactive) and HWMP (hybrid) and performance of each of them are evaluated using routing metrics under different network scenarios and traffic applications.

The heart of Wireless Mesh Networks is Routing Protocols which control the formation, configuration and maintenance of the topology of the network. Most routing proto cols for wireless mesh networks are ex-tended unicast ad ho c routing protocols. Existing unicast routing protocols like for example AODV, DSR are not suited well for wireless mesh networks as in such networks, most traffic flow between a large number of mobile nodes and a few access points with Internet connectivity. In this period, the performance evaluation of recently developed scalable routing protocol for this type of communication that is designed to scale to the network size and to be robust to node mobility has been carried out. The performance evaluation of ad hoc on demand distance vector (AODV), optimized link state routing Protocol (OLSR) and hybrid wireless mesh protocol (HWMP) are considered as popular protocols in each category under different network scenarios. The considered metrics include airtime, EXT, ETT and WCETT. The impacts of varying traffic loads, number of sources, network size and real time and non real time applications on Wireless Mesh Networks using metrics have been invested through simulation.

The remainder of this paper is organized as follows: Section II discuss related work carried out in analyzing the performance of scalable routing protocols in WMNs. The scalable routing protocols considered for simulation are presented in Section III. The brief descriptions of the four routing metrics used for performance evaluation are done in Section IV. Section V elaborates the simulation environment and the simulation result are analyzed and discussed in Section VI. The conclusion for this simulation is drawn in Section VII.

II. RELATED WORK

Recently, routing protocols and associated metrics for wireless mesh networks have been extensively examined [5]. Wireless Mesh Networks considered having common features with mobile ad hoc networks. Many of the routing protocol for WMN are derived from the ad hoc networks. IEEE 802.11s used HMWP [6] which is based on Ad hoc On demand distance vector (AODV) and Microsoft mesh network [7] was based on Dynamic Source Routing (DSR).

All the existing routing protocols used in WMNs completely depend on the IP layer and enable multi-hop communication. The major problem with focusing only on network layer is it cannot capture the nature of the wireless link perfectly [8]. It is common that, wireless links are more vulnerable than the wired and multi-hop routing protocol has responsibility of managing these wireless links. Although IEEE 802.11s has set HWMP as a default routing metrics and default routing metrics, there is no effort seen to study the behavior of these protocol under varied network scenario and possible high end applications.

III. SCALABLE ROUTING PROTOCOLS FOR WIRELESS MESH NETWORKS

We have considered three types of routing protocols for evaluation under different network scenarios in this paper, namely AODV (reactive), OLSR (proactive) and HWMP (hybrid). In this section the operation of each routing protocols are explained briefly.

A. Ad hoc On Demand Distance Vector Routing Protocol

This protocol perform*s* Route Discovery using control messages route request (RREQ) and route reply (RREP) whenever a node wishes to send packets to destination. To control network wide broadcasts of RREQs, the source node uses an *expanding* ring search technique. The forward path sets up an intermediate node in its route table with a lifetime association RREP. When either destination or intermediate node using moves, a route error (RERR) is sent to the affected source node. When source node receives the (RERR), it can reinitiate route if the route is still needed. Neighborhood information is obtained from broadcast Hello packet.

As AODV protocol is a flat routing protocol it does not need any central administrative system to handle the routing process. AODV tends to reduce the control traffic messages overhead at the cost of increased latency in finding new routes. The AODV has great advantage in having less overhead over simple protocols which need to keep the entire route from the source host to the destination host in their messages. The RREQ and RREP messages, which are responsible for the route discovery, do not increase significantly the overhead from these control messages. AODV reacts relatively quickly to the topological changes in the network and updating only the hosts that may be affected by the change, using the RRER message. The Hello messages, which are responsible for the route maintenance, are also limited so that they do not create unnecessary overhead in the network. The AODV protocol is a loop free and avoids the counting to infinity problem, which were typical to the classical distance vector routing protocols, by the usage of the sequence numbers. [9]

B. Optimized Link State Routing Protocol

Optimized Link State Protocol (OLSR) is a proactive routing protocol, so the routes are always immediately available when needed. OLSR is an optimization version of a pure link state protocol. So the topological changes cause the flooding of the topological information to all available hosts in the network. To reduce the possible overhead in the network protocol uses Multipoint Relays (MPR). The idea of MPR is to reduce flooding of broadcasts by reducing the same broadcast in some regions in the network, more details about MPR can be found later in this chapter. Another reduce is to provide the shortest path. The reducing the time interval for the control messages transmission can bring more reactivity to the topological changes. [10]

OLSR uses two kinds of the control messages: Hello and Topology Control (TC). Hello messages are used for finding the information about the link status and the host's neighbors. TC messages are used for broadcasting information about own advertised neighbors which includes at least the MPR Selector list. The proactive characteristic of the protocol provides that the protocol has all the routing information to all participated hosts in the network. However, as a drawback OLSR protocol needs that each host periodically sends the updated topology information throughout the entire network, this increase the protocols bandwidth usage. But the flooding is minimized by the MPRs, which are only allowed to forward the topological messages.

C. Hybrid Wireless Mesh Protocol (HWMP)

This protocol has the flexibility of combining the on demand and proactive features and work well with any kind of topology. HWMP routing protocol make use of AODV for on demand protocol primitives and destination sequence distance vector DSDV [10] for proactive protocol primitives. This protocol is used as default routing protocol in IEEE 802.11s in MAC layer. The path selection is done in IEEE 802.11s using air time link metric which is also a default link metric [7]. Routing metric airtime is radio aware metric which can measure the amount of channel resource consumed when a frame is transmitted over a wireless link. There are four control messages are specified in HWMP which are the root announcement (RANN), path request (PREQ), path reply (PREP) and path error (PERR). It also contains three important fields such as destination sequence number (DSN), time-to-live (TTL), and metric except for PERR. The count to infinity problem is prevented using DSN and TTL and the metric field helps to find a better routing path than just using hop count.

As in case of AODV reactive routing mode, the process of broadcasting of route request packet is similar to PREQ broadcast by source Mesh Point (MP) to a destination MP. Thus, the received PREQ packets are newer or better path to the source, MP will again broadcast the updated PREQ. The destination MP in turn will reply back with PREP. During forwarding the control packets PREQ, in case if intermediate MP has no path to destination MP, it just forwards the PREQ element. The few mesh points in WMN will receive the large proportion of the traffic which is destined and offers access to a wired infrastructure and the Internet. A proactive tree based routing mode will be useful in building the same distance vector methodology as used in Radiometric AODV (RM-AODV) and the root node will periodically broadcasts a PREQ element in case of proactive mechanism. An MP in the network receiving the PREQ creates/updates the path to the root, records the metric and hops count to the root, updates the PREQ with such information, and then forwards PREQ. Thus, the presence of the root and the distance vector to the root can be disseminated to all MPs in the mesh. In the proactive RANN mechanism, the root node periodically floods an RANN element into the network. When an MP receives the RANN and also needs to create/refresh a route to the root, it sends a unicast PREQ to the root. When the root receives this unicast PREQ, it replies with a PREP to the MP. Thus, the unicast PREQ forms the reverse route from the root to the originating MP, while the unicast PREP creates the forward route from the originating MP to the root.

IV. ROUTING METRICS

The main problems in ad hoc networks are mobility and power saving. In case of ad hoc networks, the most convenient metric is hop count and this metric is used with routing strategy for fast recovery of instable routes due to link failure during transmission. But when wireless mesh networks is considered the mesh routers with routing protocols are optimized to consider new link quality metrics such as Expected Transmission Count (ETX), ETT, Weighted Cumulative Expected Transmission Time (WCETT) and airtime are [6][12] are proposed towards a quality aware routing in order to reflect more the link variations such as network load, interferences, loss probability, transmission capacity etc.

A. ETX

The Expected Transmission Count (ETX) [13] metric is only of the early routing metrics developed for wireless network to capture the link quality by estimating the number of transmission attempts required for a successful transmission on a particular wireless link. ETX aims essentially to find the route with the highest probability of packet delivery. ETX assumes that wireless links are asymmetric and the ETC is calculated as

$$ETX = 1/(d_f \times d_r) \quad (1)$$

Where d_f is forward link delivery ratio and d_r reverse link delivery ratio of the wireless links. Nodes broadcast small size probes at an average period τ during a time window ω so that each node estimate how much probes it should receive during this period which is τ / ω. The probe contains the number of received probes for each neighbor during the last ω. So, each receiving node becomes aware of the forward delivery ratio for each link. The forward delivery information is broadcasted to make all neighbors aware of the ETX of the link. The small loss probability ETX is considered as best link quality and ETX of a route is the sum of the link metrics.

B. *ETT*

Expected Transmission Time (ETT) is a routing metric proposed by Draves et al. [14] improves ETX by considering the differences in link transmission rates. The ETT of a link is defined as the expected MAC layer duration for a successful transmission of a packet. ETT collects the impact of link bandwidth on the performance of the path selected during routing. ETT is expressed as follows:

$$ETT = ETX \times PS/B \quad (2)$$

Where *PS* is the probe packet size and *B* measures the transmission rate of the link. The ETT of a path p is the summation of the ETTs of the links on the path.

C. *WCETT*

Weighted Cumulative Expected Transmission Time (WCETT) proposed by Draves et al. [15] as a path metric for routing in multi-radio multi-channel WMNs. WCETT is based on ETT. ETT does not consider the presence of multiple channels and multiple radios. This is addressed in [5] and proposed calculation is:

$$WCETT = (1-\beta) \Sigma^{N}_{i=1} ETTi + \beta \max (Xj) \quad (3)$$

Where $\beta \max (Xj)$ estimates the bottleneck channel of a given routing path. This cannot be applied in single radio multichannel operation because broadcast probe message cannot be sent on different channel of the same radio simultaneously. WCETT does not consider the interflow and intraflow interference of the link.

D. Airtime cost

Airtime routing metric [5] is amount of channel resource consumed for transmitting a frame over a particular link. It is calculated for each link as follows:

$$C_a = [O_{ca} + O_p = B_t] [r / (1-e_{pt})] \quad (4)$$

Where O_{ca} is the channel access overhead, O_p is the protocol overhead, B_t is the number of bit in the test frame, r is the bit rate in Mbps and e_{pt} is the frame error rate.

V. SIMULATION ENVIRONMENT

The performance of different routing protocols in WMN environment is simulated using Qualnet 5.2 [16]. The simulation software Qualnet is a software that provides scalable simulations of wireless networks. The network topology of 250 static node are created and placed randomly within area of 1500 m x 1500 m. Each scenario simulation is ran over for 800 seconds and data collected over those runs are averaged. The 802.11 a/g is used as radio type and 802.11s standard as MAC protocol. The broadcast data rate in this simulation is 54 Mbps with Constant Bit Rate (CBR) traffic source, sending at a rate of 1 packet per seconds. The packets with 512 bytes size is scheduled on a first in first out (FIFO) basis [17]. A constant shadowing model with two-ray propagation path loss model is used in this simulation.

TABLE 1: Simulation Parameters

Parameter	**Value**
Simulation area	1500 x 1500 meter
No of Nodes	250
Radio Type	802.11 a/g
Routing Protocol	AODV, OSLR and HWMP
Simulation Time	800 seconds
Data rate	54 Mbps
Data type	CBR
Data packet size	512 bytes
Tx Range	250 m
Traffic Source/Destination	Random
MAC Protocol	IEEE 802.11s MAC
Path Loss model	Two-ray propagation
Channel Frequency	2.4 GHz

The performance of the routing protocol in WMN was evaluated by using several routing metrics. Specifically, four different quantitative metrics were employed, namely ETX, ETT, WCETT, airtime.

TABLE 2: Application Type and Packet Size

Application type	**PacketSize (Byte)**	**Packet Interval**	**Duration**
CBR (Non Real Time)	512	10 ms	80s
FTP (Non Real Time)	1460	8 ms	60s

VoIP (Real Time)	160	20 ms	80s
Video Streaming (Real Time)	512	1 ms	20s

VI. RESULTS AND DISCUSSIONS

The performance of AODV, OLSR and HWMP routing protocol was evaluated by varying the application traffic type, traffic loads and routing metrics. Simulation results obtained are discussed in detail.

A. *Different Application Traffic Types*

The performance of AODV, OLSR and HWMP protocol for wireless mesh networks is carried out through extensive simulations. Four different types of applications are used with different packet size and data rate. The complete transfer of data traffic is taking place from source node to gateway or from gateway to source node. The throughput of the proactive PREQ in HWMP is higher than reactive mode for all application type except VOIP.

A number of simulations have been done to explore the performance of HWMP protocol for wireless internet access. Five different types of applications used with different packet size and data rate. All data traffic is either from source node to gateway (root node) or from gateway to source node. According to simulation, throughput of the HWMP is higher than reactive part for all application type except VoIP.

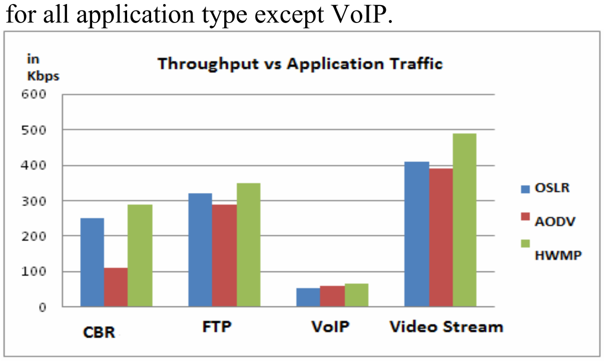

Figure 1. Throughput (in Kbps) versus Different Types of Application Traffic

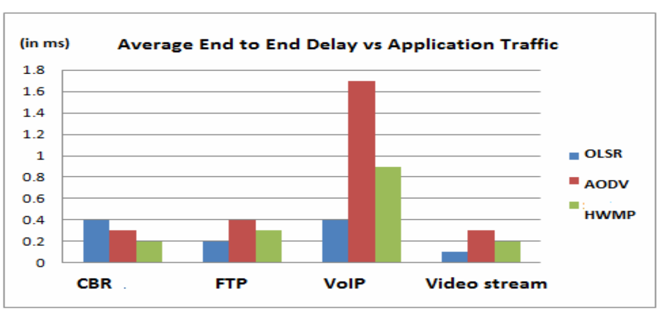

Figure 2. Average End to End Delay versus Different Types of Application Traffic

For average end-to-end delay, HWMP is shows better performance for all the traffic except for Video stream. In case of VoIP the OLSR, AODV and HWMP shows almost 80% less delay than other three application types.

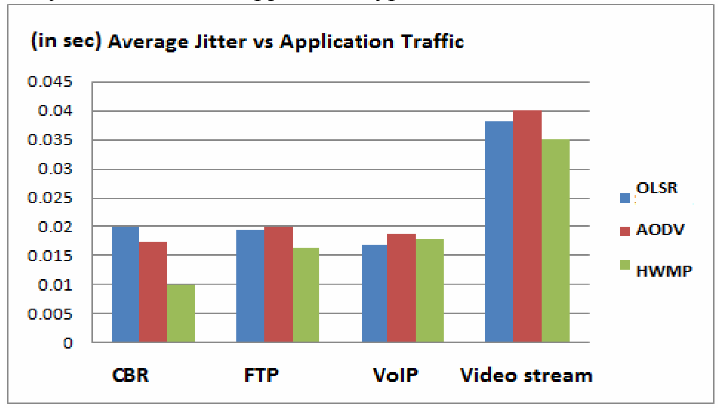

Figure 3. Average Jitter versus Different Types of Application Traffic

The HWMP has low jitter for all the application traffic except for VOIP. The interesting CBR has very low jitter which is very important for real time application. This is because, the path is already established in case of HWMP before any data traffic is generated and sent. But reactive HWMP has to establish the path on demand and hence in all cases AODV has high jitter except for CBR. Overall the HWMP has got better performance in delay, jitter and throughput in Proactive mode. There is a clear message that, application will affect each other. The performance of the HWMP is improved by considering application type during negotiation for path selection before data traffic is sent.

B. *Varying Traffic Loads*

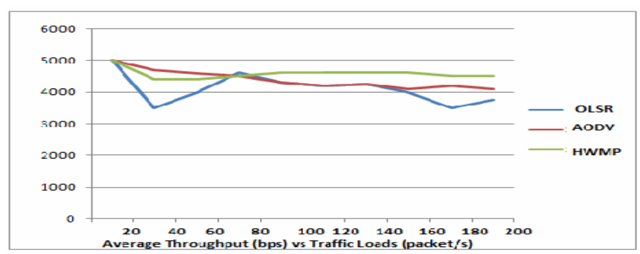

Figure 4. Average Throughput versus Traffic Loads for OSLR, AODV and HWMP

The simulation area 1500 m x 1500 m consists of 250 nodes randomly placed with traffic load is varied from 20 packets/s to 200 packets/s. The performance of three routing protocol in terms of average throughput with varying number of traffic loads as shown in figure. As usual the average throughput of all the three routing protocols are decreasing as the number of traffic loads increased. AODV and HWMP attained highest throughput when compared to OLSR when the traffic loads increased. This is because AODV and OLSR do not require reliable transmission of control messages. The responsibility of sending control message periodically lies on each node in the network and can therefore sustain a reasonable loss of some of the control messages.

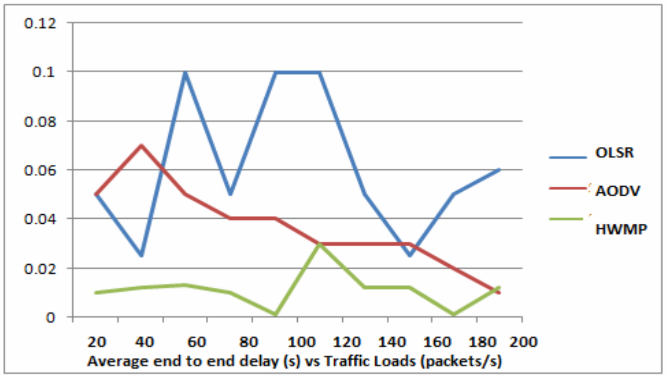

Figure 5. Average end to end delay (s) versus Traffic Loads (packets/s)

The average end to end delay is induced in the network when traffic is varied from 20 packets/s to 200 packets/s is depicted in the figure. It can be observed that HWMP obtained the lowest average end to end delay throughout the simulation as compared to AODV and OLSR. The average end to end delay for HWMP is approximately 2 milliseconds and almost consistent throughout the simulation as the traffic loads increased. The major difference is noticed when OLSR recorded between 80 to 200 milliseconds of average end to end delay and it varies as the traffic load is increased. This is due to the OLSR is required to send broadcast control signal which is a overhead when compared to AODV and HWMP. The results obtained clearly shows the variation in traffic loads have greater influence on the performance of the routing protocol in WMN.

C. *Routing Metrics*

The UDP traffic is generated between the different pairs of nodes while varying the transmission rate and average packet loss of series of tests conducted. The figure shows the average packet loss rate for each metric experience by node *S* when pinging node *D*.

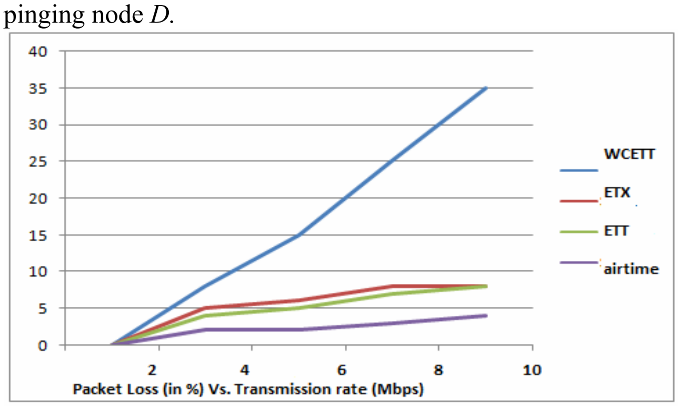

Figure 6. Packet Loss (%) Versus Transmission rate (Mbps)

In common for the all metrics, as the transmission rate increases, packet loss rate also increases. When a link is overloaded by heavy traffic, the more risk of loss because of congestion or time out in queues of gateway happen for all metrics used. The ETX and ETT metrics, the pattern is same for any pair of nodes, when the route is same with all metrics. WCETT has considerable higher at important rates when there is increase in packet loss.

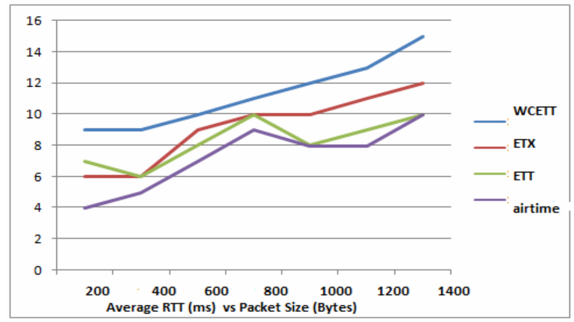

Figure 7. Average RTT (ms) versus Packet Size (bytes)

The average Round Trip Time (RTT) is carried out by transmitting 200 pings between each pair of nodes and repeated 20 times. The average RTT is measure while increasing the packet size. The figure shows that the round trip time produced with the ETX and ETT are lowest among the four metrics at all scenarios. This better performance is expected as the ETT metric is indeed designed to estimate the transmission and retransmission times. Since WCETT is based ETT, the influence of it on the performance of the routing protocol reflects clearly. ETX, RTT and ETT incorporated in AODV influence the performance on packet throughput, end to end delay of the protocol. Air time metrics will try to capture link layer performance parameter by using a procedure in the network layer.

VII.CONCLUSION

In this paper, we have been simulated HWMP protocol using Qualnet network simulator. From the simulation result, it is evident that when most of the traffic is from and towards internet, HWMP Proactive PREQ method performs better than Reactive (on-demand) method in terms of throughput, average end-to-end delay and jitter. The popular routing protocols OLSR, AODV and HWMP are simulated using Qualnet network simulator. The results obtained show the evident that when most of the traffic is from and towards outside, HWMP performs better than OLSR and AODV in terms of throughput, average end-to-end delay and jitter. The main requirement is fairly static nodes with the aims of achieving satisfactory performance in terms of high throughput and low delay. Simulation has been performed to quantify performance of various routing protocols while considering a number of network parameters such as traffic loads, application traffic and routing metrics. It was observed that these parameters have different impacts on OLSR, AODV and HWMP routing methods. Simulated results indicate that HWMP has additional benefits to WMNs as it reached the highest average throughput at lowest end to end delay in comparison to AODV and OLSR. Three routing protocols are configured and evaluated in order to get a comparative study of the most known routing metrics: WCETT, ETX, ETT and airtime in a wireless mesh network. Our measurements show that HWMP-airtime outperforms HWMP-ETX and HWMP-ETT in terms of packet loss, delay and load balancing. Results obtained are related to the considered topology, further study of other topologies is needed to validate this conclusion. In conclusion, we have investigated more on the impact of different application type on routing protocol using different routing metrics and integrated the feature that consider application type for path selection decision.

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