QoS-Aware Multipath Communications over MANETs

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\textbf{Abstract}—To enhance the Quality of service (QoS) communications over mobile ad hoc networks (MANETs), this paper proposes QoS-Aware Multipath Routing Protocol (QMRP). Delay is the most crucial factor for multimedia applications which can be minimized by providing more than one path between source-destination pair as well as choosing the path based on the quality in terms of reliability and stability of the link. To the best of our knowledge no one before included projected load; load introduced by the node requesting a path to a destination into the delay computation for a path between source-destination pair as well as maintaining loop freedom through the neighbor hop list of the source. The originality of the proposed protocol comes from the fact that it introduces this new parameter into route quality computation which makes QMRP unlike its precursors providing more accurate measure of the realistic delay as well as maintaining loop freedom of multiple node disjoint paths using neighbor hop list. Cross layer communications between physical (PHY), MAC and routing layers interact to achieve QoS against the network and channel dynamics by minimizing delay and choosing more reliable and stable paths without requiring any additional resources. Performance evaluation of the proposed protocol against a single path AODV routing protocol using OPNET has been conducted. Results show that QMRP outperforms AODV in terms of E2E delay, packet delivery fraction (PDF) and route discovery frequency. However, routing overhead for QMRP is more than that of AODV due to the discovery of more one path in each route discovery process.

\textbf{Index Terms}—Multipath routing; Quality of Service (QoS); Cross layer; MANET

\section{I. INTRODUCTION}

MANET is an autonomous infrastructure-less multihop network that can be built on demand without the need for any backbone. In MANETs each mobile node operates not only as a host but also as a router by forwarding the traffic of other mobile nodes in the network. The ease of deployment of MANETs make it attractive for many applications such as rescue and recovery in disaster areas, education and research expeditions in remote places and emergency mobile medical units [1]. Nonetheless, MANETs have distinctive challenges including security, power management, efficient dynamic routing and QoS guarantees.

This paper investigates one of the above mentioned challenges; it focuses on routing to support QoS. To design an effective routing protocol for MANETs it’s essential to understand the fundamental characteristics of these networks, MANETs are characterized by (i) dynamic nature; nodes are mobile and changing their location randomly and so topology is unpredictable which means the network status changes in a very short time (ii) radio properties; topology changes can occur even in low, or complete absence of mobility due to variation in the wireless medium as a result of attenuation, interference, multipath effects, shadowing and fading. The previous mentioned constraints of MANETs make it very difficult to achieve hard QoS (e.g., guaranteed delay and constant bit rate (CBR)) without wasting much of the network resources. Therefore, the aim is to develop a QoS-aware routing protocol that provides soft QoS; for more details on soft QoS see [2].

Two factors are required in order to provide quality assurance for delay-sensitive; real time applications in MANETs. First requirement, route selection criterion needs to be QoS-aware. Second, instantaneous response to the dynamics of the network is required so that switching routes are seamless to the user experience over the lifetime of a session [3]. To fulfill the first requirement is to be able to find a path with sufficient resources and including links in the paths that are stable to meet QoS constraints. To address the second issue, multipath routing has gained attention in the research community in the past several years [4]. Multipath
protocols establish multiple paths between source-destination pairs; this approach has many advantages such as fault tolerance, load balancing and QoS assurance [5].

The rest of the paper is organized as follows. Section II describes related work. Section III presents background information. Section IV defines the problem and explains QoS-aware multipath routing protocol. Simulation environment and parameters are detailed in V. Section VI performance evaluation results of the proposed protocol are presented. Section VII draws conclusions.

II. RELATED WORK

The fundamental proposed routing protocols for MANETs are single-path routing protocols use single path to set up communications between source-destination pairs. Multipath routing protocols based on single-path Ad Hoc on Demand Distance Vector (AODV) proposed by Perkins and Royer [6] have been proposed in the literature. As a modified multipath version of AODV M. Marina et al. proposed Ad hoc On demand Multipath Distance Vector (AOMDV) [7]. AOMDV establishes link-disjoint and loop-free paths based on the minimum hop count similar to AODV criteria. Link-disjointness is achieved by a special flooding mechanism, while loop-freedom is ensured by using the notion of advertised hop count value at node N for destination D; this value represents the maximum hop count at N available for D. As a result, alternative paths at node N for D are accepted only if they have a lower hop count than the advertised hop count.

Z. Ye et al. proposed AODV-Multipath (AODVM) [8] which finds multiple node disjoint paths with no limit on the number of paths. Duplicate Route REQuests (RREQ) for the same source-destination pair are not discarded instead recorded in the RREQ table, the destination consequently replies to all RREQs. When intermediate node overhears broadcasting of a Route REPLY (RREP) message from neighboring node, it deletes the corresponding entry of the transmitting node from its RREQ table. When an intermediate node receives a RREP which it cannot forward any further it generates route discovery error message to the node from which it received the RREP; this node will try to look up an alternate path from its table to the source.

The Shortest Multipath Routing Using Labeled Distanced (SMLDR) uses the shortest path regardless of the link quality [9]. SMLDR introduces a metric called limiting distance; that is the minimum distance to the destination known at each node. Lee and Gerla proposed AODV Backup Route (AODV-BR) [10], this is an extension of AODV with a back up route in case of the primary route failure without considering the link quality also it has been shown that the protocol does not perform well in heavy load conditions. Perkins and Royer proposed QoS AODV (QS-AODV), which considers delay joint with hop count as a criterion for choosing the route [11]. Nonetheless, the protocol does not consider the dynamics of MANET; such as topology changes due to mobility and/or link/node failure that will lead to changes in the estimated delay.

A. Valera et al. proposed Caching and Multi-path (CHAMP) routing protocol [12]. CHAMP uses the joint packet caching and shortest multipath routing to minimize packet loss ratio due to route failure. Split Multi-path Routing (SMR) protocol proposed by Lee, S. et al. [13]. SMR is an extension of Dynamic Source Routing (DSR) [14]. This protocol attempts to establish maximally disjoint paths. The source broadcasts a RREQ message; however, unlike DSR the intermediate nodes do not send RREP if they have a path to the destination, from the received RREPs, the destination identifies multiple disjoint paths and sends a RREP packet back to the source for each individual route. SMR performs poorly in highly dense networks due to immense routing over head due to source routing nature of the protocol.

Recent years have shown increased interest in routing protocols that utilize Cross Layer (CL) in MANETs [15][16][17]. H. Sun et al. proposed an adaptive QoS routing protocol by cross layer cooperation [18], based on the current network conditions QoS requirements assured by adaptively using multipath routing and Forward Error Correction (FEC). In [19] M. Li et al presented cross layer multipath routing protocol (EMRP), which exchange information between PHY, MAC and routing layer to utilize the network resources.

Most of previous discussed protocols use minimum hop count as a criterion in finding and establishing paths between source-destination pairs. However, R. Draves et al. [19] have shown that minimum hop count routes without considering link quality could degrade the network performance since they might include wireless links that are bad or congested along the path causing the overall throughput of the network to degrade and cause even more delays than longer paths that consist of good links.

This work represents a follow-up to a previous work of ours [20] where the performance of QMRP over wireless link has been studied and compared with single path routing protocol AODV. On the contrary of the previous work that uses Max_Tx_out this work uses a more realistic measure Actual_Tx_out; actual transmission rate out from the MAC layer is used in order to better capture the channel dynamics to enhance the chances of QoS support over MANETs. In addition the average queuing delay is used in the delay computation instead of using current queue size solely along with queue occupancy factor. Moreover, a salvaging mechanism adopted similar to that in [21]. Also, a preemptive handoff mechanism is used to switch to paths with lower Expected Path Delay (EPD) value as in (1) through the use of an update packet to check the status of the paths, see section V for more details.

III. BACKGROUND AND TERMINOLOGY

A. AODV

AODV is one of the most studied on demand reactive routing protocols [22]. Sequence number plays an important role in AODV and serves as a time stamp.
Each node maintains a monotonically increasing sequence number, every time a node generates a routing message it increments its sequence number. The node also keeps the highest known sequence number for each destination in its routing table. The highest sequence number means a fresher up to date route.

When a source node \( S \) needs to communicate with a destination node \( D \) in the network and \( S \) does not have a route to \( D \), it initiates a route discovery process that starts by broadcasting a RREQ packet tagged with a sequence number to achieve limited flooding of the RREQ. Every node that receives the RREQ checks its routing table to see if it has a route to \( D \). If it does, it sends a RREP back to \( S \); otherwise it rebroadcasts the RREQ incrementing the hop count by one. This way, when a node receives several RREQ through multiple routes, it discards RREqs that result in a higher hop count. Intermediate nodes between \( S \) and \( D \) create an entry for the neighbor ID in its routing table from which the RREQ was received. The destination \( D \) responds to the first RREQ it receives by unicasting a RREP, intermediate nodes forward the RREP back to the source according to their routing table.

Every node maintains an entry in its routing table that updates the route expiry time. Every route in considered valid for a certain time after which the route entry is deleted from the routing table. Whenever a route is used to forward data packets the route expiry time is updated to the current time plus the Active Route Timeout. When a route expires the node deletes the entry for the route and invalidates it. When a link to the next hop is broken the node generates a Route Error (RERR) message to all nodes listed as active neighbors to the node in its routing table and invalidates all routes through the link [23][24] the node increments the sequence number and sets up the hop count to \( \infty \) making AODV loop free at all times, for more details see[6].

B. Multipath and Disjointness

Multi-path routing protocols are of special interest in mobile ad hoc network because of limited bandwidth of mobile nodes. Multi-path routing in Ad hoc networks permits the establishment of more than one path between source and destination to assure the QoS requirements. Because of dynamic nature of Ad hoc networks due to mobility and nodes joining and leaving the network, limited transmission range and limited source power of the nodes, multi-path routing is needed to increase network resilience and load balancing, which decreases congestion and bottlenecks, increases aggregate bandwidth, reduces end to end delay, delay variation and packet loss ratio (PLR) [25] [26] [27]. It was found in [27] that the performance of multipath outperforms multiple descriptions techniques.

Multi-path routing protocols could be classified into two types; node disjoint and link disjoint routes through the network. Node disjoint paths; which have no node and so no link in common provide higher degree of fault tolerance than link disjoint paths; which are paths that have no link in common. Since node failure in link disjoint can cause many links to fail while node failure in node disjoint will cause only one link to fail which means paths fail independently. However, node disjoint paths are harder to find, therefore, less abundant than link disjoint paths [25] [26]. Nonetheless, if the aim is to accomplish load balancing then node disjoint paths are more effective also node disjoint can increase the life time of the whole network by avoiding draining the resources of a node that is located in strategic location as node \( I \) in Fig. 1.

Suppose that node \( S \) needs a path to destination \( D \), as can be seen \( S \) has two link disjoint paths to \( D \); \( S-A-I-E-D \) and \( S-B-I-F-D \) but one node disjoint path to \( D \) since \( I \) is common node between the two paths. Since \( I \) is part of two link disjoint paths this can cause node \( I \) to reach exhaustion point and causes \( I \) to use its resources in a very short period of time which might cause node \( I \) to fail and hence all paths through \( I \) fail increasing the number of dropped packets and causing longer delays which may also lead to network partitioning this is similar when a node participating in more than one path move out of range due to mobility, hence the choice was to choose node disjoint multipath routing protocol.

C. Cross-Layer Design

The exploitation of dependence between different layers of the protocol stack to maximize the performance gain is referred to as Cross-Layer Design. Taxonomy of cross-layer schemes is suggested based on the violations done to the layered approach [27].

Such a design has its pros and cons. On one hand, it violates the layered architecture compromising the independence of protocol design at one layer from other layers. In addition, many such violations will result in the collapse of the layered approach affecting system longevity [29]. On the other hand, nevertheless, cross-layer design addresses issues arising from the nature of the wireless medium which cannot be addressed otherwise; such issues include the broadcast nature of the wireless medium; the channel response time variations and the ability to receive multiple packets at the same time (e.g., see [30]).

![Figure 1. Node vs. Link disjointness](image)

Supporting QoS over ad hoc networks while being aware of resources availability cannot be accomplished without a cross layer design as reported by different studies [31][32]. In addition, many schemes involving a cross-layer design have reported better performance when compared to the traditional approaches [33][34][35] [36][37][38][39].
IV. PROBLEM STATEMENT AND MULTIPATH APPROACH

The objective is to develop a multipath routing protocol, the emphasis is on providing QoS for Qosstringent applications rather than on accommodating many connections and not fulfilling the QoS requirements. However, the limited resources and the dynamics of MANETs in addition to the wireless medium unpredictability make the task even harder to achieve. The question has two parts; (i) what approach to take and (ii) how to apply it.

To answer the first part, a multipath approach will be taking. The multipath aim is to find more than one path between Source-destination pair to maintain QoS assurance for the life time of a connection. Multipath increases network resilience (i.e., reliability through fault tolerance), load balancing which decreases congestion and bottlenecks also, it increases aggregate bandwidth, reduces end to end (E2E) delay, delay variation and packet loss ratio (PLR). Additional benefits of multipath routing include reduction of computation time that CPUs require, high call admission ratio in voice applications [1][2].

The main quality impairment for delay sensitive application voice is delay. ITU-T G.114 recommends [39] the one way transmission time between 0-150 ms delay is acceptable for voice. The time when a frame is generated at the source until it reaches the destination is the End-to-End (E2E) delay. E2E delay consists of packetization, queuing, propagation, transmission, and play out delay. Play out delay is the time a packet spends in the buffer at the destination for smooth play out as in Fig. 2.[40].

Bit Error Rate (BER) as a function of Signal to Noise Ratio (SNR) which is a function of distance that translates into modulation reflects the link quality and stability. Figure 3 [42] shows BER vs. SNR for five digital modulation schemes: binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), and quadrature amplitude modulation (QAM) with different number of bits per symbol.

How to employ multipath to accomplish QoS, will be through cross layer approach. The cooperation and the interaction between different layers; by extracting some crucial parameters from the physical and MAC layers and feed them into the routing layer.

V. SYSTEM ARCHITECTURE AND PROTOCOL DYNAMICS

The proposed architecture is general and works with any application as well as any routing protocol that supports multipath as shown in Fig. 4. The proposed QMRP extracts the SNR from the physical layer and passes it to the MAC layer where the later compute the actual transmission rate out from the node and the queue size then pass these values to the routing layer where delay computation takes place to find the path with the lowest delay between source-destination pair to assure QoS based on link quality. Fig. 5 shows the dynamics of the protocol.

A. Protocol Overview

This section describes the details of QMRP protocol which computes multiple node disjoint paths based on the feedback from the physical and MAC layers. QMRP improves AODV significantly by modifying the phases of route discovery, route selection and route maintenance. In this work route broadcasting packet refers to RREQ/RREP.

The QMRP protocol establishes multiple node-disjoint paths that will experience the lowest delay. Most delay-aware routing protocols in literature use the current delay or history to estimate end-to-end (E2E) delay as a metric. However, this is not an accurate measure of the delay that is going to be experienced by the route-requesting node since this node will increase the total network load. Once the network load increases, E2E delay that was obtained through route broadcasting is no longer accurate. Introducing the projected increase in load into the computation of delay a more accurate delay value will be obtained once the node starts injecting its traffic into the network. The protocol phases are explained below.

B. Route Discovery: Reverse Path

The route discovery process of QMRP starts when node S needs to communicate with another node D and S does not already have a path to D, S broadcasts a RREQ tagged with a sequence number to achieve limited flooding of the RREQ. In AODV every node that receives the RREQ rebroadcasts the RREQ incrementing the hop count by one. When a node receives several copies of the same RREQ, it uses only the first copy to form the reverse path; all duplicates that arrive later are discarded. Nonetheless, since the aim is to find multiple paths these duplicates of route broadcasting could be utilized to establish multiple paths, however, only those route broadcasting that guarantee loop freedom and node disjointness will be used to establish reverse paths.
QMRP introduces two additional fields to the route broadcasting packet the Expected Path Delay (EPD) field; which is the cumulative delay up to and including the node itself and a load field; which is the new load that will be added to the network by a node requesting a path to a destination. EPD is initialized to zero while the load initialized to the new amount of traffic that will be added into the network by the source requesting a path to a destination.

To guarantee loop freedom, (i) QMRP preserve the following update rule; keep paths for the highest known destination sequence number. When a route broadcasting packet received by a node with higher sequence number all paths correspond to lower sequence number will be invalidated. (ii) QMRP guarantees loop freedom by utilizing a neighbor hop list; a list of one hop a way neighboring node of the source node that initiates a route discovery process by generating a RREQ requesting a path to a destination that is the first hop traversed by a RREQ. (iii) Maintaining the invariant that all nodes can only broadcast one copy of a RREQ per unique neighbor hop. A maximum of three route broadcasting with unique neighbor hop is allowed.

Obtaining the neighbor hop list is as follows: if an intermediate node, I, receives a RREQ and the hop count is zero, the node checks the source of the RREQ and the node from which it received the RREQ if they match it increments the hop count and adds itself into the neighbor hop field of the RREQ in addition, an entry for the node from which it received the RREQ is added. Every subsequent node on the path maintains a list of neighbors called neighbor hop list associated with every RREQ message received. When a RREQ is received the neighbor hop field of the RREQ is checked against the neighbor hop list before adding an entry for the path into the node’s routing table. Additionally, before rebroadcasting the RREQ, intermediate node of S, I, increments the hop count of the RREQ and updates EPD field with its computed delay as in equation (1).

When a node receives duplicates of the RREQ with unique neighbor hop it records the information from these packets in a RREQ table which contains the following fields, source_id, dest_id, neighborhop_list which contains neighbor Id, EPD, last hop, Exp_timer. Where the source_id is the source that generates the RREQ, dest_id is the destination to which the RREQ is intended, neighborhop_list is the neighbor hop list, EPD for each neighbor in the list, last hop is the last hop on the path and Exp_timer is the expiration timer.

To explain how QMRP guarantees loop freedom using the neighbor hop list Fig. 6 shows the source node S wants to communicate with destination node D, S broadcasts a RREQ packet to its neighboring node within transmission range, in this case nodes A and B will receive the RREQ. Each of A and B will add itself in the neighbor hop field in the RREQ and rebroadcast the RREQ, node I receives both RREQ from A and B and accepts both of them since they arrive via different neighbor hop of the source node S, node C receives the RREQ from node B with neighbor hop field B and broadcast it, node I receives it and checks the neighbor hop field which is B in this case against its neighbor hop list, however, node I has already received a RREQ with the same neighbor hop B so it discards the packet and don’t broadcast it any further.

In order to update the node’s routing table, an entry is only added or updated if route broadcasting satisfies any one of the following criteria: (i) No route entry exists for the originator of the route broadcasting. (ii) Sequence Number of the route broadcasting packet is greater than the sequence number of the existing route entry. (iii) Sequence numbers are equal and the EPD of the route broadcasting is less than the EPD of the existing route entry and number of valid RREQs is less than three.
C. Route Reply: Forward Path

If a node receives a RREQ and it is the destination of the RREQ, the node adds/updates the entry in its routing table and generates a RREP. The RREP is unicasted back to the source node and the EPD field of the RREP is initialized to zero. Subsequent nodes that receive the RREP maintain their routing table according to the conditions specified, increment the EPD field of the RREP with their computed delay up to and including the node itself, and then forward the RREP to the next hop towards the source node that was found through the reverse path during route discovery process based on the minimum EPD; so the node checks its RREQ table and forward the RREP to the next hop with the lowest EPD.

When the destination receives subsequent RREQs from different last hops it generates a RREP to each distinct last hop and per unique neighbor hop. Additionally, all intermediate nodes can only forward one copy of the RREP per source and per destination sequence number; this is to guarantees node disjointness of the paths. If no reverse path is available, the RREP is discarded; this is also in case the node is already participating in an active path for the same source-destination pair. When the source receives all RREPs the RREP from the destination; a maximum of three paths in this study, it uses the path with the lowest EPD value and saves the other two as a backup paths in case the primary path fails for any reason.

The EPD includes various parameters from the MAC; data rate received, current queue size, and SNR from the PHY layer that is reflected in the actual transmission out rate. The equation for computing the EPD is give by (1):

\[ EPD = \sum_{i=0}^{n} \left( \bar{D}_i + \frac{\Delta t \cdot (DR_i + 1 - \text{Actual}_T \text{X}_{\text{out}(i)})}{\text{Actual}_T \text{X}_{\text{out}(i)}} \right) \]

Where \( \bar{D}_i \) is the average queuing delay at a node and is given by (2)

\[ \bar{D}_i = \alpha \cdot \bar{D}_{i-1} + (1 - \alpha) \cdot \bar{D}_j \]

Where \( \alpha \) is the queue occupancy and is given by (3)

\[ \alpha = \frac{\text{queue}_{size} - \text{queue}_{length}}{\text{queue}_{size}} \]

\( i \): a node along the path
\( \text{queue}_{size} \): is the size of the queue at node \( i \)
\( \text{queue}_{length} \): is the length of the queue at node \( i \)
\( j \): is the current period;
\( DR_i \): data rate calculated based on all traffic received at node \( i \), this parameter is passed from the MAC.
\( \Delta t \): time difference between the current time and an arbitrary time after the new load has been introduced into the network, this can vary according to how long routes are expected to remain active based on mobility and active route timeout value, for simplicity purposes \( \Delta t \) is assumed to be 2 seconds.
\( l \): is the proposed new traffic load that is added by the source initiating a route discovery process into the network. 

\[
\text{Max}_{\text{Tx}_{\text{out}}}(i) = \text{Data } \text{Tx}_{\text{Rate}} * \beta * (1 - \text{BER})
\] 

(4)

In this study we are taking the Actual \_Tx\_out actual transmission out from a node that is extracted from the MAC layer, which is based on the above equation (4).

\( \text{Data } \text{Tx}_{\text{Rate}} \): rate at which a node is able to transmit/receive;

\( \beta \): network efficiency factor, which is typically between 0.7-0.8.

BER: Bit Error Rate.

C-Routemanagement

Route maintenance in QMRP is an extension to that of AODV and is achieved by the means of generating a Route ERRor (RERR) packet. When an intermediate node, \( I \), discovers link/node failure; due to mobility, undetected hello packet, etc…, it generates a RERR packet. The RERR packet propagates towards all nodes that have a path through the failed link and invalidates all available paths in all nodes along the way that have a path through the failed link. When the RERR packet reaches the source and the source still in need for a path to the destination it switches to the second available path it the path list at the source node. If all paths are invalid and the source is still in need for a path to the same destination the source stars a new route discovery process as explained previously in A.

Each path has an ID that is a combination of the neighbor hop of the source as well as the last hop on the path which is the previous hop to the destination. At periodic interval every \( \frac{\Delta t}{2} \) the source unicasts an update packet to check the status of the path with EPD value initialized to zero towards the destination, when the destination receives the update packet it initializes the EPD to zero and sends it back to the source when the source node receives the update packet it checks the EPD field against the other EPD for alternate paths in its routing table. The preemptive handoff basically takes place when the path EPD value increases and the routing table has a lower EPD for another path it switches to the path with lower EPD; this is in order to maintain QoS for the life time of a connection and always use the best available path in terms of EPD as the primary path for data transmission Also, QMRP uses a salvaging mechanism where packets transmitted over failed path are retransmitted over back up paths.

VI. SIMULATION ENVIRONMENT AND EVALUATION

A. Simulation Environment

OPNET [43] simulation package is used to evaluate the performance of the proposed QMRP protocol and compare it with the AODV. The random way point mobility [44] model is used as the mobility model. Constant Bit Rate (CBR) where generated by all nodes of size 512 bytes each plus headers of different layers (UDP/IP/MAC). All different traffic connections set up between source-destination pairs are at random. Each reading across all scenarios and experiments is the average of 10 runs. The rest of the simulation environment parameters are summarized in the Table I.

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<th>Parameter</th>
<th>Value</th>
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<td>Number of Transmitting nodes</td>
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<td>Traffic Model</td>
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<td>Queue size</td>
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B. Performance metrics

The following four key metrics considered to evaluate the performance of the protocols.

1) Average E2E delay: is the difference in time between the reception of a packet by the destination and the moment it was generated by the source; it includes all possible delays encountered by a packet.

2) Packet Delivery Fraction: is the amount of traffic received successfully at the destination as a fraction of the traffic generated by the source node.

3) Route Discovery Frequency: number of all RREQ packets generated per sec by all sources

4) Normalized Routing Load: is the number of control packets transmitted per data packet delivered at the destination, each hop wise communication is counted as a new transmission.

C. Results and Discussion

1- Varying mobility: (experiment I)

The first set of experiments Fig. (7-10) show the four key performance metrics as a function of mobility; speed in m/s. Traffic is 20 connections through the network and the speed varies between 0 static to 25 m/s, the rest of parameters are given in table I. To analyze the performance of all protocols more accurately, we turned off one node and turned on another node randomly every 50 seconds throughout the simulation that sums up to a total of 10 nodes in the network to account for node failure due to power exhaustion; this will cause paths to fail through that node.

Fig. 7 depicts average E2E delay. QMRP has about 32% improvement over AODV in average E2E delay at high speed; this is due to the fact that AODV path selection criteria is based on minimum number of hops between
source-destination pair regardless of the nodes status along the path. On the other hand paths in QMRP are established based on the *EPD*. QMRP avoids congested nodes by choosing paths based on minimum *EPD* instead. QMRP considers delay encountered at each node into the computation of the *EPD* when establishing paths between a source–destination pair. The *EPD* includes not only the current delay, but also the expected delay due to the new load introduced by the source node into the network as well as queuing delay the most contributive factor in E2E delay. Due to mobility frequent link breaks occur in an environment such as MANET which causes AODV’s need to initiate additional route discovery process/es to continue transmission. During the search for a new route packets are being delayed and/or dropped.

Also this may cause congested nodes to exhaust their power energy quickly causing failure of a session, more dropped packets and may lead to network partitioning. QMRP decreases the number of dropped packets due to the fact that the protocol allows self load balancing by avoiding bottlenecks; along the path when establishing multiple paths based on many factors included in (1). Therefore, packet losses are due to mobility as well as node/link failure as mentioned previously.

Fig. 7 shows packet delivery fraction; the difference between the single path AODV and QMRP is about 27% increase in successfully transmitted packets this is due to the fact that QMRP is a multipath protocol and takes into consideration the channel reliability through the SNR from the PHY layer and queuing delays at each node along the path as per to equation (1).

Most of the proposed routing protocols such as AODV don’t consider channel conditions, load balancing causing heavily loaded nodes along the path between source-destination. As a result heavily loaded nodes with longer queues will cause longer delays.

As can be seen in Fig. 9 QMRP has up to 35% less than AODV in terms of route discovery frequency. This is due to the nature of the single path AODV vs. multipath in QMRP as well as node disjointness that guarantees nodes/links fail independently. In addition path selection criterion in AODV can increase heavily loaded nodes along minimum hop count path which will also increase the probability of node failure and link breaks accordingly. Also, as mobility increases that will cause links to fail which means AODV has to initiate a new route discovery process during this search for an alternative path, packets are being queued; delayed and/or dropped.

Fig. 10 shows the normalized routing load, even though QMRP has less route discovery frequency than AODV, QMRP has more overhead per route discovery process due to more forward of control packets. However this overhead is relatively low.
2- Varying number of connections: (experiment II)

In this second set of experiments, Fig. (11-14) the number of connections is varied between 0-40 connections while fixing the speed at 5 (m/s). Increasing number of connections will test the routing protocol under tense conditions. The rest of parameters remain the same as in experiment I.

As the number of connections increases so does the average E2E delay for both protocols as in Fig. 11, however, QMRP has the lower delay; this is due to the use of EPD in choosing the route. As (1) shows it has parameters from the PHY and MAC layers, so the path selection criterion chooses more stable and reliable links, this means packets along more reliable paths encounters less E2E delay. In addition QMRP does some indirect self load balancing strategy by avoiding congested nodes with longer queues.

Packet delivery fraction shown in Fig. 12 has the same behavior; as number of connections increases packet loss increases again with QMRP more packet delivered successfully, this is because QMRP has more reliable and stable paths so the probability of dropping packets decreases as compare to AODV. In the case of AODV which is based on minimum number of hops per route without considering the node’s queue status and channel conditions causing congested nodes along the path which translates into longer delays and more dropped packets.

Fig. 13 shows that after 20 connections the difference increases significantly between AODV and QMRP in terms of route discovery frequency as a result of node failure and/or link break which means for the single path AODV a new route discovery process.

Even though multipath routing protocols less route discovery processes, still it has more routing overhead over all as compare to single path routing protocol such as AODV which is illustrated in Fig. 14. QMRP has more routing overhead per each route discovery process, yet this difference is insignificant; less than 10% only when number of connections is more than 30 connections.

VII. CONCLUSION AND FUTURE WORK

In a dynamic environment like MANET on demand multipath routing protocols can achieve many aims such as but not limited to lower delay, load balancing, network resilience through network fault tolerance and increase packet delivery fraction.

This paper proposes QoS-Aware multipath routing protocol (QMRP) a node-disjoint protocol that considers channel conditions when establishing multipath between source-destination pair in wireless ad hoc networks to overcome the limitations of other single path; AODV.
QMRP uses the EPD as a metric to choose the route which takes into consideration the SNR at the physical layer as well as the actual data rate from the MAC layer in addition to the node’s average queuing delay to reflect the link quality and the medium utilization around the node, respectively. Without loss of generality QMRP introduces the new load -significant in case of delay sensitive applications-; that is introduced by the node requesting a path to a destination in the computation of the EPD to capture the real channel conditions. QMRP does self load balancing by avoiding congested nodes along the path by avoiding nodes with longer queues. As the results show, QMRP protocol outperforms the AODV protocol in terms of average E2E, packet delivery fraction, route discovery frequency. On the other hand, QMRP has insignificance more routing overhead than that of AODV.

Future work will focus on the analytical and statistical analysis for QMRP vs. other routing protocols. Also more investigation of the performance of QMRP with IEEE 802.11e since it was developed to offers QoS capabilities to WLAN. More thorough research of the protocol is needed under Rayleigh fading channel since this is usually the case for MANET’s environment.

REFERENCES


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