ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com
Journal DOI: 10.21474/IJAR01

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

LQM: A Link Quality Based Multipath Scalable Proactive Routing Protocol for Mobile Ad Hoc Networks

***Sanjeev K. Prasad[1] and Karamjit Bhatia[2].**

1. Department of Computer Application AKGEC, Ghaziabad UP India.
2. Department of Computer Science GKV, Haridwar UK India.

Manuscript Info

Manuscript History:

Received: 12 May 2016
Final Accepted: 19 June 2016
Published Online: July 2016

Key words:
Mobile Ad hoc Network, Dynamic Address Scheme, Scalability, Link Quality, Link Failure Rate, Link Bandwidth.

Corresponding Author

Sanjeev K. Prasad.

Abstract

The day by day rising interest in multimedia communication has immensely grown the size of the Mobile Ad hoc Networks. For more than hundred nodes the mobile ad hoc networks are not able to work effectively as these are not scaled properly. Current ad hoc routing architectures are largely based on flat static addressing schemes and need to keep track of each node individually. This leads to a massive overhead problem as the network size grows. Many solutions have been proposed to overcome this problem and the most appropriate solution is to divide the whole network into the groups or hierarchy. This paper aims to propose a Link Quality based Multi-path data forwarding routing protocol, called LQM, which is based on Dynamic Address hierarchical scheme for Mobile Ad hoc Networks. In this work we emphasized on two prime factors - link failure rate and link bandwidth that mainly govern the link quality of network. The performance of LQM has been investigated with the simulation runs across different experimental setups. The results confirm that LQM exhibits better or at least comparable performance with respect to DART and M-DART, the two dynamic address hierarchical scheme based routing protocols in all considered scenarios.

Introduction:-

A Mobile Ad hoc Network (MANET) is a wireless network in which the mobile nodes are able to self-configure with other mobile nodes in the network. Every node in a MANET is free to move autonomously in any direction, and will therefore change its links to other devices frequently. Each node must forward traffic unrelated to its own use, and therefore be a router. Nodes in the network should be able to sense and discover nearby nodes. As the network size increases, the performance of the communication is likely to degrade due to network splitting and network congestion. The mobility and the density factors influence the scalability of the ad-hoc routing protocols.

Routing is the process of discovering paths in a network to send network traffic [5]. Several routing protocols for the mobile ad-hoc networks are presented in the MANET working group. Mobile ad hoc routing protocols can be classified on several aspects. On the basis of the addressing schemes the mobile ad hoc routing protocols are classified in two categories - flat address scheme protocols and dynamic address scheme protocols. In flat address routing, when a node moves no new address is assigned to it whereas in dynamic address routing a new address is assigned to a node whenever it changes its location [1]. Some flat (or static) address based routing protocols are DSR [10], AODV [9], DSDV [11] and OLSR [31] while some dynamic address based routing protocols are DART [1], M-DART [7], ODR [13] and ATR [22].

Ad hoc networking technology has seen tremendous advancements over the last decade but it has yet to evolve as a widely deployed technology. Ad hoc networks related research seems to have downplayed the importance of scalability issues [6]. In fact, current mobile ad hoc architectures do not scale well beyond a few hundred nodes. In order to achieve better performance of network technologies, scalability is a crucial requirement [1]. The *scalability* is the ability of a routing protocol to perform efficiently as one or more inherent parameters of the network grow to be large in value [23]. Decentralized and autonomous mobile nodes improve the scalability of MANETs to work with respect to various design parameters including the required *bandwidth*, *time delay* to exchange control messages, and *the total number of mobile nodes* [31].With scalability as a partial goal, many efforts *using flat addressing scheme* have been made in the direction of hierarchical routing and clustering routing approaches [2] [3] [4]. A feasible way of achieving scalability in ad hoc routing is by adopting dynamic addressing mechanism [7]. With dynamic addressing, nodes change addresses as they move, i.e. here network assigns new address to the node.

The proposed protocol *LQM* is a link quality based multipath dynamic address routing protocol. It incorporates the Distributed Hash Table based shortest-path routing scheme [8]. In design of this protocol a due attention is given to the *link quality* as a successful transmission of data requires assured link and sufficient bandwidth. Keeping this in view, we adopted two metrics **-** *link failure rate* and *link bandwidth* to achieve the scalable property in LQM. The *link failure rate* metric is responsible for end-to-end connectivity check whereas *link bandwidth* provides high throughput in highly dynamic and large mobile ad hoc network in presence of hefty data traffic [25]. The main difference between LQM and M-DART is that M-DART is based on ETX metric while LQM is based on ETT metric. The ETX and ETT metrics are discussed in section 4.3. Performance comparison of proposed protocol LQM with a unipath routing protocol DART and a multi-path routing protocol M-DART is studied using parameters *Packet Delivery Ratio, Hop Count, Routing Overhead, End-To-End Delay* and *Throughput.* Several simulation runs are performed with different experimental setups and performance analysis is carried out.

The paper is organized as follows: Section 2 discusses previous work of Dynamic Addressing Routing; Section 3 discusses the system architecture of Dynamic Hash Table (DHT); Section 4 discusses the LQM routing protocol related issues; Section 5 discusses the experiment setup and performance analysis of LQM, DART and M-DART; and finally, Section 6 includes the conclusion and future work.

Related work:-

In literature review, we start with a brief idea of dynamic addressing routing, also referred to as tree based routing. In network terminology, dynamic addressing means the nodes can change addresses as they move, so that their addresses have a topological meaning. Dynamic addressing is a feasible way to achieve scalable ad hoc routing [1].

Dynamic Address RouTing (DART) [1], proposed by Jakob Eriksson et. al., is a unipath algorithm based on hop-count metric of routing and illustrates how dynamic addressing could support scalable routing. DART uses Distributed Hash Table (DHT) [8] for dynamic address based routing decisions. DART finds the path in a given subtree with minimum cost, and once in that subtree finds the minimum route cost to the next, lower-level, subtree. In the event of route failure, a current path to the given destination address may not be available, even the network is connected, and all address allocations are correct. Such temporary route failure scan is the result of route propagation delay, when a smaller route breaks, there is an interval of time where nodes are not aware of the route breakage, and a new longer path has not yet been established. In this situation, the default action by a router that finds itself without a valid path would be to drop the packet, and potentially send a “no such route” message back to the sender. DART does not have good mechanism to handle failures routes. Multipath enhancements to DART, called Augmented Tree based Routing (ATR) [22] and Multipath Dynamic Addressing Routing (M-DART) [7], have been reported in literature. The DHT system of DART is replaced by a global lookup table in ATR. This lookup table is available to all the nodes of network resulting in a great impact on the address discovery, a key process of the routing protocol [22]. M-DART is a multipath flavor of DART. M-DART stores in routing table the multiple paths from source to the destination and discovers the smallest path. However, sometimes shortest path in M-DART does not provide the best root. It adopts a simple approach of using the best available path based on hop-count until it fails else it switches to the next best available route. M-DART is able to exploit all the available paths without introducing any communication or coordination overhead with respect to the original protocol. An Opportunistic DHT-based routing (ODR) for Disruption Tolerant Networks (DTNs) is proposed by Caleffi and Paura [13]. Resorting to the opportunistic routing paradigm and to a location-dependent addressing schema, the proposed routing scheme presents an end-to-end connectivity for DTN scenarios across different environmental conditions in presence of light data traffic. ODR produces high routing overhead due to the hidden terminal problem.

A few authors considered link quality metric for flat address routing scheme [15, 16, 17, 18, 19, 20]. DART and M-DART consider link metric for dynamic address routing scheme. Both routing protocols use the link metric ETX [25] which attempts to achieve maximum throughput of the link. However, this metric does not consider link bandwidths. Performance evaluation and comparisons of M-DART with other MANET routing protocols considering different parameters such as energy consumption, end-to-end delay, throughput, packet loss, hop count, packet delivery fraction have been reported in literature [27, 28, 29, 30].

System Architecture Of Dynamic Address Based Routing Protocol:-

In order to understand operational and functional design aspects of LQM, we first present the brief description of *Dynamic Address* scheme implemented through the Distributed Hash Table. Next, an overview of some key features of the dynamic addressing routing are presented in sections 3.1 and 3.2. Network addresses are assigned to network nodes, in *dynamic address* scheme, on the basis of the node position inside the network topology. With the help of dynamic addressing, a protocol is able to implement hierarchical routing in a feasible way, reducing considerably the routing state information maintained by each node. The mapping between node identities and network addresses is provided by a Distributed Hash Table (DHT).

Network Address Structure:-

A tree based structure is found to be suitable for dynamic addressing routing. The structure of the network can be represented as a *complete binary tree* of $l + 1$ levels [7] [Fig. 1a] with leave nodes at level 0 and root node at level l. The address of a node in this tree topology network consists of l bits. The non-terminal nodes at k^{th} level (called *level-k subtree*) specifies a set of leaves having a common address prefix of $l - k$ bits. Each leaf has a network address associated with it. For example, with reference to Fig. 1a, the node with the label 00X is a level-1 subtree and represents the leaves 000 and 001.

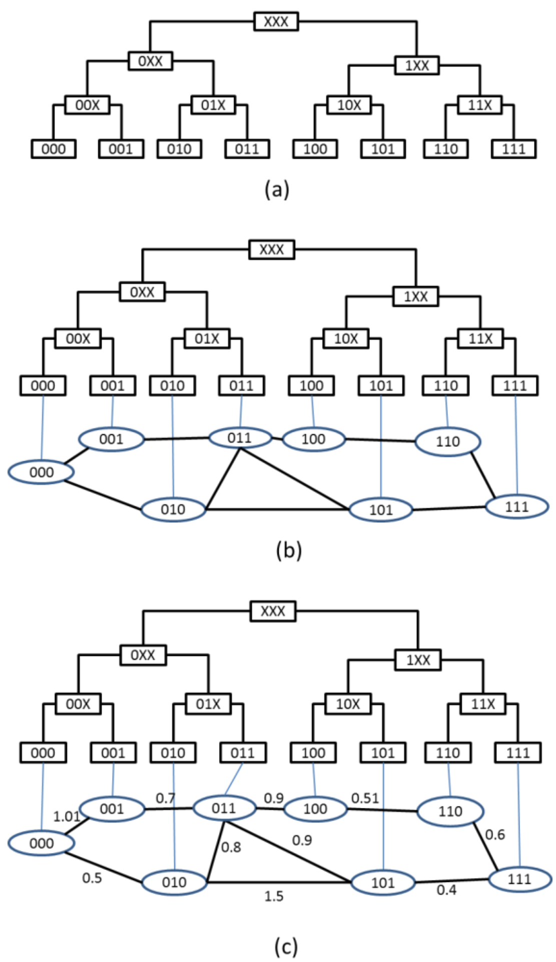

Fig. 1:- Relationship between address space structure and physical topology with link quality

Each network address (leaf) has *l* siblings. The k^{th}-*level* sibling of a leaf *f* is defined as the level-*k* subtree which has the same parent with the level-k subtree to which the leaf *f* belongs to. In Fig. 1a, the node with the label 1XX is the level-2 sibling of the address 000, and the address 100 belongs only to this sibling. The address space structure can be visualized as an *embedded network* built upon the actual physical topology in Fig. 1b.

Data Forwarding In Dynamic Address Based Routing Protocol:-

In multipath data forwarding scheme such as in M-DART, Routing Update (RU) packet is broadcasted periodically in the network. Each node receives and notifies its neighbors regarding the presence of routes towards a destination sibling without detailing the paths for packet transmission. A major decision issue arises when these route notifications are used in multi-path hierarchical routing when the multiple paths have same route cost. In view of Fig. 1b, the routing table for node 000 is given in Table I. Let node 000 wishes to transmit packets to node 111. The node 000 has two paths towards destination, one via 001 and another via 010, both nodes offer a route cost 3 toward the sibling 1XX. This is the situation of a tie where node 000 is unable to decide which one is the best suitable route to propagate the packets. The tie breaking strategy selects one of the routes arbitrarily.

TABLE 1:-ROUTING TABLE FOR NODE 000

Sibling ID	Next Hop	Route Cost	Network ID	Route Log
001	001	1	ID(000)	001
01X	001	1	ID(010)	001
	010	1	ID(010)	010
1XX	010	3	ID(100)	100
	001	3	ID(100)	100

PROPOSED ROUTING PROTOCOL LQM:-

In this section, the multi-path routing strategy based on link quality of LQM is presented. The link quality is taken to be a function of *link failure rate* and *link bandwidth*. Sections 4.1 through 4.4 present a detailed description of the multi-path data forwarding strategy of LQM.

LQM Protocol Overview:-

The LQM is a proactive routing protocol which stores all necessary information for routing in neighbor table and routing table. Being a multipath routing protocol LQM proactively discovers all possible routes between source node and destination node. The LQM route decision is based on *link quality* and *route cost* and it uses *hop-by-hop* routing method. The routing table in LQM maintains *link quality* of all the available routes, according to systematic propagation sibling-wise, from source to destination. For LQM protocol overview, the address space structure along with actual physical topology is given in Fig. 1c.

LQM Routing Table:-

The LQM routing table is shown in Fig. 2. This routing table contains six fields : Sibling ID, Next Hop, Route Cost, Link Quality, Network ID and Route Log.

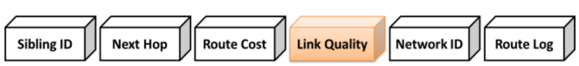

Fig.2:- LQM routing table fields

LQM Routing Update Packet:-

The LQM routing update packet is shown in Fig. 3. This packet contains five fields : Sibling ID, Route Cost, Link Quality, Network ID and Route Log.

Fig.3:- LQM routing update entry

LQM Link Quality Measurement

The proposed protocol LQM aims to provide the optimum routing paths based on link quality for data forwarding in wireless ad-hoc networks. Link quality is taken to be relying on link failure rate and link bandwidth which are estimated by the ETT metric. ETT metric [25] attempts to estimate the link-quality between two nodes in network by selecting a high-throughput route between a source and a destination. The link quality is estimated by *probe packets* and *exponentially weighted moving average* (EWMA) discussed in following sections.

Expected Transmission Count:-

Expected Transmission Count (ETX) [12], proposed by De Couto et. al., is defined as the expected number of MAC layer transmissions that is needed for successfully delivering a packet through a wireless link, including retransmissions. The ETX of a route is the sum of the ETX for each link in the route. The ETX of a link is calculated using the forward and reverse delivery ratios of the link. The forward delivery ratio p_f is the measured probability that a data packet successfully arrives at the recipient and the reverse delivery ratio p_r is the probability that the ACK packet is successfully received. The expected probability that a transmission is with success received and acknowledged is $p_f \times p_r$. The packet delivery ratio is measured as below:

$$ETX = \frac{1}{p_f \times p_r} \quad (1)$$

Expected Transmission Time:-

Expected Transmission Time (ETT) [25] routing metric, proposed by Draves et. al., is an extension of ETX metric. The ETT of a link *l* is defined as the expected MAC layer duration for a successful transmission of a packet at link. The weight of a path is simply the summation of the ETTs of the links lying on the path. The relationship between the ETT and ETX of a link *l* can be expressed as

$$ETT_l = ETX_l \times \frac{S}{B_l} \quad (2)$$

where, B_l is the transmission rate of link *l* and *S* is the packet size.

LQM Link Quality Measurement:-

LQM calculates the link quality using equation (3). For this, we need to know the forward and reverse packet failure rates (p_f and p_r) and the bandwidth of each link. The values of p_f and p_r are estimated by using the broadcast packet technique described by De Couto *et al*. [12]. Each node periodically sends out a broadcast *probe packet* (a packet used in an active measurement experiment to collect knowledge on a given network parameter of interest). A node keeps track of the number of probe packets received from each neighbor during a sliding time window. Nodes can calculate p_r directly from the number of probes they receive from a neighbor in the time window, and they can use the information about themselves received in the last probe from a neighbor to calculate p_f.

The LQM link quality measure model depends upon probe packets and EWMA. As discussed above, each node periodically transmits and receives number of probe packets in network. At the time *t*, the node *j* evaluates the link quality $lq_t\ (i \rightarrow j)$ for the packets received by the neighbor *i* within a time window *X*, depending on EWMA. The link quality between nodes *i* and *j* is given as follows:

$$lq_t(i \rightarrow j) = (1-\lambda) \times X_{t-1} + \lambda \times lq_{t-1}(i \rightarrow j) \quad (3)$$

where, lq_t is the current link quality, lq_{t-1} is the previous link quality time t and X_t is the value of time series value at time *t*. The terms λ is weighting coefficient. The chosen value of λ is 0.94. Since node *j* broadcasts its estimated link quality lq_t with the probe packets, the neighbor *i* can retrieve the link quality $lq_t(i \rightarrow j)$. In this manner, we calculate the p_r. To calculate the p_f, a node extracts the information from last received probe packet from its neighbor at the end of window session. We can compute the bi-directional link quality $lq_t\ (i,j)$ [13] as follows:

$$lq_t(i,j) = lq_t(i \rightarrow j) \times lq_t(j \rightarrow i) \quad (4)$$

LQM estimates the ETT in terms of link-quality cost (LC) between nodes *i* and *j*. The path-quality metric for path s → d in LQM is the sum of the ETT values for each link in the path and as given below:

$$LC_t(s,d) = \sum_{l(i,j)\in R(s,d)} \frac{1}{lq_t(i,j)} \times \frac{S}{B_{i,j}} \quad (5)$$

where, the *l(i, j)* is a link belonging to the route *R(s, d)*, S denotes the size of the packet and *B* the bandwidth of the link.

LQM Data Forwarding Strategy:-

As LQM is a multipath routing protocol, a node (source) may have multiple routes to another node (destination) for the data-packet forwarding. The procedure for packet forwarding in LQM is summarized in *Algorithm-1*. LQM selects the maximum *link quality* path among the paths stored in Routing Table of the node. The link quality is calculated by a node upon the receiving of routing update packets. In proposed protocol LQM, there is a two-level tie breaking mechanism. The routing decision is taken, firstly, on the basis of the link quality. In the case of a tie, the LQM selects the path with optimum route cost. The ties even in route cost values are then broken arbitrarily.

Algorithm 1:

LQM data forwarding rule: A node *i* applies the rule when it has data packets to send to node *j*.

I. IF node *i* has data packets to send to the node *j* THEN
   a. IF Node *i* has multiple routes (share the same address prefix) THEN
      i. Select path with maximum link cost.
   b. Else IF Node *i* has multiple routes with same link cost THEN
      i. Select path with lowest route cost.
II. IF selected path fails during the transmission THEN
   a. Select the next best available path on the basis of high *link quality*

TABLE 2:- ROUTING UPDATE (FROM NODE 001 TO NODE 000)

Sibling ID	Route Cost	Link Quality	Network ID	Route Log
000	1	1.01	ID(000)	000
01X	1	0.70	ID(010)	010
1XX	2	0.80	ID(100)	100

Referring to Fig. 1c, let node 000 wishes to transmit packets to node 111. The node 000 has two paths towards destination, one via 001 and another via 010. Routing update sent by node 001 and node 010 to node 000 are shown in Table II and Table III, respectively. Routing vector with node 000 is given in Table IV. There are two entries in third segment in the routing table for node 000: the first through the next hop 010 and the second through 001. The node 000 selects 010 as its next neighbor, on the basis of its greater link quality.

TABLE 3:-ROUTING UPDATE (FROM NODE 010 TO NODE 000)

Sibling ID	Route Cost	Link Quality	Network ID	Route Log
011	1	0.80	ID(011)	011
00X	1	0.80	ID(011)	011
	1	0.50	ID(000)	000
1XX	2	0.85	ID(100)	100
	2	1.10	ID(100)	100

TABLE 4:- ROUTING TABLE FOR NODE 000

Sibling ID	Next Hop	Route Cost	Network ID	Link Quality	Route Log
001	001	1	ID(001)	1.01	001
01X	001	2	ID(011)	0.90	011
	010	1	ID(010)	0.50	010
1XX	010	3	ID(100)	1.10	100
	001	3	ID(100)	0.87	100

Experimental Setup And Performance Analysis:-

In this section, we present the performance analysis of LQM routing protocol using *ns-2* (version 2.35) network simulator [24]. To assure a reasonable comparison of LQM with DART and M-DART routing protocols, we conducted several sets of experiments to explore the impact of different parameters and to find the performance of the protocols. The performance parameters adopted for study are as follows:

Packet Delivery Ratio:-

The ratio between the number of data packets successfully received at destination and those generated at source.
Hop Count: the number of hops for a data packet to reach its destination.
End-To-End Delay: the time spent by a packet to reach its destination.
Throughput: the amount of received data by the destination node in a specified period of time.
Routing Overhead: the ratio between the number of generated data packets and the total number of generated routing packets.

Experimental Setup:-

Network topologies have been generated by placing the nodes uniformly in the specified scenario. The *Random Way-point* mobility model [14] is used for movement of nodes in the network. The speed of mobile nodes was taken to be in range [0.1m/s to 1m/s]. The duration of each simulation run was kept 500s. The scalability study of LQM is carried using three experimental setups, which are discussed in the sections 1), 2), and 3). In *first experimental scenario*, the number of nodes are increased while node speed is kept same in all six simulation runs. In *second experimental scenario*, number of nodes and node speed are kept same while data load is varied from 1Mb/s to 7Mb/s. Network area is kept constant in each simulation run. In *third experimental scenario*, number of nodes and network area are same while node mobility is varied from 0.1 m/s to 1 m/s. Table IV, V and VI show the summary of first, second and third experimental scenarios, respectively.

1). First Experimental Scenario- Scalability Based On Number Of Nodes: The first set of experiment aims to compare the routing protocols performance by varying the number of nodes. We consider a scenario in which the data payload (512 Bytes/packet) is modeled as CBR traffic (4 Packet/sec) over UDP protocol. The results of this experimental scenario are depicted in Fig. 4 - Fig. 8. Table V gives the summary of experimental setup.

TABLE 5:- SUMMARY OF FIRST EXPERIMENT

S.No.	**Number of Nodes**	**Terrain Area (m^2)**	**Traffic Pattern**
1	100	1000 × 1000	CBR
2	200	1500 × 1000	CBR
3	300	2000 × 1000	CBR
4	400	2500 × 1000	CBR
5	500	3000 × 1000	CBR
6	600	3500 × 1000	CBR

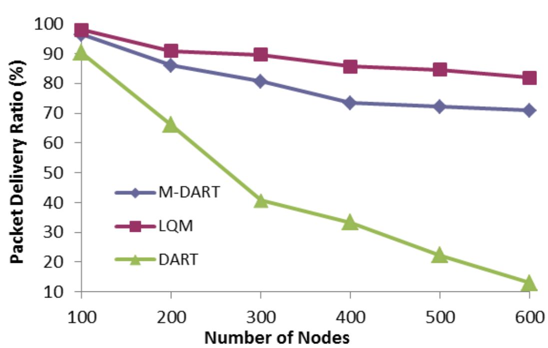

Fig. 4:- Packet delivery ratio versus number of nodes

The packet delivery ratio (PDR) versus number of nodes is shown in Fig. 4 for LQM, DART and M-DART. The link quality feature embedded in LQM protocol is responsible for its better performance in all simulation runs as compared to DART and M-DART. Being a unipath routing protocol, DART performance significantly decreases due to unavailability of backup paths for data forwarding.

Fig. 5 shows the performance comparison of three protocols on the basis of hop count. It is observed that LQM shows higher hop count as compared to DART and M-DART in a few simulation runs. LQM avoids the low link quality path which might be the reason for increase in the hop count. It is worthwhile to mention that LQM has been designed to prefer reliable and efficient paths which may increase hop number. The average hop count of DART, LQM and M-DART routing protocols in all simulation is found to be 5.89, 7.65, 7.78, respectively. DART and M-DART protocols adopt ETX as the route metric, which also do not minimize the hop number.

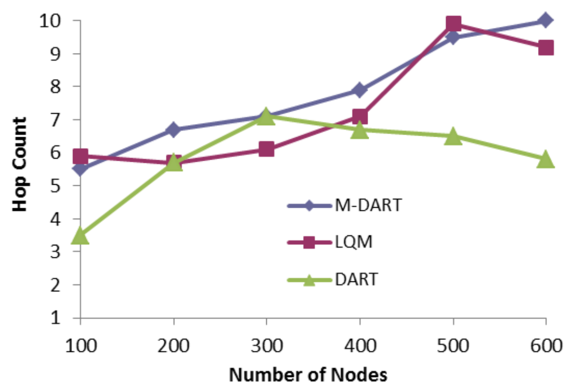

Fig. 5:- Hop count versus number of nodes

Fig. 6 shows end-to-end delay versus number of nodes for DART, M-DART and LQM protocols. The end-to-end delay depends on sending time and receiving time of packets from source to destination. Bandwidth has a significant role in routing of packets in network as insufficient bandwidth may cause congestion resulting into increase in end-to-end delay. LQM selects the path with best link quality which in turn keeps into consideration the link bandwidth. Fig. 6 depicts that LQM has lowest end-to-end delay as compared to DART and M-DART. M-DART results are also good in all simulation run as compared to DART due to its multipath mechanism.

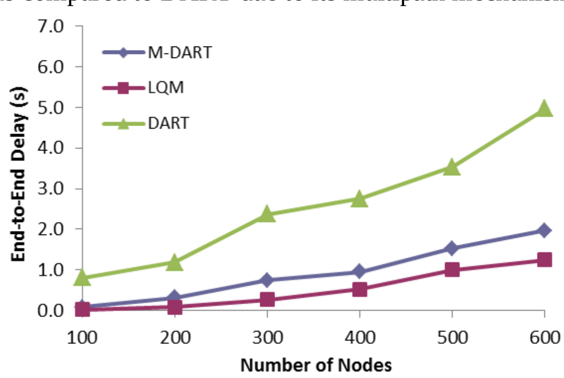

Fig. 6:- End-to-end delay versus number of nodes

Fig. 7 shows the LQM, DART, and M-DART performance comparison on the basis of routing overhead. All three protocols have high routing overhead due to their aggressive route caching policy. The routing update packet has fixed size, regardless the number of nodes. However, when the number of nodes grows, it affects the routing overhead. LQM and M-DART show better results as compared to DART protocols in all simulation runs due to their multipath mechanism. LQM has an upper hand as compared to M-DART because of link quality component incorporated in it which avoids the possibility of frequent link failures resulting in a reduction in routing overhead.

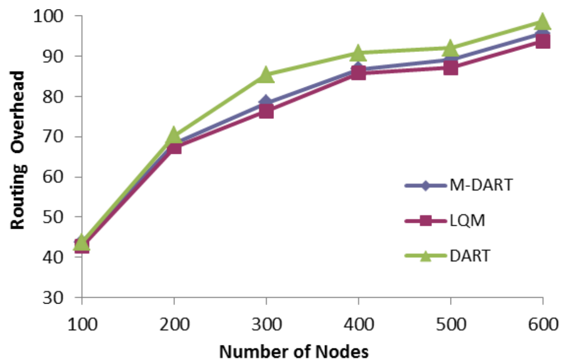

Fig. 7:- Routing overhead versus number of nodes

DART and M-DART protocols use the ETX route metric [12], whereas LQM uses ETT [25]. ETX considers failure rates on the links and not their bandwidths. Instead, ETT estimates both the *link failure rate* and *bandwidth of link*. This metric aims at selecting a high-throughput and reliable path between a source and a destination. Thus, LQM exhibits high throughput results as compared to DART and M-DART in all simulation runs. Due to single path nature of DART, it gives least throughput as compared to other two protocols. Fig. 8 shows the LQM, DART, and M-DART performance comparison on the basis of throughput.

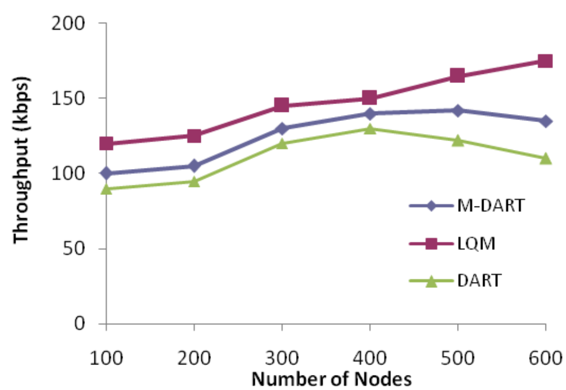

Fig. 8:- Throughput versus number of nodes

Second Experiment - Scalability Based On Data Loads:-

In this experimental setup, packet delivery ratio, hop count, end-to-end delay and routing overhead of three protocols are computed for varying data load and the scalability comparison results are presented in Fig. 9 - Fig. 12. The speed of nodes is kept same in all simulation runs and data load is varied from 1 Mb/s to 7 Mb/s. Table VI gives the summary of this experimental setup.

TABLE 6:-SUMMARY OF SECOND EXPERIMENT

S.No.	**Number of Nodes**	**Terrain Area (m^2)**	**Data Load (Mb/s)**
1	200	1000 × 1000	1
2	200	1000 × 1000	2
3	200	1000 × 1000	3
4	200	1000 × 1000	4
5	200	1000 × 1000	5
6	200	1000 × 1000	6
7	200	1000 × 1000	7

Fig. 9 shows the results of packet delivery ratio versus data loads. M-DART and LQM are able to scale well in terms of data load due to presence of alternate paths for data forwarding. The packet delivery ratio for DART is very low as compared to M-DART and LQM due to its single path methodology. LQM packet delivery ratio is slightly better than M-DART due to selection of better link quality in a path. Fig. 10 gives hop count for three protocols in second experimental setup. As LQM avoids the low link quality path so hop count may be larger in some simulation runs. However, the simulation results show overall average improvement of 0.54% in hop count for LQM as compared to M-DART. DART suffers from false route breakages so its hop count is higher than other two protocols.

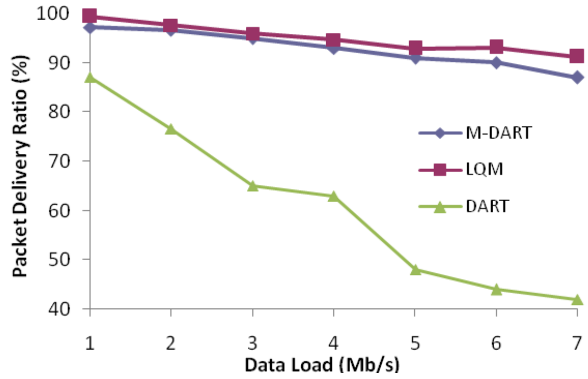

Fig. 9:- Packet delivery ratio versus data load

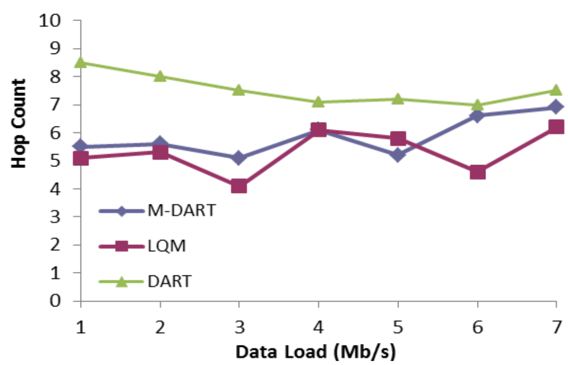

Fig. 10:- Hop Count versus Data Load

Data load affects the end-to-end (e2e) delay of all routing protocols. As data load grows, the e2e delay increases due to congestion at nodes. LQM selects the less congested link in a path due to its link quality mechanism. Simulation results show LQM outperforms DART and M-DART. Fig. 11 shows the comparison results of LQM, DART and M-DART on the basis of e2e delay.

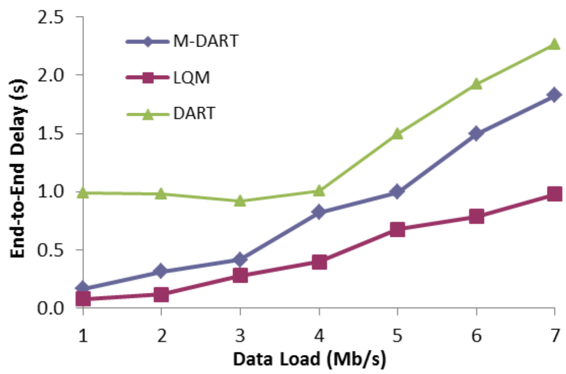

Fig. 11:- End-to-end delay versus data load

Fig. 12 shows the performance comparison results of LQM, DART and M-DART protocols based on the routing overhead. The LQM shows less routing overhead as compared to DART and M-DART due to selection of efficient link in a path thereby reducing the number of routing packets in network.

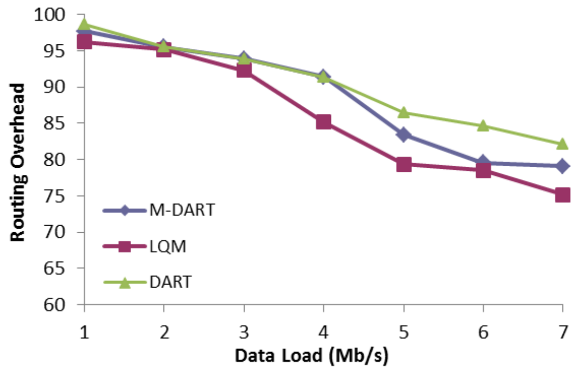

Fig. 12:-Routing overhead versus data load

3). Third Experimental Scenario- Scalability Based On Node Mobility:-

The third set of experiments aims to assess the performance of three protocols under discussion on the ground of mobility scenario. In this experimental setup, number of nodes in the terrain area is kept fixed as 300 nodes and node speed is varied from 0.1 m/s to 1.0 m/s. The traffic pattern considered is CBR traffic and link data throughput is set to 0.54 Mb/s. The results are illustrated in Fig. 13 – Fig. 17. Table VII gives the summary of this experimental setup. Fig. 13 shows the effect of node speed on to the packet delivery ratio. Packet delivery ratios of LQM, DART and M-DART are affected by the node mobility due to their hierarchical structure topology. As compared to DART and M-DART, LQM has the best PDR because of the selection of better link quality in a path even at higher node speeds.

TABLE 7:-SUMMARY OF THIRD EXPERIMENT

S.No.	Number of Nodes	Terrain Area (m^2)	Mobility (m/s)
1	300	2000 × 1500	0.1
2	300	2000 × 1500	0.2
3	300	2000 × 1500	0.4
4	300	2000 × 1500	0.6
5	300	2000 × 1500	0.8
6	300	2000 × 1500	1.0

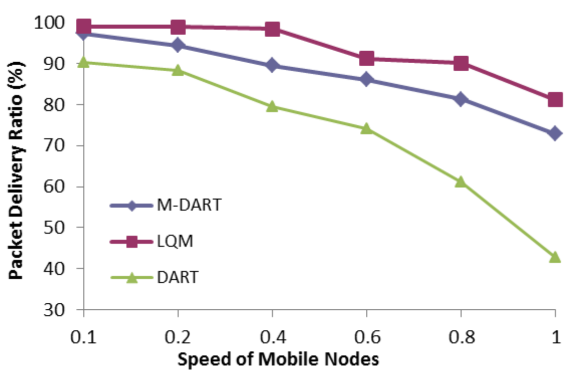

Fig. 13:- Packet delivery ratio versus mobile nodes

Fig. 14 presents the hop count metric versus node speed for DART, M-DART and LQM protocols. LQM shows higher hop count as compared to M-DART in a few simulation runs. Hop count may increase when the node becomes highly mobile as that case the p_f and p_r ratios might decrease. Further, LQM avoids the low link quality path which is the reason for increase in the hop count.

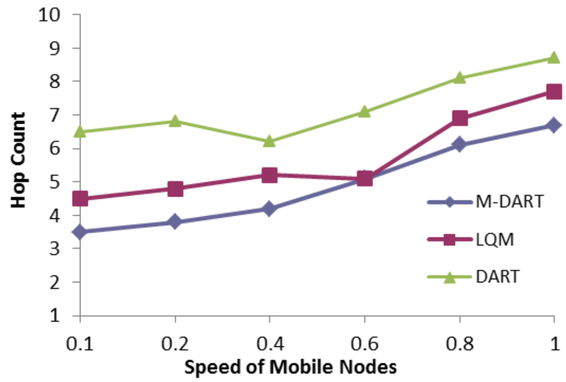

Fig. 14 :- Hop Count versus Mobile Nodes

Fig. 15 shows the end-to-end delay versus node speed for DART, M-DART and LQM protocols. The node mobility affects the end-to-end delay of all routing protocols. LQM end-to-end delay is least as compared to DART and M-DART routing protocols. If nodes mobility is high then the paths are likely to break. In the case of path break, the packets have to wait in the network until new path is selected which increases the delay. LQM is able to assure satisfactory connectivity, since the link failure probability is considered before data forwarding. The end-to-end delay of DART is high because only one path is available for data forwarding and if link fails due to mobility it needs reroute the data. Fig. 16 shows the routing overhead versus node speed for DART, M-DART and LQM protocols. All three protocols possess same overhead which is required to maintain topology and routing path.

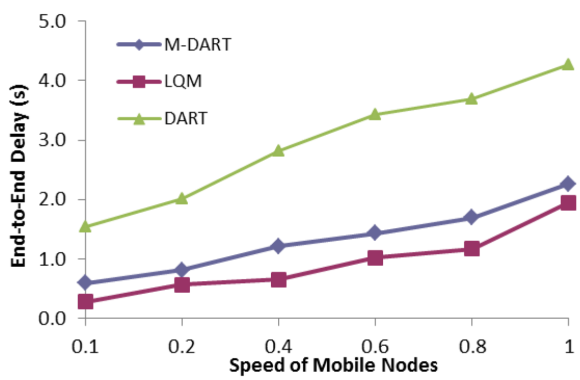

Fig. 15 :- End-to-end Delay versus Mobile Nodes

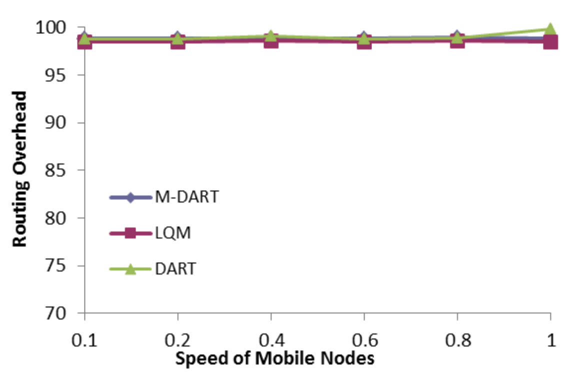

Fig. 16 :- Routing Overhead versus Mobile Nodes

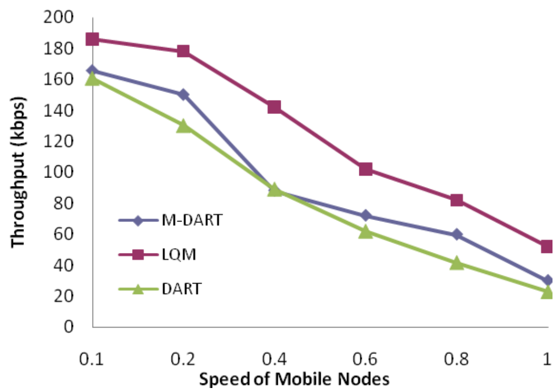

Fig. 17 :- Throughput versus Mobile Nodes

The results of throughput versus node speed for DART, M-DART and LQM protocols are shown in Fig. 17. Throughput decreases with node speed for all three protocols. Node speed affects the throughput performance of network since it causes link failure and so reduces the amount of data received. The LQM throughput is highest in all simulation runs than other protocols since it eliminates the weak links from the path.

Conclusion:-

This paper proposed a Link Quality based Multi-path data forwarding routing protocol, called LQM, which is based on Dynamic Address hierarchical scheme for Mobile Ad hoc Networks. This protocol discovers quality paths from source to destination. Quality paths are determined on the basis of *link failure rate* and *link bandwidth*. Simulation results show that due to these two important metrics the paths selected by the LQM are efficient for data forwarding even for high data loads, number of nodes and node speeds. This confirms the scalability of LQM in different scenarios and its effectiveness for data networks.

References:-

1. Eriksson J, Faloutsos M, Krishnamurthy S. *Dart: dynamic address routing for scalable ad hoc and mesh networks*, IEEE/ACM Trans. Networking, vol. 15, no. 1, pp.119–132, 2007.
2. Ram Ramanathan and Martha Steenstrup, *Hierarchically-organized, multihop mobile wireless networks for quality-of-service support*, Mobile Networks and Applications, vol. 3, no. 1, pp. 101–119, 1998.
3. Guangyu Pei, Mario Gerla, Xiaoyan Hong, and Ching-Chuan Chiang, *A wireless hierarchical routing protocol with group mobility*, in Proc WCNC’99,1999.
4. G. Pei, M. Gerla, and X. Hong, *Lanmar: Landmark routing for large scale wireless ad hoc networks with group mobility*, in Proc ACM MobiHOC’00, 2000.
5. Manoj & Murthy, *Ad Hoc Wireless Network*, Printice Hall, 2004.
6. Eriksson J, Faloutsos M, Krishnamurthy SV, *Scalable ad hoc routing: the case for dynamic addressing*, in Proc IEEE INFOCOM’04, 2004.
7. M. Caleffi and L. Paura, *M-DART: Multi-path Dynamic Address RouTing*, Wireless Communication & Mobile Computing, 2010, pp: 1–20.
8. Stoica I, Morris R, Karger D, Kaashoek MF, Balakrishnan, *H. Chord: a scalable peer-to-peer lookup service for internet applications*, in Proc SIGCOMM’01, 2001.
9. C.E. Perkins, E.M. Royer, *Ad-hoc on-demand distance vector routing*, in Proc IEEE WMCSA’99, February 1999.
10. Johnson D, Maltz D. *Dynamic source routing in ad hoc wireless networks. Mobile Computing*, Vol. 353, pp. 153–181, 1996.
11. Perkins C, Bhagwat P., *Highly dynamic destination sequenced distance-vector routing (DSDV) for mobile computers*, in ACM Proc. SIGCOMM’94, 1994.
12. D. S. J. D. Couto, D. Aguayo, J. Bicket, and R. Morris, *A high throughput path metric for multi-hop wireless routing*, Wireless Networks, vol. 11, no. 4, pp. 419–434, 2005.
13. Caleffi M, Paura L., *Opportunistic routing for disruption tolerant networks*, AINA ’09: The IEEE 23rd International Conference on Advanced Information Networking and Applications, 2009; pp. 826–831.

14. BrochJ ,Maltz D, Johnson D, Hu Y, Jetcheva J., *A performance comparison of multi-hop wireless ad hoc network routing protocols*, in Proc. ACM/IEEE MobiCom'98, 1998.
15. Chi Trung Ngoa, Hoon Oha, *A Link Quality Prediction Metric for Location based Routing Protocols under Shadowing and Fading Effects in Vehicular Ad Hoc Networks*, in Proc ELSEVIER Computer Science, 2014, pp. 565 – 570.
16. A. Sivagami, K. Pavai, D. Sridharan and S.A.V. Satya Murty, *Energy and link Quality Based Routing For Data Gathering Tree IN Wireless Sensor Networks Under Tinyos-2.x*, IJWMN, vol. 2, no. 2 May 2010.
17. Butt, M.R. ; KICS, UET, Lahore, Pakistan ; Javed, M.M., Akbar, A.H., Taj, Q.u. A., *LABILE: Link quality Based LexIcaL Routing MEtric for Reactive Routing Protocols* in IEEE 802.15.4 Networks, Published in: Future Information Technology (FutureTech), 2010 5th International Conference, May 2010, pp. 1- 6.
18. Arjan Durresia, Vamsi Paruchurib, Joythi Innamurib, Betty Lise Andersonb, Raj Jaina, *Quality Based Optical Routing Protocol*, In Proc WDM Networkin,g 2003.
19. K´assio Machado, Denis Rosario, Eduardo Cerqueira, Antonio A. F. Loureiro, Augusto Neto and Jos´e Neuman de Souza, *A Routing Protocol Based on Energy and Link Quality for Internet of Things Applications*, Sensors 2013, vol. 13, pp. 1942-1964.
20. Gregor Gaertner and Eamnn O'Nuallain, *Foundation of Cognitive Radio Systems*, Publish InTech, 2012.
21. Steven W. Smith, *The Scientist & Engineer's Guide to Digital Signal Processing*, California Technical Publishing San Diego, CA, USA, 1997.
22. Caleffi, M., Ferraiuolo, G., and Paura, L., *Augmented Tree based Routing Protocol for Scalable Ad Hoc Networks*, in Proc IEEE MHWMN'07, 2007.
23. Jakob Eriksson, Michalis Faloutsos, Srikanth Krishnamurthy, *Book Chapter: Routing Scalability in MANETs*. Handbook on theoretical and algorithmic aspects of sensor, ad hoc wireless, and peer-to-peer networks, Auerbach Publications, Edited by Jie Wu, 2006.
24. NS-2, *The ns Manual*, http: //www. isi.edu/nsnam/ns.
25. R. Draves, J. Padhye, and B. Zill, *Routing in multi-radio, multi-hop wireless mesh networks*, in Proc Mobile Computing and Networking MobiCom '04, , pp. 114–128, October 2004.
26. Joanna Kolodziej, *Advances in Intelligent Modelling and Simulation: Artificial Intelligence-Based Models and Techniques in Scalable Computing*, Springer 2012.
27. Ravinder Kaur, Kamal Preet Singh, *An Efficient Multipath Dynamic Routing Protocol for Mobile WSNs*, in Proc Computer Science ELSEVIER pp. 1032-1040, ICICT'14, 2014.
28. Avinash Giri, Jitendra Prithviraj, and Ashok Verma,, *Analysis of DHT Based Multi-Path Routing Protocol with Other Routing Protocols in MANETS*, IJESIT, vol. 1, no.1, 2012.
29. Gurmukh Singh, Dr. Savita Gupta, and Sukhvir Singh, *Performance Evaluation of DHT Based multi-path Routing Protocol for MANETs*, IJSR, vol.2, no. 6, June 2012.
30. *Zahid Khan, Tayeba, Haleem Farman3, IsraIqbalAwan, and Abdul Nawaz, Impact of Mobility Models over Multipath Routing Protocols*, Proceedings are available on IJITCS, vo. 19, no. 1, pp. 72-84, 2015
31. T. H. Clausen. G Hansen, L. Christensen, and G. Behrmann, *The Optimized Link State Routing Protocol, Evaluation Through Experiment and Simulation*, in Proc IEEE WPMC'01, 2001.