

# PAR-MAN: Position Aware Routing in Multirate Ad-hoc Networks

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**Abstract**— Conventional adhoc network routing protocols like DSR and AODV uses the minimum hop count (MH) as the link metric. However, prior work has shown that the MH metric tends to select paths of few hops which are bad links, and hence result in poorer performance. In this paper, we investigate the performance of a new position-aware routing protocol using a new routing metric that is based on link transmission time, link access and queueing delay in a multi-rate ad hoc network. In our position-aware routing scheme, instead of broadcasting a route request, a node can unicast a route request to a next-hop node. The next-hop node is selected based on the combined link transmission time and communication delay that the current node will incur in its communications with that selected node. We conducted some studies using NS-2 simulator to compare this position-aware scheme with DSR, LAR and LAKER (two location-aided routing schemes). Our simulation results for various scenarios (e.g. non-uniform node density, different load conditions) show that our new position-aware routing protocol achieves higher delivery ratio, smaller end-to-end delay, and lower routing overhead than those achieved using DSR, LAR or LAKER.

*Keywords:* multi-rate; location aware routing; ad hoc networks

## I. INTRODUCTION

Mobile ad-hoc network (MANET) has shown its great potential in military communication and commercial scenarios. Routing is a key component of MANET performance since a multihop route is normally required to deliver packets from a sender to the receiver. Proactive routing schemes such as DSDV[1] and reactive routing mechanisms, DSR [2], AODV [3], etc, have been proposed. Most of these routing schemes are designed using minimum hop-count (MH) as the metric. However, in wireless networks, making routing decision based on hop counts has been shown to produce poor performance in certain scenarios [5], [10]. The MH metric tends to choose paths with fewer hops even though the path has poor delivery performance e.g. high packet loss rates.

In addition, new radio devices can now support multiple link rates depending on the current link condition. In [6], a simulation study conducted by Ding

has shown that one can achieve higher throughput in multi-rate mobile ad hoc networks if link adaptation algorithm is invoked. In [4], Draves etc proposed using expected transmission time (ETT) as the new link metric in a multi-radio multihop wireless mesh networks. ETT is a function of the loss rate and the bandwidth of the link. The individual link weights are combined into a path metric called the weighted cumulative ETT (WCETT) that explicitly accounts for the interference among the links. In a single radio scenario, WCETT approach can achieve 16% better median throughput than another approach that merely uses expected transmission times (ETX) [10] as the link metric. However, the work in [4] does not take link congestion into consideration in their designed link metric. In [5], Zhao proposes a new routing metric that is based on link transmission time, link access and queueing delay. Their PARMA scheme based on DSDV (but with the new routing metric) was evaluated using NS-2 and compared with MH and MTM [11]. Their results indicate that it is advantageous to use both wireless link status and link rate in the routing decision. However, their simulations are based on stationary node scenarios.

In this paper, we design a new and efficient position aware routing scheme for multi-rate mobile ad hoc network based on a similar route metric defined in [5]. This new metric combines link rate (Physical layer) and link delay (Data link layer) properties. The novelty of our routing scheme is that it minimizes the routing overhead and selects a route that achieves low delay and high throughput. We conducted extension simulation studies to compare our position-aware routing protocol with DSR and two other location-aided routing protocols that we are aware of, namely LAR[7] and LAKER [8]. Our simulation results for various scenarios e.g. non-uniform node density, different load conditions) show that our new position-aware routing protocol achieves higher delivery ratio, smaller end-to-end delay and lower routing overhead than DSR, LAR or LAKER.

The rest of this paper is organized as follows. In section II, we discuss some related work. The design issues of our new routing metric and our position aware

route discovery are described in Section III. Then, we describe the implementation of our scheme in Section IV. We described our simulation setup in Section V. Simulation results are also presented and discussed in Section V. In Section VI, we summarize our main results and discuss our future work.

## II. RELATED WORK

### A. Multi-rate in MAC Layer

In IEEE 802.11b, the radios can choose different physical rates of 1, 2, 5.5, or 11Mbps depending on the environments. The same mechanism is present in 802.11a/g radios with a maximum data rate of 54 and 48 Mbps respectively. Conventional routing algorithm is based on minimum hop-count. For example in Figure 1, using minimum hop count, S will pick the 2-hop path with 1 Mbps each to reach D. However, if we consider link rate property, the best route may be the one with 4 hops but with higher data rates (11 Mbps). The simulation results in [4][5][6] demonstrate this fact.

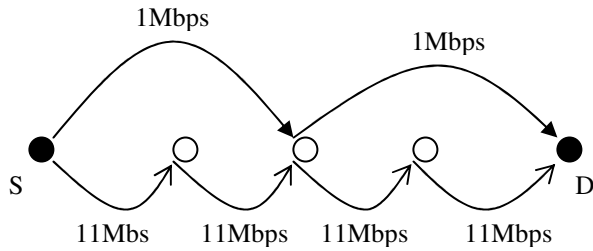


Figure 1. Multi-rate routing

### B. Location Aided Routing (LAR)

In [7], Y\_B Ko, etc proposed a location aided routing algorithm which reduces the routing overhead by limiting the flooding area of routing messages. The basic idea of LAR is illustrated in Figure 2. The locations of the source and destination are used to define a reduced flooding area. Such geographical location information is included in the route request messages so that any intermediate node can determine if it is within the flooding area. Only those nodes within the limited area can re-broadcast the route-request message, thus reducing the routing overhead.

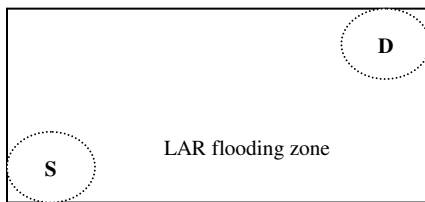


Figure 2. Location Aided Routing (LAR)

However, LAR suffers in two scenarios, namely (i) a scenario where a void area exists and the defined area is

not able to overcome this void area, (ii) the defined flooding zone is too narrow and results in severe failures during the route discovery process.

### C. Location Aided Knowledge Extraction Routing (LAKER)

In [8], the authors propose a guiding route based mobile ad hoc routing algorithm called LAKER. A guiding route is a series of important locations which start from the source and lead to the destination. The basic idea of LAKER is illustrated in Figure 3. S, P1, P2 and D constitute a guiding route. P1 and P2 are chosen based on the node density. The rationale behind such an approach is that the structure of populated areas is not expected to change rapidly.

The advantage of LAKER is that it solves the “void area” problem in LAR and reduces further the searching area. However, the disadvantages of LAKER are also obvious:

First, in LAKER, each node has to keep track of the number of neighbors it has. This is achieved by periodically broadcasting neighbor discovery messages. This increases the signaling overhead.

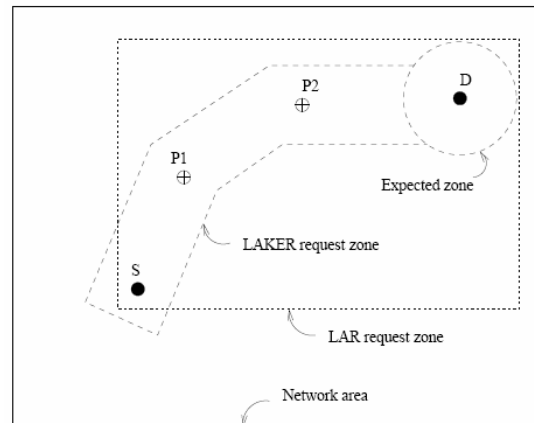


Figure 3. Location Aided Knowledge Extraction Routing (LAKER)

Second, in LAKER, the guiding route is obtained by making use of the neighbor density information observed by a node. If a node’s neighbor density is over a preset value, it will be chosen as a guiding route node. However, in some sparse networks, it is hard to set this neighbor density threshold. In highly mobile scenarios, we may not gather enough information to select a good guiding route. Third, even with the use of nodes in a guiding route, LAKER may still suffer from the overly narrow defined flooding zone problem when one of the coordinates of the source and destination are very close. Our new routing design aims to remove the problems faced in LAKER and LAR.

### III. PAR-MAN

In this section, we describe the Position Aware Routing scheme we design for multi-rate mobile ad hoc networks. Our design includes defining a new route metric and route discovery algorithm.

#### A. Route metric in Multi-rate Mobile ad hoc network

Conventional routing based on minimum hop-count (MH) in wireless ad hoc network will choose a route with the smallest number of hops. Previous work [4][5][6] has shown the need of new routing metrics for multi-rate mobile ad hoc network routing protocol design. The new routing metric (RM) we use in this work allows one to find a route with low delay and high throughput. It can be described as follows:

$$RM = T_{transmit} + T_{link}$$

$T_{transmit}$  is the packet transmission time.  $T_{link}$  denotes the link delay which includes the queueing and link access delay. Note that one can also define a routing metric where the two components are weighted differently.

1)  $T_{transmit}$  :  $T_{transmit}$  can be obtained by using the following equation:  $T_{transmit} = \frac{Pkt}{R_l}$

where Pkt denotes packet size; and  $R_l$  is data rate. For example, in 802.11g, it might range from 1 Mbps to 48 Mbps. Data rate is computed as follows [9]:

When a node receives a RTS, it calculates the packet's SNR. The SNR is defined as

$$SNR = 10\log\left(\frac{Rx\_Power}{Noise + Interference}\right)$$

As an approximation, we use the following equation

$$SNR = 10\log\left(\frac{Rx\_Power}{Noise + \sum_{i=1}^{i-1} Rx\_Power_i}\right) - (1)$$

where Rx\_Power is the signal strength of the received frame at the receiver. It can be computed using a propagation model. We use the TwoRayGround model as the propagation model in this work. The noise generated by the receiver includes thermal noise and platform noise.

$Rx\_Power_i$  is the signal strength of other frames at the receiver. We use this term to represent the interference experienced at that receiving node .

The rate adaptation scheme we use is as follows: Every time when a node receives a RTS, it will first

calculate its SNR using the method described in Eqn (1). Then, with this SNR value, it selects a proper data rate based on the SNR/Data Rate mapping table, and includes this information in the CTS that it sends back to the sender. Table 1 tabulates the SNR versus data rate mappings for 802.11g radios.

Table 1: SNR versus Data Rate Mapping for 802.11g

SNR	Data Rate(Mb/s)
>30	48
26-30	36
21-26	24
18-21	11
16-18	5.5
14-16	2
<14	1

2)  $T_{link}$  :  $T_{link}$  refers to the sum of link access delay and queueing delay. We propose a simple and efficient method to estimate this value. Every time a sender sends data to a receiver, it will record the sending time. And when a receiver sends back ACK, the sender will record the time it receives the ACK and  $T_{link}$  can then be computed by subtracting the two numbers. Rather than using an instantaneous value for  $T_{link}$ , we use a smoothed value.

#### B. Position Aware Route (PAR) Discovery

Our position aware route discovery scheme works as follows: Each node maintains a neighbor table where it stores entries of neighbors. Each entry consists of a neighbor's identifier,  $T_{transmit}$ , and  $T_{link}$ , that this node will incur by communicating with that neighbor. If the number of neighbors in the neighbor table of a node is below a threshold,  $Neigh\_Thr$ , DSR is used to find routes to a destination. Once a source node has at least  $Neigh\_Thr$  neighbors , it will use the position aware route discovery procedure. During the PAR route discovery, each node constructs a request zone which is a rectangle between itself and the destination node (as shown in Figure 4 (a)) and then selects a neighbor which has the best routing metric value within that request zone, and unicasts its route request to that node. This process is repeated until the request arrives at the destination. Note that one can also use an ellipse with the current node and the destination node as the two foci of an ellipse. If an intermediate node cannot find a next hop node to deliver the packet, it sends a route failure packet to its previous hop. The previous hop node then tries to find another neighbor to deliver the packet.

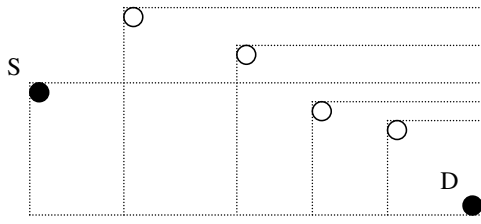


Figure 4(a): PAR request zone

A node needs to consider its relative orientation to the destination before constructing the request zone. For example, if the current node and the destination are further apart in the x-axis direction, then, the request zone rectangle will be constructed as shown in Figure 4(b). However, if the current node and the destination are further apart in the y-axis direction, then the request zone will be constructed as shown in Figure 4(c). Only nodes within the request zone needs to re-broadcast route request messages.

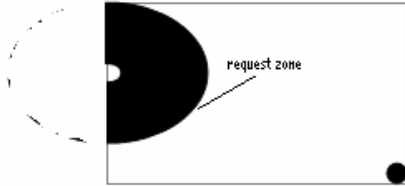


Figure 4(b) PAR horizontal request zone.

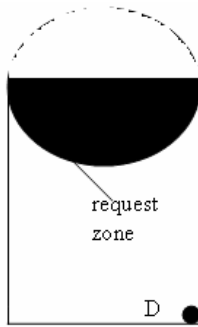


Figure 4(c) PAR vertical request zone

#### IV. PAR IMPLEMENTATION DETAILS

In this section, we describe how PAR can be implemented.

##### A. Neighbor Table.

Every time each node,  $n_i$ , receives a route request or route reply, it searches for the identifier of the sending node in its neighbor table. If none is found, the receiving node will create a new entry in its neighbor table and record also the  $T_{transmit}$  information. Later, if a route is chosen that goes through this neighbor, say,  $n_j$ , then

when  $n_i$  sends data to  $n_j$ ,  $n_i$  will record the packet sending time. When  $n_j$  sends an ACK back,  $n_i$  can compute  $T_{link}$ , and record this value in  $n_j$ 's entry in its Neighbor Table. Note that no extra message is needed to obtain the information maintained in the Neighbor Table. For each entry, node  $n_i$  also maintains the latest time when it communicates with node  $n_j$ . Such information allows node  $n_i$  to know how stale the information about  $n_j$  is. When the neighbor table is full, node  $n_i$  can delete those neighbor entries that are stale. An example of the neighbor table entry is shown in Table 2.

Table 2 Neighbor Table Entry

Neighbor ID	$T_{transmit}$	$T_{link}$	Time_stamp
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Neighbor ID: The identifier of a neighbor

$T_{transmit}$ : The time it takes to transmit a fixed size packet. This value reflects the feasible data rate on the wireless link from node  $n_i$  to this neighbor.

$T_{link}$ : the communication delay incurred by this node  $n_i$  in communicating with this neighbor.

Timestamp: the time when node  $n_i$  receives the latest ACK from this neighbor. This is used to indicate the freshness of a particular neighbor entry.

##### Neighbor Table Maintenance.

A table entry is considered stale if Stale\_time has passed since the last time (denoted by Timestamp) this entry is updated. Stale entries will be deleted when there is no room for inserting new neighbors. Least Recently Used strategy is used to select the entry that will be removed among those stale entries. The maximum number of entries for the Neighbor Table is configurable.

##### B. Position Aware Routing Algorithm

PAR is implemented as follows:

1. Once the system starts to run, each node will begin to build its own Neighbor Table.
2. When a node has a packet to send, it will check its cache first to see if it already has a route to the destination
3. If there is no cached route, route discovery will be initiated.
4. If the node that initiates a route discovery process has Neigh\_Thr entries in its neighbor table, it will invoke the unicast route request approach. Otherwise, it will broadcast its route request.

5. If a node invokes its unicast route request approach, it will pick a neighbor with the best route metric value that lies within the request zone constructed between this node and the destination, and then unicasts the route request to the selected neighbor.
6. Repeat 4) at each intermediate node until the destination node is reached. Then, the destination node will return a route reply to the source indicating the selected path.

## V. PERFORMANCE EVALUATION

### A. Simulation Setup

The LAR, LAKER and PAR schemes are implemented in NS-2 simulator [12]. Different sets of experiments are conducted. In the first set of experiments, we randomly distribute 50 nodes in an area of size  $700 \times 700 \text{m}^2$ . We assume that the nodes know their own positions and exchange such information during the regular neighbor discovery process. We simulate 12 flows with each flow generating 2 packets/sec unless otherwise specified. The packet size is 512 bytes. A warm up period of 200 seconds is used while the simulation runs for 300 seconds. The stale timer is set to 10 seconds. The maximum number of entries in the Neighbor Table is set to 20. We use random waypoint as the mobility model and vary the pause time to simulate different mobility rates. The maximum speed of the nodes is set at 5 m/s. The metrics we use to compare different routing schemes are (i) routing overhead, (ii) delivery ratio, (iii) end-to-end delay. In our second set of experiments, we use the non-uniform node distribution shown in Figure 5 where there are more nodes at the four corners, moderate number of nodes at the upper and lower middle regions, and few nodes around the center region. Our aim is to investigate how various schemes perform in a non-uniform node distribution scenario.

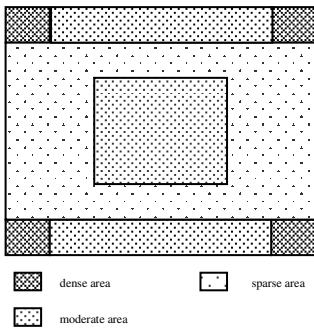


Figure 5: Non-Uniform Node Distribution

### B. Performance Evaluation

In this section, we report the results obtained in the various experiments. In Scenario 1, we vary the

mobility of the nodes by varying the pause time. In Scenario 2, we vary the traffic load. In Scenario 3, we did an experiment where we use the non-uniform node distribution shown in Figure 5 with  $700 \times 700 \text{m}^2$  and vary the traffic load.

#### 1) Results for Scenario 1

Figures 6, 7, 8 show the routing overhead, packet delivery ratio and end-to-end delay results we obtain in Scenario 1. Neigh\_Thr is set to either 4 or 1 (denoted as PAR(4) and PAR(1) in the plots). The plots indicate that our PAR scheme achieves the best delivery ratio (84% to 92%) with the lowest routing overhead (when Neigh\_Thr is set to 1). Our scheme also achieves the lowest end-to-end delay.

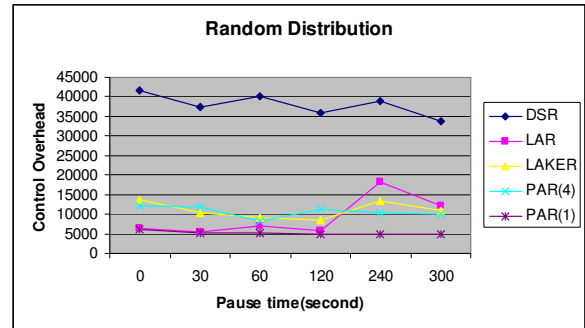


Figure 6: Routing Overhead for Scenario 1

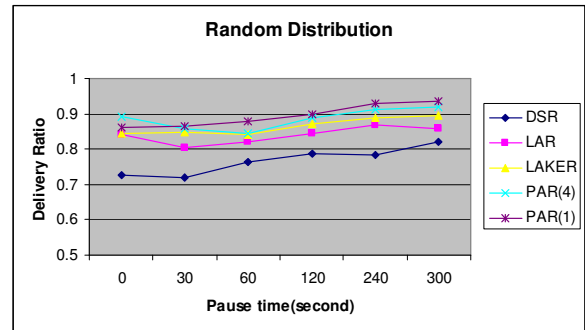


Figure 7: Delivery Ratio for Scenario 1

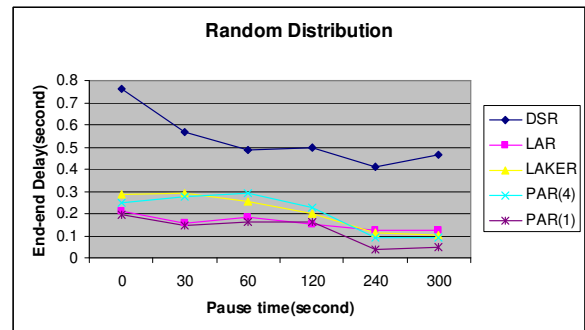


Figure 8: End-to-end Delay for Scenario 1

#### 2) Impact of Traffic Load

In Scenario 2, we set the pause time to 0 and vary the traffic load. Figures 9,10,11 plot the results we obtain.

Again, we see that the PAR scheme achieves the highest delivery ratio with much reduced control overhead. Our scheme outperforms DSR, LAR or LAKER schemes.

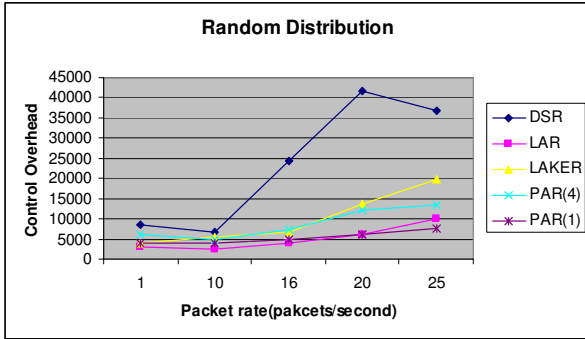


Figure 9: Routing Overhead for Scenario 2

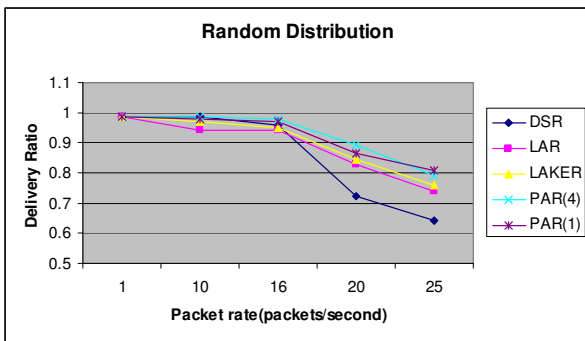


Figure 10: Delivery Ratio for Scenario 2

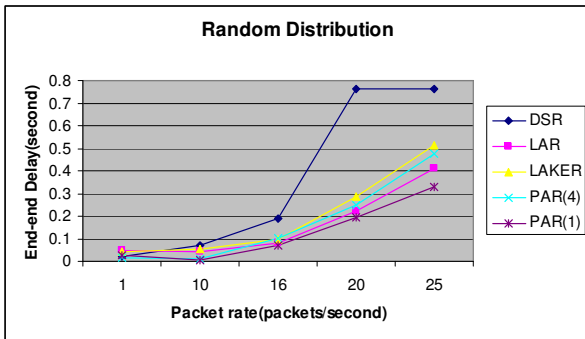


Figure 11: End-to-End Delay for Scenario 2.

### 3) Impact of Node Distribution

Scenario 3 is designed to see how the different schemes will perform when the nodes are not uniformly distributed. The node distribution is shown in Figure 5 where there are more nodes at the four corners but few nodes in the middle region. Figures 12, 13, 14 plot the results we obtain in Scenario 3. Figure 12 clearly indicates that both the LAR and PAR schemes incur significantly smaller routing overhead in this non-uniform node distribution scenario. However, Figure 13 shows that our PAR scheme can achieve much higher delivery ratio than the LAR or LAKER schemes and

hence is the best of the four schemes. Our PAR scheme also achieves the lowest end-to-end delay. The 12 chosen flows have to go through more hops in this non uniform node distribution scenario and hence the end-to-end delay has significantly increased when compared to those reported in Figure 11.

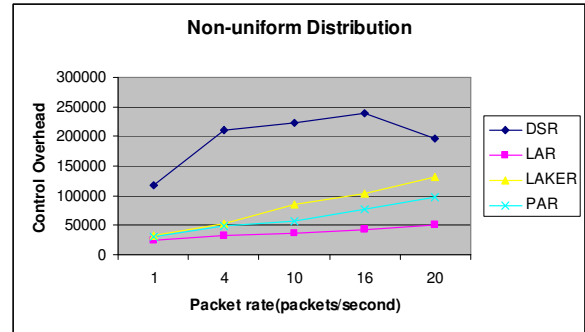


Figure 12: Routing overhead for Scenario 3

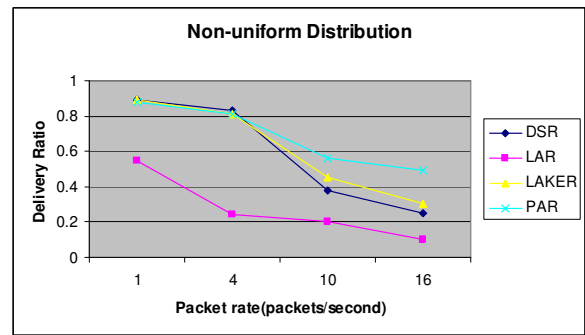


Figure 13: Delivery Ratio for Scenario 3

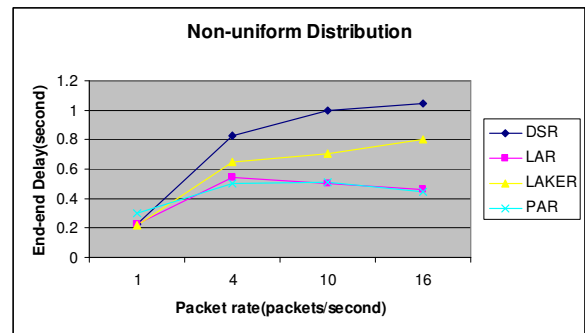


Figure 14: End-to-end Delay for Scenario 3

## VI. CONCLUSION

In this paper, we describe a new adaptive position aware routing scheme that can achieve higher delivery ratio than DSR, LAR or LAKER for multi-rate mobile ad hoc networks with random and non-uniform node distribution. A routing metric that reflects link quality and link access delay is used in our evaluations. Our adaptive position aware scheme also achieves the smallest end-to-end delay. There are several areas where we can extend our work. In our current design, each node

makes local decision for next hop. We intend to compare this with a scheme where each intermediate node updates the route metric in the route reply and the source will make a final selection after hearing multiple route replies with different cost.

#### ACKNOWLEDGMENT

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