

# Design and Performance of QOSRGA Protocol for Mobile Adhoc Networks

J. Abdullah <sup>1,\*</sup>

<sup>1</sup>Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia

\*Corresponding email: [jiwa@uthm.edu.my](mailto:jiwa@uthm.edu.my)

---

## Abstract

QoS Routing for Mobile Ad Hoc Network (MANET) generally poses several challenges that must be addressed. In selecting the best route from source to destination, one has to choose from a set of routes with the corresponding quality of connectivity and resources. Due to the nature of node mobility the protocol demands an exceptional performance. It needs to select a single route with the longest residual node-pair connectivity time simultaneously. As the name implies, QOSRGA (QoS Routing Using GA) was designed to select QoS route based on QoS metrics such as bandwidth, delay and node connectivity index (nci). The design of QOSRGA and its choice of parameters are elaborated. The performance considered here is the effect of mobility and node density on the average packet delivery ratio, average packet end to end delay and total average throughputs.

Keywords: Genetic Algorithm, MANET, protocol performances, QoS Routing.

---

## 1 INTRODUCTION

The objective of QoS routing is to ensure an application gets connected making up a session which is sustainable in the context of QoS routing metrics. The metrics which are interest included the bandwidth, MAC delay, end-to-end delay, jitter, packet loss and packet lost rate. The GA-based QoS Routing (QOSRGA) was designed to utilize several feasible multiple paths discovered in a mobile ad hoc networks searching for the optimal route. Genetic Algorithm technique is used for the searching with a number of measured QoS metrics. Most existing QoS routing protocol uses heuristics in the selection of the best routes from a selection of available routes. The main heuristics used in most of the protocols are as follows: (i) metric ordering, (ii) sequential filtering, (iii) scheduling disciplines, (iv) admission control and (v) using the mechanism of control theory. Multiple routes have been recognized as an important feature in networks to increase reliability [1]. Literature on this subject suggests that the proposed protocol may work correctly although no mention about the performance of such protocol [2], [3]. Several papers measure route coupling [4]–[6], the mutual interference of routes in a common-channel multi-hop ad hoc network, and find routes with low coupling. Most of the works on mobile ad hoc multiple routes restrict the number of potential routes to a small number, usually two. SMR [8] builds two paths from the quickest RREQ and then collects RREQs for a period and chooses a second maximally disjoint path from the first. In a zone-disjoint scheme [9], only two paths are built, but they are not necessarily the minimum. This method repeat iteratively to discard the

worst choice each round until only two remained. Routes with poor quality, shorter node pair connectivity or significantly longer distance should be avoided. In this paper we introduce the design of GA-based QoS routing protocol which is made up of Non-Disjoint Multiple Routes Discovery (NDMRD) protocol [23], Node State Monitoring (NSM) protocol and QoS Route Selection protocol. The function of NDMRD is to discover multiple routes and disseminate QoS metrics whereas the NSM extract various QoS metrics for monitoring purposes. Section 2 describes the design of the QOSRGA. Section 3 describes the performance of QOSRGA considering the velocity and the node density. Lastly, Section 4 summarized the paper.

## 1 THE DESIGN OF QOSRGA

The proposed QOSRGA is based on source routing which effectively select the most viable routes in terms of bandwidth availability, end-to-end delay, media access delay and the sum of nci. The NDMRD protocol [23] initially determined a number of potential routes by calculating the number of returning Route Reply (RREP) packet from destination. The returning RREP packets extract the QoS parameters from each node along the routes. Genetic Algorithm (GA), then operated on the accumulated set of routes and the corresponding set of QoS parameters. The flowchart operation of GA is shown in Fig. 1. A genetic algorithm for this particular problem must have these five issues resolved before the application of the generic GA framework as (i) a genetic representation for potential solutions to the problem called

chromosomes, (ii) a methodology to create an initial population of potential solutions, (iii) an evolution function that plays the role of the environment, rating solutions in terms of their fitness, (iv) GA operators that alter the structure of chromosomes and (v) values for various parameters that the genetic algorithm uses such as population size and probabilities of applying genetic operators.

## 2.1 Chromosome Representations

The chromosome consists of sequences of positive integers, which represent the identity of nodes through which a route passes. Each locus of the chromosome represents an order or position of a node in a route. The gene of the first and the last locus is always reserved for the source node, S and destination node, T respectively. The length of the chromosome is variable, but it should not exceed the maximum length  $|V|$ , where  $|V|$  is the total number of nodes in the network [14]. It is unlikely that more genes are needed than the total number of nodes to form a route. A chromosome which represents the route encodes the problem by listing up node identity from its source node to its destination node based on node information monitored by the Node State Monitoring protocol [22].

## 2.2 Limited Population Initialization

GA process typically starts with a large number of initial population which has better chances of getting good solutions. The initial population was obtained by generating the chromosome randomly producing the initial solutions and then remove the invalid solutions before being fed to the GA routine. In MANET system,

with 5 nodes, the possible number of solutions were calculated as 10 according to the formula  $n(n-1)/2$  [13]. For QOSRGA the operation of route selection need to be done in realtime. The NDMRD protocol [23] was initiated in order to accumulate enough number of chromosomes to be set as the initial population. The outcome of the NDMRD protocol was a set of routes represented as a connectivity matrix. The infeasible solutions which may occur can be eliminated, using the restoration function. Clearly a set of useful solutions can be extracted, before being processed by the GA routine. This set of solutions are the node non-disjoint multiple routes. A set of node non-disjoint routes is defined as routes which occur such that an intermediate node is a member of at least two different routes simultaneously. The initial population also depends on the route accumulation latency, which is the length of time allow for multiple routes accumulation and the maximum number of RREQ duplicates.

Table 1: Nomenclature

$C_{i,j}$	matrix of nci for all node pair from S to T
$F_{1,2,3}$	fitness function
$w$	weighting coefficient for the fitness function
$\frac{1}{4}$	fittest fraction for elitism selection method
$P_c$	probability of crossover
$P_m$	probability of mutation
$B_i$	bandwidth consumed at a node
BQOS	bandwidth required for an application
nci	node pair connectivity index
$D_{ij}$	matrix of end-to-end delay where the element is $D_{ij}$ indicating the ete delay from node i to node j
DQOS	delay specification as required for an application
$Q_{i,j}$	node connectivity matrix between node i and j
$N_j$	list of nodes from souce to target
$d_j$	delay for a pair node connectivity

### 2.3 Fitness Calculation

In GA operation, fitness calculation which depends on the multiple metrics, is the most paramount important aspect, where best route can be identified. In this case the least value of fitness constitutes the lowest cost and the one that is to be chosen. Fitness value of the routes is based on multiple QoS metrics as bandwidth, node delay, end to end delay and the nci. It can be classified as multiple-objectives optimisation problem. According to M. Gen et al [13], each objective function can be assigned a weight and then the weighted objectives are combined into a single objective function. For QOSRGA protocol, the weighted-sum approach is represented as follows.

Consider F1 as a fitness function due to node-pair connectivity, where,

$$F_1 = \sum_{i=1}^m \sum_{\substack{j=1 \\ j \neq i \\ (i,j) \neq (s,t)}}^{|s \rightarrow t|} C_{ij} \cdot Q_{ij} \quad (1)$$

Next, the combined end to end delay and MAC delay which are represented by matrix  $D_{ij}$  and  $d_j$  respectively, is given by the equation of F2,

$$F_2 = \left( \sum_{i=1}^m \sum_{\substack{j=1 \\ j \neq i}}^{|s \rightarrow t|} D_{ij} \cdot Q_{ij} + \sum_{j=1}^{|s \rightarrow t|} d_j \cdot N_j \right) - D_{QoS} \quad (2)$$

The bandwidth consideration is given by F3, as follows,

$$F_3 = \begin{cases} 1/B_i & \text{if } B_i - B_{QoS} > 0 \\ 1000 & \text{if } B_i - B_{QoS} \leq 0 \end{cases} \quad (3)$$

The multiple objectives fitness function then operates to minimize the weighted-sum  $F$ , which is given as,

$$F = \alpha \cdot F_1 + \beta \cdot F_2 + \gamma \cdot F_3 \quad (4)$$

The weight  $\alpha$ ,  $\beta$  and  $\gamma$  are interpreted as the relative emphasis of one objective as compared to the others. The values of  $\alpha$ ,  $\beta$  and  $\gamma$  are chosen such that it increases the selection pressure on any of the three objective functions.

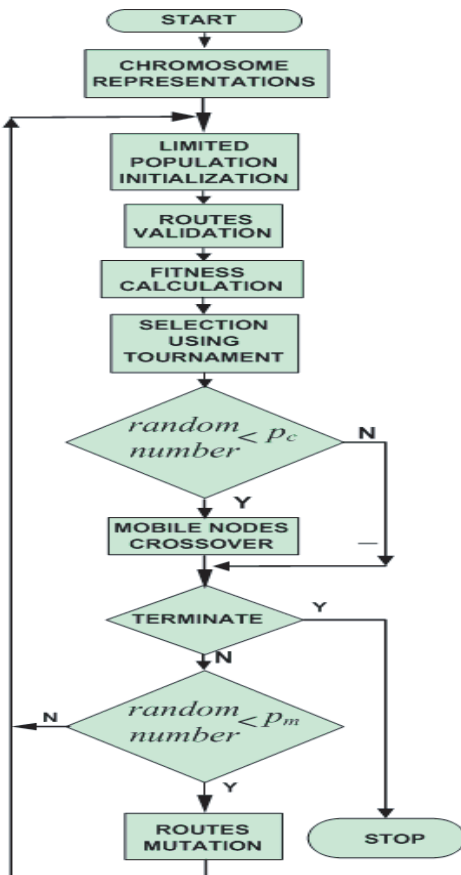
### 2.4 Mobile Nodes Crossover

Mobile nodes crossover examines the current routes in order to find better one. Physically, the crossover operation in the QoS routing problem plays the role of exchanging each partial route of two chosen chromosomes in such a manner that the offsprings produced by the crossover represent only one route. This dictates selection of one-point crossover as a good candidate scheme for the proposed GA. One partial route connects the source node to an intermediate node, and the other partial route connects the intermediate node to the destination node. The crossover between two dominant parents, gives a higher probability of producing offsprings having dominant traits. But the mechanism of the crossover is not the same as that of the conventional one-point crossover. In the proposed scheme, the two chromosomes chosen for crossover should have at least one common gene beside source and target nodes. They are not necessarily of the same length. The crossover operation may generate infeasible chromosomes that violate the constraints, causing loops to be generated in the routing paths. Restoration

method is thus employed in the proposed GA.

### 2.5 Route Mutation

Mutation is used to randomly change the value of a number of the genes within the candidate chromosomes. It generates an alternative chromosome from a selected chromosome. It can thus be seen as an operator charged with maintaining the genetic diversity of the population, thereby keeping away from local optima. Mutation may also induce a subtle bias in which it generates an alternative partial route from the mutation node to the destination node. Thus, a new mutation technique is proposed as shown in Fig. 2.



parameters, after which reasonably suitable parameters are adopted for the specific application. In designing QOSRGA, four selection methods namely the roulette wheel selection (RWS), tournament selection (TS), stochastic universal selection (SUS) and elitism technique are first experimented by simulation. Next, the parameters  $P_c$ ,  $P_m$  and population size are considered. It needs to examine the performances of each and select the one preferred. Matlab was used to initially design GA-based routing algorithm without the QoS function.

The route selection is based on the shortest path without considering the bandwidth, delay and node connectivity index. The cost for each path is randomly generated. The aim is to examine all the GA parameters that are useful for our protocol designed and would use them in the design of QOSRGA route algorithm. Hence, in this section simulation was conducted where mobile network consisting of 20 nodes, randomly distributed within a perimeter of 1000m by 1000m. Each node has a transmission range of 250m.

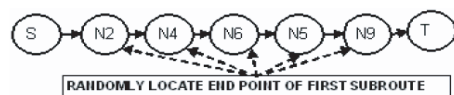


Fig.2(a) The End Point of First Subroute is Determined Randomly

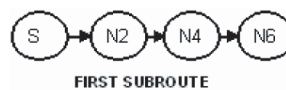


Fig.2(b) An Example of First Subroute

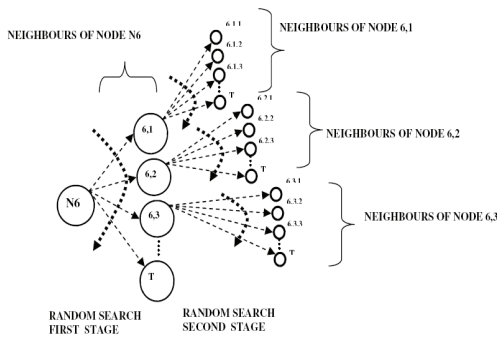


Fig. 2(c). The process of obtaining a second subroutes using a two stage search. The search stops on finding destination node T and repeats the search for another subroute. The search completes after all possible combination of nodes that make up the second subroute are covered. From the list of the second subroutes, the algorithm chooses the least hop.

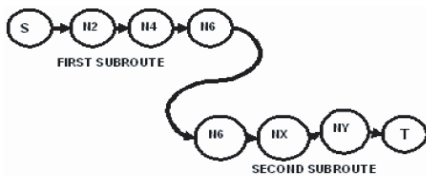


Fig.2(d) Combining first subroute and second subroute.



Fig.2(e) New route obtained after mutation process.

### 2.6.1 Population Size

The effect of population is investigated by fixing the mutation rate ( $P_m = 0.01$ ) and changing the population size. The simulation is run for 2000 generations. The minimum cost in each generation is recorded and the average minimum cost CAMC is evaluated over the range from 0 until the 2000th generation. Fig. 2 plots CAMC for the four different selection

methods (with  $\mu = 0.05$  for Elitism). It shows that in RWS, a population size in excess of 700 produces a significantly low cost. This is because with a large population, the RWS method finds it easier to choose the low cost individuals. Consequently, the probability of a low cost individual being selected becomes low. Apart from this, with a large population size there are too many sectors within the wheel making the probability of selecting each sector smaller. The most significant result is that of the tournament selection and elitism. With a population size of approximately 10, it produces very low CAMC. Hence the best choice of selection method would be the tournament selection and elitism. In fact we could use a population as low as 20 and still produce good fitness. We opt for Tournament selection and leave Elitism method as future works.

### 2.6.2 Crossover Probability and Mutation Probability

Another set of very important parameters for the GA implementation are the crossover probability  $P_c$  and the mutation probability  $P_m$ . The parameters determine how many times crossovers occurred and how many times mutations occurred within a transmission period. The occurrence of crossover and mutation increases the convergence rate. De Jong [16] tested various combinations of GA parameters and concluded that mutation is necessary to restore lost genes but this should be kept at a low rate for otherwise the GA degenerates into a random search. Further study by Schaffer et al. [20], suggest that the parameters should have these

recommended ranges; population size of 20 to 30; mutation rate of 0.005 to 0.1 and crossover rate of 0.75 to 0.95. Another study by Haupt [21] concluded that the best mutation rate for GA's lies between 5% and 20% while the population size should be less than 16. For our case, where GA operation is done online, the value of  $P_c$  and  $P_m$  is taken to be 0.7 and 0.1 respectively. The choice of these parameters should produce a reasonably high efficiency packet transmission. We limit the population size up to the number of routes discovered. The limit is also imposed on the number of generations [21] up to 20.

### 3. PERFORMANCE EVALUATIONS

#### 3.1 Performance Metrics

The following metrics [19] were used in varying scenarios to evaluate the three different protocols.

##### 3.1.1 Average packet delivery ratio

Since our study is essentially based on bandwidth measurement, we propose a metric which expresses the efficiency of bandwidth, as an average packet delivery ratio. We defined the average packet delivery ratio (APDR) as the ratio between the total packets generated by every node to the total received packets at the upper layer within the nodes in the system. We expressed it in terms of a percentage.

$$APDR = \frac{\sum_{TOTAL\_NUM\_NODES}^{TOTAL\_NUM\_NODES} AVG\ NUMBER\ OF\ PACKET\ ARRIVED}{\sum_{TOTAL\_NUM\_NODES}^{TOTAL\_NUM\_NODES} AVG\ NUMBER\ OF\ PACKET\ GENERATED} \quad (5)$$

##### 3.1.2 Average total end to end delay of data packets

This includes all possible delays from the moment the packet is generated to the moment it is received by the destination node. The statistic of average delay of all the packets received during the simulation time is taken and then divided by the average total number of packets arrived at every receiving node. This gives the average delay of a packet.

$$ATETED = \frac{\sum TIME\ PKT\ ARRIVED - TIME\ PKT\ SENT}{\sum NUMBER\ OF\ PKT\ DELIVERED} \quad (6)$$

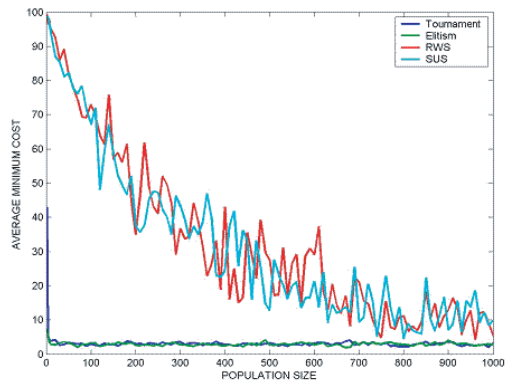


Fig. 3 Average Min Cost Against Population Size

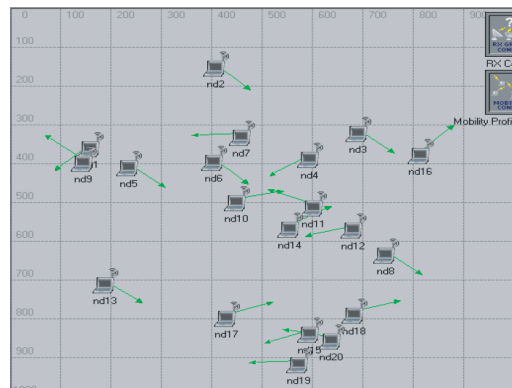


Fig. 4 Nodes in random waypoint motion

### 3.1.3 Total Average Throughput

In this context the throughput is defined as the total number of bits (in bits/sec) forwarded from the WLAN layers to higher layers in all WLAN nodes of the network. To find the average throughput of a single node one has to divide by the number of nodes in the system.

$$TAT = \frac{\sum_{i=1}^{TOTAL\ NODE} \left( \frac{Total\ Number\ of\ Pkt\ Delivered}{Time\ Taken} \right)}{N} \quad (7)$$

### 3.2 Effect of Node Mobility on QOSRGA Performance

The simulation experiments are done using OPNET Modeler 10.5. We vary the velocity for 40 nodes network and 10 CBR sources. Each source produce CBR packet with sizes varies according to exponential distribution with mean output as 4096 bit. The packet sending rate varies according to setting of packet inter arrival rate that follows an exponential distribution with mean outcome as 0.1024 (40kbps) and 0.2048 seconds (20 kbps). The mobility was varied to see how it affects the different metrics that are measured. The simulations were run with uniform velocity where the maximum velocities are 0.5, 1, 1.5, 2, 5, 10, 15, 20, and 25 m/s. In our simulations we limit the velocity up to 25 m/s, since the analysis in [22] suggested that the upper bound on the velocity is limited up to 25 m/s which is equivalent to 90 km/h, in order to successfully maintained node connectivity. Each data point is obtained after 10 runs with different seed values for the random number generator.

### 3.2.1 Average Packet Delivery Ratio

The graph of Average Packet Delivery Ratio against node maximum velocity is shown in Fig. 5. Two set of results are obtained, one for CBR sources 4 packets/s and the other for 98 packets/s. Consider the 4 packets/s sources. By comparing QOSRGA and BE-DSR, QOSRGA produced a slightly better APDR. When the mobility is less than 12 m/s, QOSRGA shows a similar reading. When node mobility is more than 12 m/s QOSRGA performed better, in fact 5% better than BE-DSR. For high bandwidth source of 98 packets/s, clearly QOSRGA consistently performed better than BE-DSR for all the mobility ranges. Generally, it's 5% to 30% better than BE-DSR. In QOSRGA, it accumulated multiple routes and the corresponding QOS metrics information BAVA, DETE, DMAC and nci. The selection of the routes is based on residual length of time each node pair stay connected. The degradation of BE-DSR occurred as the mobility rate increases. In high mobility scenarios, many route reconstruction processes are invoked. When a source floods a new RREQ packet to recover a broken route, many intermediate nodes send RREP packet back to the source, because of route caching mechanism of BE-DSR. But that routes overlap the existing routes hence resulted in severe congestion and cannot deliver packets along the route. Moreover the stale routes produce a reply to source with invalid routes. Ultimately, many packets dropped resulting poor BE-DSR performance. In QOSRGA, aging mechanism is used, hence the stale routes always been replaced.



## 2.2 Average End to End Packet Delay

The average end-to-end delay includes all possible delays from the moment the packet is generated to the moment it is received by the destination nodes. Generally, there are three factors affecting end-to-end delay of a packet as (i) routes discovery time, which causes packets to wait in the queue before a route is found; (ii) buffering waiting time, which causes packets to wait in the queue before they can be transmitted; (iii) the length of routing path. More hops means longer time it takes to reach its destination node. Fig. 6 depicts the variation of the average end-to-end delay as a function of maximum velocity of nodes. It can be seen that the general trend of all curves is an increase in delay with the increase of velocity of nodes. The reason is mainly that high mobility of nodes results in an increased probability of link failure that causes an increase in the number of routing rediscovery processes. This makes data packets have to wait for more time in its queue until a new routing path is found. The delay of BE-DSR is better than QOSRGA for 98 packets/sec source data. When the source sent 4 packet/sec BE-DSR is better than QOSRGA. When the velocity is more than 5 m/s, the delay in all protocols is maintained at almost the same level. As result, QOSRGA performed badly. This is obvious since, QOSRGA was designed to collect as much information about the network as possible, so that the process of route selection using GA is done based on these imprecise information. But all the delays incurred by QOSRGA are still less than 0.1s which is the delay bound for multimedia signals. This is

because availability of node non-disjoint routing paths in QOSRGA eliminates route discovery latency that contributes to the delay when active route fails. In addition, when congestion occurs in a routing path, the source node can distribute incoming data packets to the other non-disjoint routing paths to avoid congestion. This reduces the waiting time of data packets in queue.

## 3.2.3 Total Average Throughputs

Fig. 7 shows the total average throughput of the QOSRGA compare BE-DSR. Throughput is the total number of bits delivered to the destination hosts. For QOSRGA, the ability of transferring the data dropped from 2.5 Mbps to 1.5 Mbps as the mobility increases from 2 m/s until 25 m/s. The throughput of QOSRGA when compared to BE-DSR, it offers an improvement of 25% to 80% better. Nodes with high velocity will produce small number of low value nci among the node pairs. The number of routes of longer lifetime will be less and hence the rate of data transfer to the destination nodes will be less.

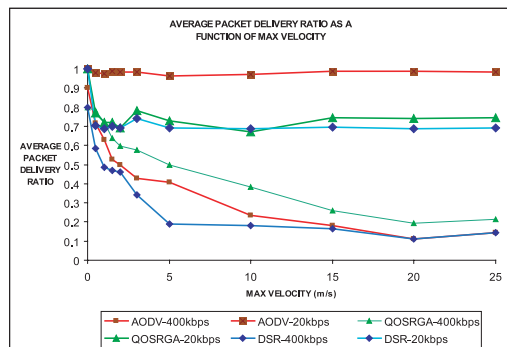


Fig. 5 Average Packet Delivery Ratio vs Max Velocity

### 3.3 Effect of Node Density on QOSRGA Performance

The ability of different MANET protocol schemes to handle node density was analyzed in this set of simulations. It inherently assessed the scalability of QOSRGA, and compared its performance to BE-DSR and BE-AODV with different node densities. In this case, the area, source traffic rate and maximum velocity are kept constant at 1000 m x 1000 m, 100 kbps and 2 m/s, respectively. The number of CBR source nodes was set to 10, generating CBR towards random destinations. Each point was obtained after 10 runs with different seed numbers. The node density is defined as the ratio of the total number of nodes in the network to the area of the field configuration. The number of nodes were varied from 10 to 50, with the same size field configuration. The simulation experiments are based on the densities of  $1 \times 10^{-5}$ ,  $2 \times 10^{-5}$ ,  $3 \times 10^{-5}$ ,  $4 \times 10^{-5}$  and  $5 \times 10^{-6}$  nodes per square meter. The metrics measured were: (i) average packet delivery ratio, (ii) average end to end packet delay and (iii) total average throughput.

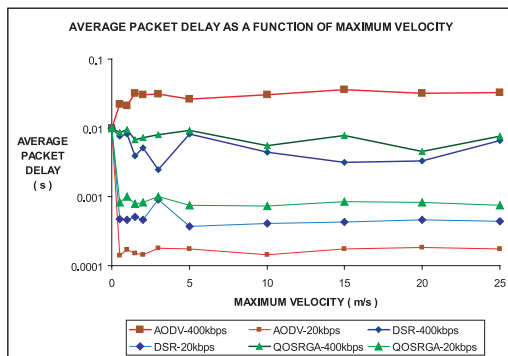


Fig. 6 Average End to End Packet Delay Against Max Velocity

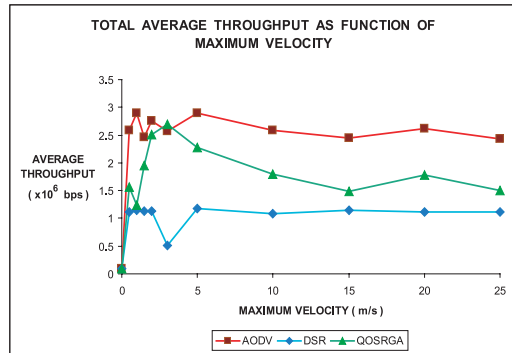


Fig. 7 Total Average Throughputs Against Max Velocity

#### 3.3.1 Average Packet Delivery Ratio

Fig. 8 illustrates the Average Packet Delivery Ratio for QOSRGA, BE-AODV and BE-DSR as a function of node density. Overall the patterns of the QOSRGA graph and BE-DSR graph are normally quite similar. BE-DSR fall more rapidly from its maximum value down to a density of  $2.0 \times 10^{-6}$ , and then stabilized at  $4.0 \times 10^{-6}$  and  $5.0 \times 10^{-6}$ . After  $5.0 \times 10^{-6}$  onwards, QOSRGA produced better results. It is 10% better than the BE-DSR at high node density. The operation of QOSRGA requires fast accumulation of multiple routes. As the node density increases, a reasonable number of routes as an initial population can be obtained. A good number of multiple routes ensure better selection process by the GA algorithm. A route with very low nci could then be produced and selected.

#### 3.3.2 Average End-to-End Packet Delay

Fig. 9 illustrates the Average End to End Packet Delay as a function of node density. Generally QOSRGA performed the worst

among the other protocols. It varied from approximately 0.05 to 0.1. This can be attributed to the fact that for QOSRGA, in every intermediate node, the processing time is significant.

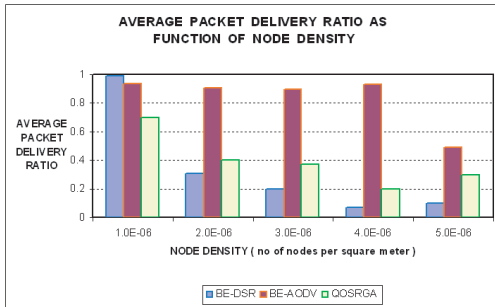


Fig. 8 Average Packet Delivery Ratio as a Function of node Density

The node had to do the monitoring of packet arrival, set and reset all the node cache, perform the bandwidth calculation, nci calculation and, most importantly, run the route selection routine using the GA. Hence, the packet delay observed from Fig. 9 can be attributed to these node state manifestations. However, for node densities of more than  $3.0 \times 10^{-6}$ , the delay is less than 0.1 second, which is the maximum delay allowed.

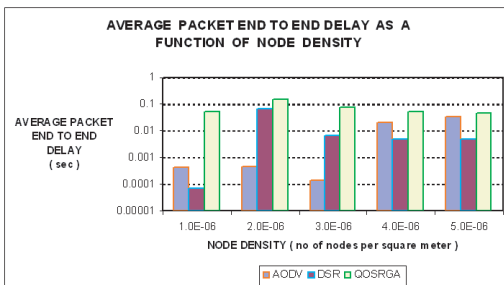


Fig. 9 Average Packet End to End Delay as a Function of Node Density

### 3.3.3 Total Average Throughputs

Fig. 10 shows the average total throughput of the QOSRGA compared to other protocols. The average throughput increased as the node density is increased. In this context, QOSRGA performed on a par with the BE-DSR protocol. When a node density is high, then the probability of longer route lifetime can be realized.

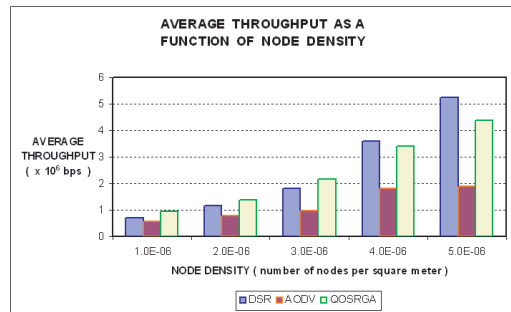


Fig. 10 Average Throughput as a Function of Node Density.

## 4. SUMMARY

The paper addressed the problem of QoS Routing for MANET with node mobility. The goal of QoS routing is to select the most optimal route to send data packet against the constraint of bandwidth, delay and mobility. The working of QOSRGA was outlined and the corresponding results were given. The proposed protocol using GA could contribute to the better understanding of how QoS routing in MANET can be properly designed. We utilized nci as one of the fitness variable within the GA techniques for QoS route selection. GA will always select a chromosome where the sum of nci is the least. We compared QOSRGA protocol

and BE-DSR whereby we concluded that QOSRGA had a potential as one of the viable QoS routing protocol for 40 nodes moving randomly at maximum speed from 1 to 25 m/s and 1000 m x1000 m field configurations.

## REFERENCES

- [1] P. Baran, S. Boehm, and P. Smith, "On distributed communication," RAND Corp., Santa Monica, CA, USA, Tech. Rep. 9, 1964.
- [2] M. Mosko and J.J. Garcia-Luna-Aceves, "Multipath Routing in Wireless Mesh Networks"
- [3] H. Rangarajan and J. Garcia-Luna-Aceves, "Using labeled paths for loop-free on-demand routing in ad hoc networks," in *MobiHoc*, 2004.
- [4] M. Pearlman, Z. Haas, P. Sholander, and S. Tabrizi, "The impact of alternate path routing for load balancing in mobile ad hoc networks," in *Proc. ACM MobiHoc*, 2000, pp. 3–10.
- [5] K. Wu and J. Harms, "On-demand multipath routing for mobile ad hoc networks," in *Proc. EPMCC*, 2001.
- [6] S. Roy, D. Saha, S. Bandyopadhyay, T. Ueda, and S. Tanaka, "Improving end-to-end delay through load balancing with multipath routing in ad hoc wireless networks using directional antenna," in *Proc. IWDC 2003: 5th International Workshop, LNCS v2918*, Jan. 2003, pp. 225–234.
- [7] M. Marina and S. Das, "On-demand multipath distance vector routing in ad hoc networks," in *Proc. ICNP*, 2001, pp. 14–23.
- [8] S.-J. Lee and M. Gerla, "Split multipath routing with maximally disjoint paths in ad hoc networks," in *IEEE ICC*, 2001, pp. 3201–3205.
- [9] W.H. Liao, Y.C. Tseng, J.P. Sheu, and S.L. Wang. "A Multi-Path QoS Routing Protocol in a Wireless Mobile Ad Hoc Network." In *Proc. of IEEE ICN'01: International Conference on Networking, Part II*, pages 158–167, July, 2001.
- [10] Imrich Chlamtac, Marco Conti, Jennifer J.-N. Liu, "Mobile ad hoc networking: imperatives and challenges," *Adhoc*, vol. 1, pp. 13-64, 2003. 2003.
- [11] Manet Working Group Charter, "Internet Engineering Task Force," vol. 2005, 2005.
- [12] S. B. Lee, A. Gahng-Seop, X. Zhang and A. T. Campbell, "INSIGNIA: An IP-based quality of service framework for mobile ad hoc networks," *Journ PADC*, vol. 60, pp. 374-406, 2000. 2000.
- [13] M. Gen and R. Cheng, *Genetic Algorithms and Engineering Optimization*. Canada: Wiley-Intersciences Publication, 2000,
- [14] C. Y. Lee and E. K. Antonsson, "Variable length genomes for evolution strategies," in *Proceedings of the Genetic and Evolutionary Computation Conference (GECCO 2000)* 2000,
- [15] J. Inagaki, M. Haseyama and H. and Kigajima, "A genetic algorithm for determining multiple routes and its applications," in *Proceedings of the IEEE International Symposium on*

- Circuits and Systems, 1999, pp. 137-140.
- [16] R. L. Haupt and S. E. Haupt, Practical Genetic Algorithms. Canada: Wiley-Interscience, 1998,
- [17] Opnet Modeler. Available: [www.opnet.co](http://www.opnet.co)
- [18] A. Nasipuri, R. Castaneda, and S.R. Das, "Performance of multipath routing for on-demand protocols in mobile ad hoc networks," in ACM/Baltzer Mobile Networks and Applications Journal, Vol 6, 2001, pp. 339-349.
- [19] S. Corson and J. Macker, "Mobile and hoc networking (MANET) : Routing protocol performance issues and evaluation considerations," IETF RFC 2501, January 1999. Available : <http://www.ietf.org/rfc/rfc2501.txt46>
- [20] J.D. Schaffer; R.A. Caruana; L.J. Eshelman and R. Das, A study of control parameters affecting online performance of genetic algorithms for function optimization, Proceedings of the third international conference on Genetic algorithms, 1989, pp. 51-60, George Mason University, Morgan Kaufmann Publishers Inc.
- [21] Haupt, R.L. , Optimum population size and mutation rate for a simple real genetic algorithm that optimizes array factors, Antennas and Propagation Society International Symposium, 2000. IEEE, Vol.2, Iss., 2000, pp:1034-1037 vol.2
- [22] J. Abdullah and D.J. Parish, "Impact of QoS Routing Metrics for MANETs in the Pervasive Computing Environment." Proc. IEEE WOCN2007, 2-4 July 07, Singapore.
- [23] J. Abdullah, "GA-Based QoS Route Selection Algorithm for Mobile Ad-Hoc Networks.," Proceeding of the National Conference on Telecommunication Technologies and Malaysia Conference on Photonics 2008 (NCTT-MCP 2008), Putrajaya, Malaysia, 26-28 August 2008.
- [24] J. C. Z. Wang, "Quality of Service Routing For Supporting Multimedia Applications," J-SAC, vol. 14, pp. 1228-1234, 1996. 1996.
- [25] Q. Ma and P. Steenkiste, "Quality-of-service routing for traffic with performance guarantees," in Proceedings of IFIP Fifth International Workshop on Quality of Service, 1997,
- [26] B. Li and K. Nahrstedt, "A control theoretical model for quality of service adaptations " in Proceedings of Sixth IEEE International Workshop on Quality of Service, 1998, pp. 145-153.
- [27] S. B. Lee, A. Gahng-Seop, X. Zhang and A. T. Campbell, "INSIGNIA: An IP-based quality of service framework for mobile ad hoc networks," Journ PADC, vol. 60, pp. 374-406, 2000.

