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Design of a Double-objective QoS Routing in Dynamic Wireless Networks using Evolutionary Adaptive Genetic Algorithm

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Abstract: The shortest path problem is studied for finding the shortest route from a specified source to a specified destination in a mobile wireless networks with minimizing the total cost associated with the path. Several QoS measures are proposed to calculate the best path for routing the packets from specific sources to their destination. These measures are end-to-end delay, bandwidth, and No. of hops. The main goal of this work is to solve the problem of route optimization between the sender and receiver in a dynamic mobile wireless networks, and formulating the multi objective QoS measures in such dynamic environment as a multi- objective optimization using weighted sum approach. A new algorithm based on evolutionary multi objective genetic algorithm technique has been proposed and called Adaptive Genetic Algorithm (AGA) to find out the optimal route in dynamic wireless networks that satisfied the multi objective QoS measures. The proposed algorithm is adaptive in the sense that it finds the shortest route even with the dynamic nature of the mobile wireless networks, e.g. moving nodes and a reproduction operator of the proposed algorithm which uses six different selection methods that are changing through the generations of the proposed algorithm and the best selection method is chosen by AGA according to maximum fitness. An experiment has been made for illustrating the behaviour of our proposed algorithm in wireless networks; in this experiment, the AGA has been implemented on double objectives QoS. The AGA is implemented online with predetermined initial population and fitness values. The simulations have been done under MATLAB and Visual Basic environments, and they showed that our proposed AGA performs excellently and adapts quickly to the dynamic nature of the wireless network and satisfying all of the constraints and objective measures imposed on the networks.

Keywords: Adaptive Genetic algorithm, Quality of Service (QoS), double objective optimization, routing, end-to-end delay, shortest path, dynamic networks.

I. INTRODUCTION

Over the past five years, the world has become increasingly mobile. As a result traditional ways of networking the world have proven inadequate to meet the challenges posed by our new collective lifestyle. If users must be connected to a network by physical cables, their movement is dramatically reduced. Wireless connectivity, however, poses no such restriction and allows a great deal more free movement on the part of the network user. As a result, wireless technologies are encroaching on the traditional realm of "fixed or "wired" networks [1].

Routing is one of the most important design issues of multi-hop wireless networks, which has a significant impact on their achievable performance. Hence, efficient routing techniques should be designed for ensuring that the data packets propagate in an ’optimal’ manner in terms of several metrics, such as delay, delay jitter, bandwidth, number of hops, and packet loss ratio. In conventional multi-hop networks, all the desired objectives are optimized together. Nonetheless, in some practical applications finding multiple solutions, each of which is optimal in terms of a single metric may be better than finding a single meritorious solution, which strikes a trade-off amongst several conflicting factors [2]. Several shortest Path (SP) search algorithms, such as Dijkstra’s algorithm and Bellman-Ford algorithm, work effectively for fixed infrastructure wired or wireless networks. But, they suffer from high computational complexity for real-time applications in mobile networks with rapidly changing topology and/or network status. [3].

Quality of Service (QoS) requirements for traffic, including the cost, bandwidth, end-to-end delay, delay jitter, packet loss ratio and hop count, etc. The notion of QoS in networks means the data delivery service should satisfy certain performance requirements or metrics. These metrics define the QoS guarantees that a network should provide. However, originally, the Internet was designed to support the best effort service for time independent information streams such as file transfer and electronic mail, and thus no QoS guarantees can be provided. In order to support QoS requirements, new challenges for network routing have emerged to satisfy certain constraints defined by the QoS requirements. QoS routing in computer networks is defined as the process of transferring information from a source to a destination (or a group of destinations) through network elements, including hosts and routers, under certain constraints or performance metrics. It means that QoS constrained network routing must be able to utilize the network

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resources efficiently while providing the requested QoS requirements [4]. In MANET, the nodes are free to move randomly, thus the network topology which is typically multihop may change randomly in unpredictable time. Genetic algorithms are an optimization technique that deals with such uncertainties related with dynamic environment. Since the network topologies are changing, it is necessary to change the routes randomly and find out the optimum path in real time [5].

Researchers have resorted to a wide variety of techniques. Bahador Bakhshi et al. [6] presented a study on algorithmic aspects of the QoS routing problem. They show that the problem of finding a feasible path with only one QoS requirement, (which is described in terms of end-to-end bandwidth). Carlos Lozano-Garzon et al. [7] proposed a routing algorithm based on the Strength Pareto Evolutionary Algorithm (SPEA) which intends to build the most efficient routes taking into account the shortest path, energy consumption and QoS restrictions (delay and bandwidth). As result, the routing protocol designed could be used in unicast or multicast schemes, with or without restrictions and into centralized or decentralized environments. T. Priyadharshini et al [8], used Genetic algorithm (GA) to find the optimal path between the source and destination nodes. GA is uses either crossover and mutation reproduction. The developed genetic algorithm uses evaluation of fitness function for cost and bandwidth in MANET. the simulation of routing protocol using JAVA and the results obtained showed the optimal routing path.

M. R. Girgis et al [9] proposed three different approaches for solving the routing and capacity assignment (RCA) problem. The first approach uses a GA. The second approach uses the SA algorithm. The last approach combines the GA with the SA to improve the performance of the GA. The objective find optimum path with minimum delay.

T. Priyadharshini et al [10] applied Genetic algorithm (GA) to find the optimal path between the source and destination nodes in Ad-hoc network. GA maintains a population of candidate solutions, where each candidate solution is called chromosome. GA is uses either crossover and mutation reproduction. The steps of GA are reproduction, fitness evaluation and selection.

Dr. T. R. Gopalakrishnan Nair et al [11] discussed the implementation of GA in the SP routing problem in MANET, dynamic optimization problem (DOP).The implementation then uses GAs with immigrants and memory schemes to solve the dynamic SP routing problem (DSPRP) in MANETS. In this algorithm the quality of service (QOS) is determined in terms of path cost. Results shows GA with new immigrants shows better convergence result than GA with memory scheme. The remainder of the paper is organized as follows: section 2 explains the genetic algorithm used in network routing, while the Quality of Services (QoS) presented in section 3. In section 4 the developed the modeling of routing discovery in dynamic network using genetic algorithm is proposed. The Simulation results presented and discussed in Section 5. The paper is concluding in Section 6.

II. EVOLUTIONARY GENETIC ALGORITHM

Genetic algorithm provides the solution of optimal path using the technique which is inspired by the natural process that is initial population, selection, crossover and Mutation it can search the solution space effectively and speedily [12].

A. Priority-Based Encoding

How to encode a path for a graph is critical for developing a genetic algorithm to solve the shortest path problem. As we know, a gene in a chromosome is characterized by two factors: locus, the position of the gene, and allele, the value the gene takes .the position of a gene is used to represent a node, and the value is used to represent the priority of the node for constructing a path among candidates. The encoding method is denoted as Priority-Based Encoding [13] as shown in Fig. 1.

Position: node	1	2	3	4	5	6	7	8	9	10
Value: priority	7	3	4	6	2	5	8	10	1	9

Fig.1: Example of Priority-Based Encoding [10].

B. Representation of Chromosomes

A path (route) is encoded by listing a node from its source to its destination based on the topological data base of a network. For example, a path from node 0 to node 9 is encoded into a list of nodes along the path (0 12 5 8 2 9). If a path cannot be realized on the network , it cannot encoded into a chromosome , which mean that each step in a path must pass through a physical link in the network. A chromosome consists of a path and the its fitness value , in case of delay the fitness represent the delay of the path, and so on with the other cases[13].

C. Genetic Operators

1. selection methods

The selection mechanism determines which individuals are chosen for mating (reproduction) and how many offspring each selected individual produces. The main principle of selection strategy is “the better is an individual; the higher is its chance of being parent. "[14].there are many types of selection methods, The selection methods used in this paper are:

- Roulette Wheel selection RWS: In roulette wheel, individuals are selected with a probability that is directly proportional to their fitness values i.e. an individual's selection corresponds to a portion of a roulette wheel. The probabilities of selecting a parent can be seen as spinning a roulette wheel with the size of the segment for each parent being proportional to its fitness. Obviously, those with the largest fitness (i.e. largest segment sizes) have more probability of being chosen. The fittest individual occupies the largest segment, whereas the least fit have correspondingly smaller segment within the roulette wheel. The circumference of the roulette wheel is the sum of all fitness values of the individuals [15].
- Tournament selection TS: is probably the most popular selection method in genetic algorithm due to its

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efficiency and simple implementation. In tournament selection, n individuals are selected randomly from the larger population, and the selected individuals compete against each other. The individual with the highest fitness wins and will be included as one of the next generation population, as shown in fig. 2. The number of individuals competing in each tournament is referred to as tournament size, commonly set to 2 (also called binary tournament) [15].

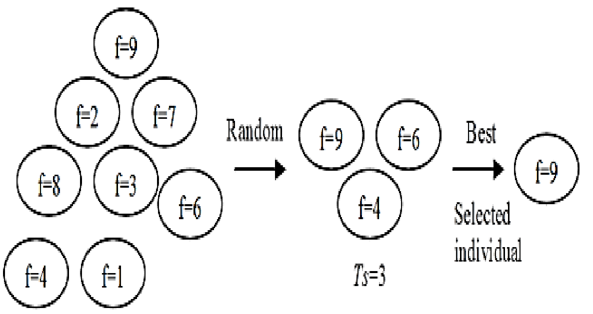

Fig. 2: Selection strategy with tournament mechanism [15].

- Steady state selection SSS: only a few individuals are replaced in each generation: usually a small number of the least fit individuals are replaced by offspring resulting from crossover and mutation of the fittest individuals [16].
- Boltizmann selection BS:(an approach similar to simulated annealing), in which a continuously varying "temperature" controls the rate of selection according to a present schedule. the temperature starts out high, which means that selection pressure is low and vice versa thereby allowing GA to narrow in ever more closely to the best part of the search space[16].
- Sigma scaling selection SigSS: which keeps the selection pressure relatively constant over the course of the run rather than depending on the fitness variances in the population. Under sigma scaling, an individual's expected value is a function of its fitness, the population mean, and the population standard deviation [16].
- Rank selection RS: Rank-based selection schemes first sort individuals in the population according to their fitness and then computes selection probabilities according to their ranks rather than fitness values. Hence rank-based selection can maintain a constant pressure in the evolutionary search where it introduces a uniform scaling across the population and is not influenced by super-individuals or the spreading of fitness values at all as in proportional selection [15].

2. Path Crossover

The path crossover operator exchanges sub routes between two chromosomes; the chromosomes should have the same source and destination node to apply the crossover. Crossover sites for the path crossover operator are limited to the nodes contained in both chromosomes .A node is randomly selected as a crossover site from the potential crossing sites and exchange sub routes when applying the crossover operator to the pair of chromosomes P1 and P2[13]. The operation proceeds shown in Fig. 3:

Path P1	0	2	3	7	9	11	12	15	17	18	20
Path P2	0	4	5	7	10	11	12	15	16	20	

selected point

Child P1'	0	2	3	7	9	11	12	15	16	20	
Child P2'	0	4	5	7	10	11	12	15	17	18	20

Fig. 3: Example of Single point Crossover [13].

Fig. 3 shows an overview of the operator applying for a pair of parents P1 and P2 from node no. 0 to node no. 20.Their potential crossing sites are nodes 7, 11, and 15.We select node 11 as a crossing site .When a common node in a pair of chromosomes does not exist, a crossing site is not able to select; Therefore, it is impossible to perform the crossover operator.

3. Path Mutation

The path mutation operator generates an alternative chromosome from chromosomes. To perform a mutation, first, a node is randomly selected from the chromosomes, which is called a mutation node. Then another node is randomly selected from the node directly connected to the mutation node. Finally, according to Dijkstra's Shortest-path algorithm, an alternative route is generated by connecting the source node to the selected node and the selected node to the destination. As shown in Fig. 4, where offspring V' represents the path resulted from the path mutation operator [13].

Parent V	0	3	5	6	7	10	12	15
Sub route r1	0	2	4	8				
Sub route r2				8	10	12	15	
Offspring V'	0	2	4	8	10	12	15	

III. QUALITY OF SERVICES MEASURES (QOS)

A routing problem in wireless networks is to find one path between two nodes, which satisfies QoS requirements , the problem can be represented as finding a path P*,where P* is the optimum path. Here in our work we are considering QoS parameters for real time applications. In real time applications most important QoS parameters to be considered are delay and data rate (Bandwidth), and no. of hops. Our main concern is to provide robust algorithm than only to provide optimum path [17, 18], and so for this reason for better routing we applied one of Evolutionary Algorithm that is Genetic Algorithm. The parameters that will consider in the proposed routing algorithm are:

1) End-to-End delay,
2) Bandwidth, and
3) Number of Hops.

In this paper an experiment is provision for optimizing these parameters as double objectives, by taking two parameters to satisfy its QoS in each time, with respect to end-to-end delay with number of hops, and with respect to end-to-end delay with the bandwidth in the second case.

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IV. MODELLING OF ROUTING IN A MOBILE WIRELESS NETWORKS USING AGA

A Dynamic network under consideration represented as a connected graph with N nodes. The metric of optimization a QoS of doubly objectives are optimized. This part presents a simple and effective proposed Adaptive genetic algorithm (AGA) to find the shortest path with double objective quality of service (QoS). The details of the algorithm are given in the following subsections; while the investigation of the performance is achieved via a simulation work in the next section. Our contribution in this work lies in two points: 1. the proposed algorithm deals with dynamic topology network where nodes are mobile, and the second contribution is he adaptive selection method used in the proposed AGA with proposed selection methods deals with six selection criteria, each generation is obtained using one selection method with best fitness.

A. QoS of Double Objectives(End-to End Delay and Number of Hops)

In this case a QoS of doubly objectives are optimized, which are minimizing both end-to-end delay and number of hops for a mobile wireless networks.

1. Initial population

This initial process is used to compose the routing tables (all chromosomes) in the current generation. Each chromosome includes a random routing table for the given network topology.

2. Fitness Function of double objectives

The fitness value of routes is based on various QoS parameters end-to- end delay, number of hops. Clearly it is a multiple-objective optimization problem; the weighted sum approach can be represented as follows. The fitness function operates to minimize the weighted-sum F which, is given as:

$$F= \alpha_1 F_1 + \alpha_2 F_2 \quad (1)$$

Weights α_1,α_2 are interpreted as the relative emphasis of one objective as compared to the others,F_1 ,F_2 are the objective functions which describe the delay, and number of hops, given by:

$$F_1 = \min \ \text{Delay}\ (P(s,d)) \quad (2)$$

$$F_2 = \min \ \text{Hops}\ (P(s,d)) \quad (3)$$

St. Delay (P(s ,d))<= Dmax

St. Hops(P(s ,d))<= hops

Where Dmax is the maximum allowable delay.The values of α_1,α_2 are chosen to increase the selection pressure on any of the two objective functions, such that:

$$\sum_{i=1}^{n} \alpha i = 1 \quad \mathbf{(4)}$$

3. Proposed Selection methods

Selection is an operator to select two parent chromosomes for generating new chromosomes. In this paper, a proposed selection method of six selection methods the AGA selected the optimum fitness value (with minimum end-to-end delay, minimum no. of hops) of the best selection method.

4. Path Crossovers and Mutations

Follows the same procedures discussed in section II.

B. QoS of Double Objectives(End-to End Delay and Bandwidth)

In this section a QoS of doubly objectives are optimized, which are minimizing both end-to-end delay and bandwidth for a mobile wireless networks.

1. Initial population

This initial process is used to compose the routing tables (all chromosomes) in the current generation. Each chromosome includes a random routing table, which include a path, end-to-end delay, and bandwidth, for the given network topology.

2. Fitness Function of double objectives

The fitness value of routes is based on various QoS parameters end-to- end delay, bandwidth. Clearly it is a multiple-objective optimization problem; the weighted sum approach can be represented as follows. The fitness function operates to minimize the weighted-sum F which, is given as:

$$F = \alpha 1F1 + \alpha 2F2 \quad \mathbf{(5)}$$

Again the weights $\alpha 1$,$\alpha 2$ are interpreted as the relative emphasis of one objective as compared to the others, F1 ,F2 are the objective functions which describe the delay, and number of hops, given by:

$$F1 = \min \ \text{Delay}(P(s,d)) \quad \mathbf{(6)}$$

$$F2 = \max \ \text{Bandwidth}(P(s,d)) \quad \mathbf{(7)}$$

St. $\text{Delay}(P(s,d)) <= D\max$

St. $\text{Bandwidth}(P(s,d)) \geq B\min$

Where Bmin is the minimum required bandwidth for the network. The values of$\alpha 1$,$\alpha 2$ are chosen to increase the selection pressure on any of the two objective functions, such that:

$$\sum_{i=1}^{n} \alpha i = 1 \quad \mathbf{(8)}$$

3. Proposed Selection methods

Selection is an operator to select two parent chromosomes for generating new chromosomes. In the paper, a proposed selection method of six selection methods the AGA selected the optimum fitness value (with minimum end-to-end delay, maximum bandwidth) of the best selection method.

4. Path Crossovers and Mutation

Follow the same procedures discussed in section II.

V. SIMULATION AND RESULTS

Network with 50 nodes were selected for simulation connection were designed to allow multi path alternate from source to destination, see Fig. 5 .A network can be expressed as a weighted graph G= (, E), where V set of nodes and E set of links.

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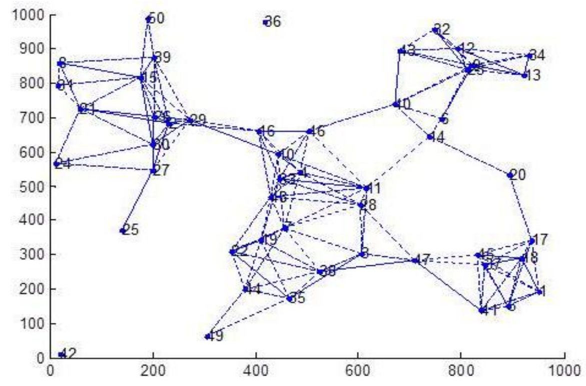

Fig. 5: Network Topology of 50 nodes.

A. End-to End Delay and Number of Hops QoS measure

1. Initialization

The network model used in this simulation is shown in Fig. 5. The simulation network parameters are chosen as follows:

- The node coverage area is 200 m.
- Source node s is node number 1, where the destination d node is 50.
- The proposed AGA initial parameters are shown in Table 1. Population size = 50, Table 2 shows the routing table of 50 random route from the source to the destination. Each route has an end-to-end delay, number of hops. The fitness value depends on both of them. Our aim is to find the optimum path from node number 1 to node number 50, with minimum delay, minimum hops. The values of α_1, α_2 are 0.75, 0.25 respectively.

TABLE 1 GA INITIAL PARAMETERS

Name	Value
Pop size	50
Selection methods	RWS, TS, SSS, BS, SigSS, RS
generation	100
Crossover probability	0.75
Mutation probability	0.01

2. Proposed Selection methods

The six selection methods are applied at the same time. The fitness value for each method is represent by its maximum and minimum fitness values for the inial iteration, as shown in Table 3. In our experiment we concerned with minimum values of end-to- end delay and number of hops optimization.

TABLE 2 INITIAL ROUTING TABLE FOR DELAY AND NUMBER OF HOPS QOS.

path no.	Path									delay	hops	fitness
1	1	21	13	3	46	50	0	0	0	1.5	6	3.75
2	1	20	44	48	46	50	0	0	0	1.4	6	3.70
3	1	41	43	17	50	0	0	0	0	1.6	5	3.30
4	1	43	50	0	0	0	0	0	0	1.7	3	2.35
5	1	14	16	50	0	0	0	0	0	1.4	4	2.70
6	1	42	29	26	19	50	0	0	0	2.0	6	4.00
7	1	16	50	0	0	0	0	0	0	1.4	3	2.20
8	1	31	50	0	0	0	0	0	0	2.2	3	2.60
9	1	3	6	50	0	0	0	0	0	1.3	4	2.60
10	1	5	15	50	0	0	0	0	0	2.00	4	2.65
11	1	22	5	24	4	40	9	50	0	1.8	8	3.00
12	1	14	28	43	7	39	50	0	0	1.6	7	4.90
13	1	28	9	11	50	0	0	0	0	1.9	5	4.30
14	1	8	50	0	0	0	0	0	0	2.6	3	3.45
15	1	32	50	0	0	0	0	0	0	1.5	3	2.80
16	1	15	43	18	50	0	0	0	0	1.3	5	2.25
17	1	32	19	38	43	13	50	0	0	1.4	7	3.15
18	1	18	45	50	0	0	0	0	0	2.2	4	4.20
19	1	47	50	0	0	0	0	0	0	2.4	3	3.10
20	1	36	50	0	0	0	0	0	0	1.5	3	2.70
21	1	3	33	50	0	0	0	0	0	1.3	4	2.25
22	1	11	36	50	0	0	0	0	0	1.4	4	2.65
23	1	11	18	37	12	13	50	0	0	1.2	7	2.70
24	1	42	41	50	0	0	0	0	0	1.6	4	4.10
25	1	28	29	12	40	22	50	0	0	1.8	7	2.80
26	1	18	35	6	50	0	0	0	0	1.3	5	4.40
27	1	41	49	11	50	0	0	0	0	1.8	5	3.15
28	1	41	8	6	35	50	0	0	0	2.7	6	3.40
29	1	12	3	50	0	0	0	0	0	1.4	4	4.35
30	1	6	22	29	50	0	0	0	0	2.0	5	2.70
31	1	33	2	50	0	0	0	0	0	1.9	4	3.50
32	1	33	16	50	0	0	0	0	0	1.4	4	2.95
33	1	15	17	9	50	0	0	0	0	1.5	5	2.70
34	1	26	20	29	5	50	0	0	0	1.4	6	3.35
35	1	45	50	0	0	0	0	0	0	2.2	3	3.70
36	1	34	22	39	7	38	49	9	50	1.2	9	2.60
37	1	41	14	33	12	50	0	0	0	1.5	6	5.10
38	1	28	22	46	50	0	0	0	0	1.7	5	3.75
39	1	12	36	48	27	50	0	0	0	1.8	6	3.35
40	1	7	40	32	50	0	0	0	0	1.6	5	3.90
41	1	49	7	22	50	0	0	0	0	1.3	5	3.30
42	1	49	26	10	50	0	0	0	0	1.8	5	3.15
43	1	26	45	8	20	13	29	50	0	1.6	8	3.40
44	1	11	50	0	0	0	0	0	0	1.4	3	4.80
45	1	35	42	45	50	0	0	0	0	1.60	5	2.20
46	1	26	9	50	0	0	0	0	0	2.60	4	3.30
47	1	34	50	0	0	0	0	0	0	1.70	3	3.15
48	1	12	32	40	50	0	0	0	0	1.40	5	3.40
49	1	14	22	25	50	0	0	0	0	2.90	5	4.80
50	1	5	50	0	0	0	0	0	0	1.50	3	2.20

TABLE 3 SELECTION METHOD OF DOUBLE OBJECTIVES, END-TO-END DELAY, AND NUMBER OF HOPS QOS.

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Selection no.	Selection method	Maximum	Minimum
1	RWS	28.1	18.225
2	TS	28.4999	17.9229
3	SSS	28.4	18.225
4	BS	28.7	18.225
5	Sig SS	28.1	18.225
6	RS	29	18.225

3. Multi-Objectives Optimization Results

The results of applying proposed GA using six selection methods for every generation are as follows:

- The shortest path from node 1 to node 50 is: **1 20 38 47 50**, as shown in Fig.6 in red line.

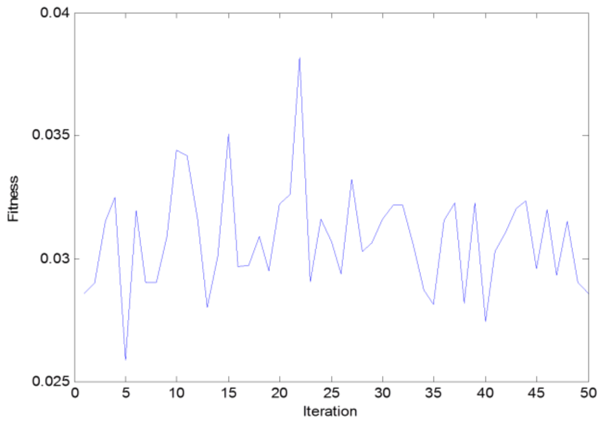

Fig. 6 Network topology showing shortest path with respect to double objectives: end-to-end delay, and number of hops QoS.

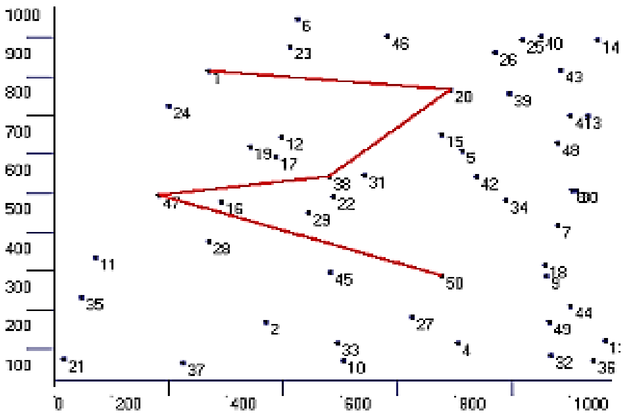

Fig. 7: Fitness and Pop size correlation.

- The total end-to-end delay is 7.1msec, and the number of hops equal to four.

- The best fitness is 16. 92 resulted from selection method two, so Tournament selection gives best fitness value with minimum delay and number of hops as shown in table 4. While the variation of the fitness values during generations is shown in Fig. 7.

TABLE 4 INITIAL ROUTING TABLE FOR DELAY AND NUMBER OF HOPS QoS.

iteration	Path										fitness	Best fitness	selection
1	40	46	42	3	6	21	41	43	2	11	17.9229	17.92	2
2	6	35	50	18	37	40	20	29	30	28	25.15	17.92	2
3	33	18	12	19	48	10	9	25	28	31	25.15	17.92	2
4	23	47	12	5	39	22	24	44	21	26	26.8	17.92	2
5	39	49	19	32	20	7	33	4	3	30	26.75	17.92	2
6	12	29	16	20	45	31	25	42	40	11	25.15	17.92	2
7	32	6	48	45	22	37	7	4	27	50	27.1	17.92	2
8	2	34	3	8	16	6	36	45	44	49	27.9	17.92	2
9	21	27	34	14	26	25	41	44	47	39	26.7	17.92	2
10	13	28	20	5	38	40	10	37	42	2	26.9	17.92	2
11	35	48	22	23	49	7	19	46	15	45	25.45	17.92	2
12	18	35	10	36	46	41	8	42	14	48	25.8	17.92	2
13	9	14	11	22	38	2	10	20	43	16	25.8	17.92	2
14	18	49	5	24	32	22	2	47	48	46	27.25	17.92	2
15	1	37	43	50	16	42	41	7	47	23	25.75	17.92	2
16	21	4	43	12	3	44	8	17	1	38	25.75	17.92	2
17	38	15	23	35	12	31	11	34	1	13	26.75	17.92	2
18	1	49	43	11	8	30	14	24	26	41	27.45	17.92	2
19	42	12	14	23	45	27	5	21	2	8	26.75	17.92	2
20	26	34	24	5	50	49	4	39	33	19	26.2	17.92	2
21	44	30	46	49	2	18	26	10	6	45	27.1	17.92	2
22	15	6	47	10	20	3	41	28	4	25	26.35	17.92	2
23	37	1	33	50	41	15	4	2	46	13	17.4	17.4	3
24	10	32	3	27	33	29	40	43	7	28	24.25	17.4	3
25	29	39	48	43	21	36	4	24	42	37	27.1	17.4	3
26	27	7	16	15	19	5	48	34	47	46	26.2	17.4	3
27	12	15	18	10	34	49	41	26	9	11	26.2	17.4	3
28	31	8	13	26	36	6	19	7	44	20	26.75	17.4	3
29	41	40	17	49	16	2	6	31	7	11	27.9	17.4	3
30	29	26	48	19	43	35	31	9	23	44	27.85	17.4	3
31	32	41	14	9	37	39	20	40	45	3	26.8	17.4	3
32	42	23	32	30	35	8	14	21	50	13	26.2	17.4	3
33	12	27	31	34	26	50	14	7	42	24	23.4	17.4	3
34	27	47	24	28	42	38	22	35	9	36	25.55	17.4	3
35	44	6	33	2	32	5	22	47	27	45	23.4	17.4	3
36	29	1	35	45	47	8	25	39	46	48	26.35	17.4	3
37	7	30	25	3	5	36	42	11	18	8	23.4	17.4	3
38	39	34	35	33	38	23	30	37	3	29	25.45	17.4	3
39	28	43	34	36	2	30	10	8	40	29	27.4	17.4	3
40	1	20	38	47	50	44	32	6	24	12	16.92	16.92	2
41	22	49	18	48	21	38	50	36	30	47	26.45	16.92	2
42	45	16	1	11	17	13	24	41	42	12	26.9	16.92	2
43	14	23	45	27	5	21	2	8	26	34	27.65	16.92	2
44	24	5	50	49	4	39	33	19	44	30	26.45	16.92	2
45	46	49	2	44	18	26	10	6	45	15	26.45	16.92	2
46	6	47	10	20	3	41	28	4	25	37	26.35	16.92	2
47	1	33	50	37	41	15	4	2	46	13	27.75	16.92	2
48	10	32	3	27	33	29	40	43	7	28	27.8	16.92	2
49	29	39	48	43	21	36	4	24	42	37	25.2	16.92	2
50	27	7	16	15	19	5	48	34	47	46	25.65	16.92	2

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67	38	15	23	35	12	31	11	34	1	13	25.2	16.92	2
68	1	49	43	11	8	30	14	24	26	41	25.2	16.92	2
69	42	12	14	23	45	27	5	21	2	8	26	16.92	2
70	26	34	24	5	50	49	4	39	33	19	26	16.92	2
71	44	30	46	49	2	18	26	10	6	45	25.75	16.92	2
72	15	6	47	10	20	3	41	28	4	25	25.75	16.92	2
73	37	1	33	50	41	15	4	2	46	13	25.75	16.92	2
74	10	32	3	27	33	29	40	43	7	28	24.35	16.92	2
75	29	39	48	43	21	36	4	24	42	37	25.2	16.92	2
76	27	7	16	15	19	5	48	34	47	46	25.75	16.92	2
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79	41	40	17	49	16	2	6	31	7	11	26.1	16.92	2
80	29	26	48	19	43	35	31	9	23	44	25.75	16.92	2
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82	42	23	32	30	35	8	14	21	50	13	27.45	16.92	2
83	12	27	31	34	26	50	14	7	42	24	26.35	16.92	2
84	27	47	24	28	42	38	22	35	9	36	26.9	16.92	2
85	44	6	33	2	32	5	22	47	27	45	25.95	16.92	2
86	29	1	35	45	47	8	25	39	46	48	26.5	16.92	2
87	7	30	25	3	5	36	42	11	18	8	25.2	16.92	2
88	39	34	35	33	38	23	30	37	3	29	26.5	16.92	2
89	28	43	34	36	2	30	10	8	40	29	28.1	16.92	2
90	1	20	38	47	50	-	-	-	-	-	17.92	16.92	2
91	22	49	18	48	21	38	50	36	30	47	26.35	16.92	2
92	45	16	1	11	17	13	24	41	42	12	26.9	16.92	2
93	14	23	45	27	5	21	2	8	26	34	25.9	16.92	2
94	24	5	50	49	4	39	33	19	44	30	24.35	16.92	2
95	46	49	2	44	18	26	10	6	45	15	27	16.92	2
96	6	47	10	20	3	41	28	4	25	37	26.5	16.92	2
97	1	33	50	37	41	15	4	2	46	13	26	16.92	2
98	10	32	3	27	33	29	40	43	7	28	26.1	16.92	2
99	29	39	48	43	21	36	4	24	42	37	27.85	16.92	2
100	27	7	16	15	19	5	48	34	47	46	28.8	16.92	2

B. End-to End Delay and Bandwidth QoS Measure

1. Initialization

The network model used in this simulation is shown in Fig. 5. The simulation network parameters are chosen as follows:

- Source node s is node number 1, where the destination node d is node 50.

2. Population size=50, The proposed genetic algorithm inial parameters are shown in Table 5. Our goal is to find the optimum path from 1 to 50 with minimum end-to-end delay and maximum bandwidth. The values of α1, α2 are 0.75, 0.25 respectively.

TABLE 5 GA INITIAL PARAMETERS

Name	Value
Pop size	50
Selection methods	RWS, TS, SSS, BS, SigSS, RS
generation	100
Crossover probability	0.75
Mutation probability	0.01

2. Proposed Selection Methods

The six selection methods are applied at the same time. The fitness value of each method is represented by its maximum and minimum values, are shown in shown in Table 6, where our aim is to pick the selection method with minimum fitness.

TABLE 6 SELECTION METHOD OF DOUBLE OBJECTIVES, DELAY AND BANDWIDTH

Selection no.	Selection method	Maximum	Minimum
1	RWS	14.7037	11.4862
2	TS	14.8037	11.1841
3	SSS	14.7037	11.4862
4	BS	14.7037	11.4862
5	Sig SS	14.7037	11.5091
6	RS	14.7037	11.6055

3. Multi-Objective Optimization Results

The results of applying proposed GA using six selection methods are as follows:

- The shortest path from node 1 to node 50 is 1 15 48 50, as shown in Fig. 8 in red line.
- The total end-to-end delay is 6.6 msec, while the bandwidth is 1.8565 Mbps.

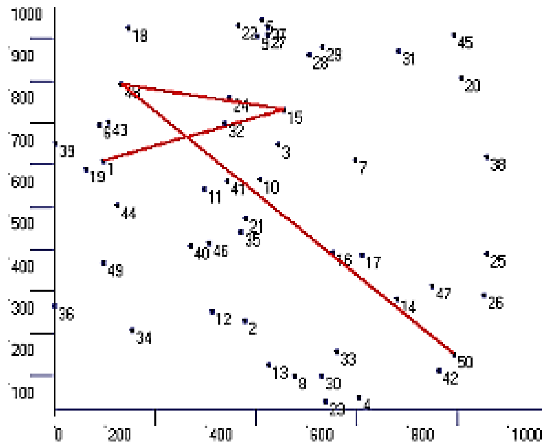

Fig. 8: Network topology showing shortest path with respect to double objectives: delay, and bandwidths QoS.

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TABLE 8 INITIAL ROUTING TABLE FOR DELAY AND NUMBER OF HOPS QOS.

iteration	Path										fitness	Best fitness	selection
1	34	33	49	2	5	47	21	35	28	13	11.18	11.18	2
2	46	48	18	45	49	13	9	43	6	30	12.18	11.18	2
3	30	7	15	27	4	23	3	26	43	18	13.81	11.18	2
4	43	4	48	16	50	22	6	18	30	46	12.42	11.18	2
5	10	18	19	28	1	46	24	26	7	13	12.69	11.18	2
6	32	40	29	10	5	6	4	9	45	1	12.69	11.18	2
7	8	24	50	49	14	5	7	23	1	31	12.69	11.18	2
8	29	11	50	20	2	15	25	9	8	46	13.45	11.18	2
9	46	22	31	43	20	39	19	42	9	21	11.13	11.13	5
10	9	7	1	19	16	38	22	32	34	45	12.30	11.13	5
11	12	13	33	35	44	17	48	27	42	23	13.11	11.13	5
12	29	48	5	45	26	21	22	20	25	10	12.57	11.13	5
13	4	11	40	15	1	17	21	23	39	47	13.57	11.13	5
14	31	27	16	36	18	41	25	24	12	49	13.57	11.13	5
15	25	46	9	22	4	21	8	12	37	23	13.62	11.13	5
16	17	34	32	3	24	48	4	50	11	14	13.58	11.13	5
17	29	49	1	10	19	14	42	7	26	45	11.53	11.13	5
18	13	8	48	28	37	36	41	26	19	6	13.81	11.13	5
19	18	17	33	36	39	31	5	20	12	47	13.81	11.13	5
20	30	32	2	29	34	47	7	27	40	28	12.30	11.13	5
21	15	41	12	11	38	20	37	24	27	2	14.09	11.13	5
22	28	38	33	50	47	19	40	14	6	3	14.70	11.13	5
23	14	30	44	15	3	12	35	8	10	41	14.70	11.13	5
24	11	16	24	14	44	3	2	6	29	35	12.3004	11.13	5
25	42	21	34	33	49	2	5	47	35	28	12.30	11.13	5
26	13	46	48	18	45	49	9	43	6	30	13.72	11.13	5
27	30	7	15	27	4	23	3	26	43	18	14.70	11.13	5
28	43	4	48	16	50	22	6	18	30	46	13.30	11.13	5
29	10	18	19	28	1	46	24	26	7	13	11.90	11.13	5
30	32	40	29	10	5	6	4	9	45	1	11.90	11.13	5
31	8	24	50	49	14	5	1	23	1	31	11.90	11.13	5
32	29	11	50	20	2	15	25	9	8	46	13.57	11.13	5
33	46	22	31	43	20	39	19	42	9	21	11.32	11.13	5
34	9	7	1	19	16	38	22	32	34	45	11.32	11.13	5
35	12	13	33	35	44	17	48	27	42	23	13.58	11.13	5
36	29	48	54	52	6 2	1 2	2	20	25	10	11.32	11.13	5
37	4	11	40	15	1	17	21	23	39	47	13.81	11.13	5
38	31	27	16	36	18	41	25	24	12	49	13.58	11.13	5
39	25	46	9	22	4	21	8	12	37	23	13.58	11.13	5
40	17	34	32	3	24	48	4	50	11	14	11.32	11.13	5
41	29	49	1	10	19	14	42	7	26	45	12.30	11.13	5
42	13	8	48	28	37	36	41	26	19	6	13.58	11.13	5
43	18	17	33	36	39	31	5	20	12	47	13.58	11.13	5
44	30	32	2	29	34	47	7	27	40	28	14.58	11.13	5
45	15	41	12	11	38	20	37	24	27	2	11.32	11.13	5
46	14	25	19	37	34	6	27	1	43	39	11.32	11.13	5
47	50	17	31	2	40	49	22	45	47	28	11.32	11.13	5
48	47	3	10	50	31	39	40	38	43	15	13.58	11.13	5
49	22	29	8	21	20	35	39	42	34	15	13.58	11.13	5
50	1	15	48	50	36	46	30	43	17	2	8.92	8.92	6
51	34	33	49	2	5	47	21	35	28	13	10.38	8.92	6
52	46	48	18	45	49	13	9	43	6	30	14.70	8.92	6
53	30	7	15	27	4	23	3	26	43	18	13.72	8.92	6
54	43	4	48	16	50	22	6	18	30	46	13.78	8.92	6
55	10	18	19	28	1	46	24	26	7	13	14.48	8.92	6
56	32	40	29	10	5	6	4	9	45	1	12.69	8.92	6
57	8	24	50	49	14	5	7	23	1	31	13.62	8.92	6
58	29	11	50	20	2	15	25	9	8	46	13.11	8.92	6
59	46	22	31	43	20	39	19	42	9	21	14.70	8.92	6
60	9	7	1	19	16	38	22	32	34	45	14.55	8.92	6
61	12	13	33	35	44	17	48	27	42	23	13.38	8.92	6
62	29	48	5	45	26	21	22	20	25	10	13.11	8.92	6
63	4	11	40	15	1	17	21	23	39	47	13.78	8.92	6
64	31	27	16	36	18	41	25	24	12	49	14.70	8.92	6
65	25	46	9	22	4	21	8	12	37	23	14.12	8.92	6
66	17	34	32	3	24	48	4	50	11	14	14.70	8.92	6
67	29	49	1	10	19	14	42	7	26	45	13.46	8.92	6
68	13	8	48	28	37	36	41	26	19	6	13.26	8.92	6
69	18	17	33	36	39	31	5	20	12	47	13.36	8.92	6
70	30	32	2	29	34	47	7	27	40	28	13.26	8.92	6
71	15	41	12	11	38	20	37	24	27	2	13.36	8.92	6
72	28	38	33	50	47	19	40	14	6	3	13.62	8.92	6
73	14	30	44	15	3	12	35	8	10	41	11.38	8.92	6
74	11	16	24	14	44	3	2	6	29	35	10.90	8.92	6
75	42	21	34	33	49	2	5	47	35	28	11.65	8.92	6
76	13	46	48	18	45	49	9	43	6	30	13.08	8.92	6
77	30	7	15	27	4	23	3	26	43	18	14.42	8.92	6
78	43	4	48	16	50	22	6	18	30	46	14.70	8.92	6
79	10	18	19	28	1	46	24	26	7	13	14.42	8.92	6
80	32	40	29	10	5	6	4	9	45	1	13.08	8.92	6
81	8	24	50	49	14	5	7	23	1	31	13.33	8.92	6
82	29	11	50	20	2	15	25	9	8	46	13.17	8.92	6
83	46	22	31	43	20	39	19	42	9	21	13.33	8.92	6
84	9	7	1	19	16	38	22	32	34	45	13.11	8.92	6
85	12	13	33	35	44	17	48	27	42	23	11.35	8.92	6
86	29	48	5	45	26	21	22	20	25	10	13.65	8.92	6
87	4	11	40	15	1	17	21	23	39	47	8.92	8.92	6
88	31	27	16	36	18	41	25	24	12	49	13.11	8.92	6
89	25	46	9	22	4	21	8	12	37	23	14.42	8.92	6
90	17	34	32	3	24	48	4	50	11	14	10.90	8.92	6
91	29	49	1	10	19	14	42	7	26	45	13.08	8.92	6
92	13	8	48	28	37	36	41	26	19	6	13.17	8.92	6
93	18	17	33	36	39	31	5	20	12	47	13.26	8.92	6
94	30	32	2	29	34	47	7	27	40	28	12.63	8.92	6
95	15	41	12	11	38	20	37	24	27	2	13.08	8.94	6
96	14	25	19	37	34	6	27	1	43	39	14.64	8.92	6
97	50	17	31	2	40	49	22	45	47	28	11.38	8.92	6
98	47	3	10	50	31	39	40	38	43	15	12.36	8.92	6
99	22	29	8	21	20	35	39	42	34	15	14.40	8.92	6
100	1	15	48	50	-	-	-	-	-	-	11.65	8.92	6

4. Discussion: In this section the simulation results of the two experiments applied on route optimization in mobile wireless networks using Adaptive Genetic Algorithm (AGA) are discussed as follows:

- End-to-end delay and no.of hops: There are 50 possible paths from 1 to 50 as initial populations. The list

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is shown in Table 1. Table 3 illustrate the six different selection criteria used in this simulation, where all of them are evaluated at the same time for each generation in proposed AGA, the minimum and maximum values of the fitness function are evaluated using these criteria, the best selection method is picked for that generation which has the minimum fitness value which is the case of case study, because our QoS is the optimization of the path that has minimum end-to-end delay, no. of hops. The simulation is terminated when the number of generations reached for optimal solution is 100. The optimal path obtained is shown in fig. 6 is**1 20 38 47 50** with minimum total delay equal to 7.9 msec, no. of hops=4, resulted from selection method two, tournament selection (TS). Fig. 7 show the value of the fitness versus the population size.

- End-to-end delay and bandwidth: There are 50 possible paths from 1 to 50 as initial populations. The list is shown in Table 5. Table 6 illustrate the six different selection criteriaused in this simulation, where all of them are evaluated at the same time for each generation in proposed AGA, the minimum and maximum values of the fitness function are evaluated using these criteria, the best selection method is picked for that generation which has the minimum fitness value which is the minimum of case study. The simulation is terminated when the number of generations reached 100 generation. The optimal path obtained is shown in fig. 8 is**1 15 48 50** with minimum total delay equal to 6.6 msec, no. of hops=3, resulted from selection method six, Rank selection (RS). Fig. 9 show the value of the fitness versus the population size.

- The work in this research can be compared with a previous work done in the same field but with single-objective QoS measures [19].

VI. CONCLUSION

This paper presented adaptive genetic algorithm for solving the shortest path routing problem. The proposed algorithm is more suitable and convenient to update with the development in the routing difficulties in contrast to other traditional methods like, such as Dijkstra algorithm which works with static network topology only. Intuitively. While our proposed AGA adapts very well and so fast with dynamic network environment like wireless networks with moving nodes such as MANETS. Also the proposed AGA is capable to solve the double objectives problems and reaches the optimum solution faster than traditional methods, whereas Crossover and mutation operators explored the search routes space where selection operator reduced the search areas within population by discarding poor routes.

The different selection strategies used in the proposed AGA in this work significantly affected the performance of the algorithm. Whereas it is widened the search space and improved the selection process. Our proposed AGA performs better and effectively even to changes in the network due to node mobility and topology changes and give optimum path with best results.

VII. ACKNOWLEDGMENT

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REFERENCES

[1] M. Gast, "802.11®. Wireless Networks: The Definitive Guide", Publisher: O'Reilly, ISBN: 0-596-00183-5, April 2002.
[2] H. Yetgin, K. T. K. Cheung and L. Hanzo. Multi-objective Routing Optimization using Evolutionary Algorithm. IN 2012 IEEE WIRELESS COMMUNICATIONS AND NETWORKING CONFERENCE, PARIS, APRIL 2012.
[3] S. Banerjee, R. Poddar, and P. K. G. Thakurta. A Real Time Framework of Multiobjective Genetic Algorithm for Routing in Mobile Networks. ACEEE Int. J. on Network Security , Vol. 4, No. 1, July 2013.
[4] Ying Xu,Metaheuristic Approaches for QoS Multicast Routing Problems,. Thesis submitted to the University of Nottingham for the degree of Doctor of Philosophy, 2011.
[5] Z. Ishrat, K. B. Ali. Optimization of Route in a Network using Genetic Algorithm. International Conference on Advances in Computer Application (ICACA - 2013), Proceedings published in International Journal of Computer Applications® (IJCA) (0975 -8887).2013.
[6] B. Bakhshi and S. Khorsandi,. Complexity and design of QoS routing algorithms in wireless mesh networks, Computer Communications, vol. 34, no. 14, pp. 1722-1737.2011.
[7] C. Lozano-Garzon, M. Camelo, P. Vila, Y. Donoso.Green Routing Algorithm for Wireless Mesh Network: A Multi-Objective Evolutionary Approach, conference of :Performance Evaluation of Computer and Telecommunication Systems (SPECTS), 2013 International Symposium on Toronto, ON, Canada, 07 Jul - 10 Jul 2013.
[8] PriyadharshiniAr.Arunachalam. Algorithm for Optimal Routing In Ad Hoc Networks. International Journal of Advanced Research in Computer Science and Software Engg. 3(2), pp. 364-367. February - 2013
[9] Girgis, M. R., et al. "Routing and capacity assignment problem in computer networks using genetic algorithm." Information Science Letters 2 (): 13-25, 2013.

[10] T.Priyadharshini, Ar.Arunachalam," Efficient Genetic Algorithm for Optimal Routing In Ad Hoc Networks", International Journal of Advanced Research in Computer Science and Software Engineering Research Paper, Available online at: www.ijarcsse.com, Volume 3, Issue 2, ISSN: 2277 128X,February 2013.
[11] T. R. G. Nair, Ms.K. Sooda and Ms. Y.M B," Enhanced Genetic Algorithm approach for Solving Dynamic Shortest Path Routing Problems using Immigrants and Memory Schemes", International Conference on Frontiers of Computer Science,7 TH TO 9 TH, JN Tata Convention Centre, IISc, Bangalore, India,August 2011.
[12] A. A. Mohammed., G. Nagib. Optimal Routing In Ad-Hoc Network Using Genetic Algorithm. Int. J. Advanced Networking and Applications, Volume: 03, Issue: 05, Pages: 1323-1328 (2012).
[13] Mitsuo G., R.Cheng,. Genetic Algorithms and Engineering Optimization", Copyright © John Wiley & Sons, Inc,2000.
[14] A. Mehta, A. Sharma. Observing the Effect of Elitism on the Performance of GA. International Journal of Advanced Research in Computer Science and Software Engineering. Volume 3, Issue 6, Research Paper Available online at: www.ijarcsse.com,June 2013.
[15] N. M. Razali, J.Geraghty. Genetic Algorithm Performance with Different Selection Strategies in Solving TSP. Proceedings of the World Congress on Engineering Vol II ,WCE 2011, London, U.K.July 6 - 8, 2011
[16] M. Mitchell.. An introduction to Genetic algorithm. 1st edition, MIT Press, London, England, 1999.
[17] Dr. K.Kotecha, and S. Popat.Multiobjective Genetic Algorithm based Adaptive QoS Routing in MANET .2007 IEEE Congress on Evolutionary Computation (CEC 2007)@2007 IEEE Authorized licensed use limited to: Iraq Virtual Science Library. Downloaded on January 27, 2012 at 15:08:56 UTC from IEEE Explore, Restrictions apply.
[18] D. E. Goldberg,. Genetic Algorithms in Search, Optimization and Machine Learning. University of Alabama, 1989.
[19] I. K. Ibraheem, A. A. Alyaa. Application of an Evolutionary Optimization Technique to Routing in Mobile Wireless Networks.

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