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Exponential Genetic Algorithm-Based Stable and Load-Aware QoS Routing Protocol for MANET

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Abstract: As the actual links in mobile ad hoc networks (MANETs) are dynamic, the feasible path generated may not exist during the transmission of multimedia data. There is a need for generating multiple paths for guaranteed transmission. The multi-path finding can be achieved through a genetic-based algorithm that faces the major challenge in quality-of-service (QoS)-aware routing. To enhance the QoS communication over the MANETs, an exponential genetic algorithm (GA)-based stable and load-aware QoS routing protocol (SLAQR) is proposed in this paper. This paper chiefly focuses on the enhancement of the GA-based routing algorithm by including exponential function in the searching process and modifying the fitness function, which incorporates QoS metrics like the node's static resource capacity, dynamic resource availability, neighborhood quality, and link quality. The originality of the proposed protocol comes from the fact that it introduces multiple parameters into the route quality computation and integrates the exponential function into the GA. For experimental validation, the simulation of the proposed method is done and the results are compared with existing protocols such as GAQR (GA-Based QoS Routing), QMRB-AODV (QoS Mobile Routing Backbone Over Ad Hoc On-Demand Distance Vector Routing), and EISGA (Ensemble of Immigrant Strategies with Genetic Algorithm). From the outcome, we conclude that the delivery ratio, throughput, and delay of our proposed SLAQR approach have improved the GAQR approach by 58%, 56%, and 97%, respectively.

Keywords: Genetic algorithm (GA), routing, MANET, quality of service, crossover, throughput.

1 Introduction

Due to the recent developments in multi-media and real-time applications, such as audio and video, quality-of-service (QoS)-based routing [2, 3, 5, 7, 8, 10, 11, 14, 15, 20–22, 24, 26, 27, 29, 30] has received more attention among researchers. In QoS-based routing problems, a genetic algorithm (GA)-based routing algorithm is proposed to handle the multiple constraints. The problem that is to be solved by GA is encoded as a chromosome that consists of several genes. The solution is represented by a group of chromosomes referred to as a population. During every iteration of the algorithm, the chromosomes in the population undergo single or multiple genetic operations, such as crossover and mutation. The result of the genetic operations will become the next generation of the solution. This process continues until either the solution is found or a certain termination condition is met. The idea behind GA is to have the chromosomes in the population to slowly converge to an optimal solution. At the same time, the algorithm is supposed to maintain enough diversity so that it can search a large search space [30]. In addition, to solve the multi-constrained path (MCP) problem, the GA is also able to produce multiple feasible paths, and this enables the algorithm to become more robust in the case that the actual state information in the network has changed since the last state information update received by the router. If the first feasible path found turns out to be no longer feasible, there are other alter-

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native paths that can be tried without having to execute a new routing computation. This will increase the success of finding a feasible path that can fulfill a particular QoS requirement [10].

In QMRB-AODV (QoS Mobile Routing Backbone Over Ad Hoc On-Demand Distance Vector Routing) [10], the feasible path was generated by considering metrics like the node's static resource capacity, dynamic resource availability, neighborhood quality, and link quality. The simulation results showed that it produces the best results in terms of packet delivery ratio, end-to-end delay, and bandwidth utilization. At the same time, the reliability of the generated feasible path drives the QoS in routing [10]. In this paper, an exponential GA (EGA)-based stable and load-aware QoS routing protocol (SLAQR) is proposed for mobile ad hoc networks (MANETs). Here, new neighbors are generated based on the exponential function. The discovery of routes is performed using four objectives, including static resource capacity, dynamic resource availability, neighborhood quality, and link quality. The four objectives relevant to every link are then utilized to develop a fitness function that considers multiple parameters. Then, this objective is utilized in EGA for discovering the routes optimally.

The main contributions of the paper are as follows:

Contribution 1: A new routing protocol called the SLAQR protocol is developed using EGA. This algorithm is developed by including an exponential order-based process to generate a neighbor solution.

Contribution 2: A fitness function is developed by including four objectives like static resource capacity, dynamic resource availability, neighborhood quality, and link quality.

The paper is organized as follows. In Section 2, a literature review on different routing algorithms is presented. Section 3 presents the network model and problem statement. The proposed EGA-based SLAQR protocol for MANET is described in Section 4. In Section 5, the experiments performed and the results of the experiments are presented. The paper concludes with a summary of the results in Section 6.

2 Literature Review

The literature presents a variety of routing protocols based on the quality metrics considered and algorithms utilized for MANET. Here, we review four kinds of routing protocols: multicast routing, cluster-based routing, QoS routing, and optimization-based routing. Multicast routing: Mysamy and Sankaranarayanan [16] proposed a preference-based protocol for trust and head selection (2PTH) algorithm for communication privacy from intermediate malicious nodes. However, the 2PTH algorithm does not include the dynamics of MANET, such as topology changes due to mobility and/or link/node failures that make vulnerable changes in the estimated delay. Yadav and Tripathi [26] proposed a traffic load balanced multicast routing protocol in order to reduce the network overhead and increase the network life. The major drawback of this traffic-aware multicast routing is that it does not include the quality metrics to decide the path of communication that will affect the link quality. Jahanshahi et al. [11] took the objective of promoting the adoption of learning automata for joint channel assignment and multicast routing problem. The adaptation of the learning model and the corresponding prediction of the model consume more computational operations that require more energy and memory. Park et al. [18] presented the design and evaluation of a highly efficient on-demand MANET. As a result, alternative paths can be computed only if they have a lower hop count than the defined hop count.

After that, various QoS parameters are included in the routing protocols to find the path of data transfer from source to destination. QoS routing: Ivascu et al. [10] presented a new approach called QMRB-AODV for supporting QoS in MANETs. Even though the QoS parameters are effectively integrated into the AODV protocol, the assignment of weights of every QoS was not perfectly handled because of the lack of optimization algorithm. Yussuf and See [30] presented a GA to QoS routing algorithm for solving the general k-constrained problem, which has the capability to return multiple feasible paths in a single run. The GA-based routing performs poorly in finding the QoS constrained paths due to local minimum. Calafate et al. [2] proposed a QoS architecture that is able to support applications with the bandwidth, delay, and jitter requirements in

MANET environments. The proposed architecture is modular, allowing the plugging in of different protocols, which offers great flexibility; however, it performs poorly in highly dense networks due to immense routing overhead due to the source routing nature of the protocol. Obaidat et al. [17] proposed a QoS-Aware Multipath Routing Protocol (QMRP) for MANETs. They introduced a parameter into the route quality computation that makes QMRP unlike its precursors, providing a more accurate measure of the realistic delay as well as maintaining loop freedom of multiple node disjoint paths using the neighbor hop list. The performance evaluation of the protocol against a single-path AODV routing protocol has been conducted to show the improvement in terms of end-to-end delay, packet delivery fraction, and route discovery frequency. QMRP has insignificantly more routing overhead than AODV, and the performance is not satisfactory with the Rayleigh fading channel.

Liu et al. [14] presented EARA-QoS (Emergent Ad hoc Routing Algorithm with QoS provision). This ad hoc QoS routing algorithm is based on a swarm intelligence-inspired routing infrastructure that is mainly affected by the exploration problem that generates the solution based on the local minimum. Qin and Liu [21] extensively proposed a multipath source routing protocol that provides bandwidth and reliability guarantee. In the routing discovery phase, the protocol selects several multiple alternate paths that meet the QoS requirements, and the ideal number of multipath routing is achieved to compromise between load balancing and network overhead. This QoS routing protocol used minimum hop count as a criterion in finding and establishing paths between source-destination pairs. In Ref. [10], QMRB-AODV was proposed to support QoS in MANETs. Wang et al. [25] proposed an algorithm that is based on the analysis of local node information, such as node queue length, node forwarding number of data packets, and node residual energy, which balances the relationship between the network throughput and the energy consumption, thus improving the performance of network in multi-constrained QoS routing. Even though the performance of the algorithm is good in various QoS metrics, it finds difficulty in high-mobility nodes.

Cluster-based routing: Pathak and Jain [19] proposed a method of cluster formation by taking into account two most vital factor node degrees and bandwidth requirements for construction of the cluster and selection of the cluster head. The cluster formation requires an iterative procedure, which usually consumes more computational time. Yau and Gao [28] constructed multi-hop clusters with balanced sizes, based on the neighborhood benchmark to quantify the connectivity and link stability of mobile nodes. This cluster-based algorithm misses the flexibility of the cluster formation, which can strengthen the cluster formation. Recently, the routing of packets is formulated as a search problem, so optimization algorithms play a major role in the routing protocol.

Optimization-based routing: Chatterjee and Das [4] proposed an enhanced version of the well-known dynamic source routing scheme based on the ant colony optimization (ACO) algorithm, which can produce a high data packet delivery ratio in low end-to-end delay with low routing overhead and low energy consumption. The optimal finding of paths explores the problems in achieving the better results due to the sequences of random decisions generated independently by the ACO algorithm. Karthikeyan and Baskar [12] proposed EISGA (Ensemble of Immigrant Strategies with Genetic Algorithm), which optimizes the combined objectives of network lifetime and delay for solving multicast routing problems but QoS assurance to increase the network resilience (i.e. reliability through fault tolerance); load balancing through congestion avoidance was not handled. Karthikeyan et al. [13] proposed a modified topology crossover, Energy-II and Energy-III mutations, and genetic operator combinations for integer-coded GA with sequence and topological representations to improve the efficiency of the GA for multicast routing in ad hoc networks. The generation of new solution based on crossover might be disrupted by a non-respectful crossover operator that affects the ordering of the variables.

3 Network Model and Problem Description

Assume that a MANET is represented as a weighted graph $G(V, E)$, where V and E denote the set of nodes and links, respectively. It can be modeled as a graph $G(V, E)$, where s is a set of nodes (mobile hosts) and

$E=\{(i, j)|v_i, v_j \in V\}$ is a set of links. $(i, j) \in E$ indicates that v_i and v_j are within the control coverage area of each other. The connectivity of the network depends on the transmission power of each node. Each node can dynamically change its transmission power level. A node can use a different power level for each multicast tree in which it participates. All nodes use omni-directional antennas. Each link (i, j) is associated with neighborhood quality $NQ_{i,j}$, link quality $LQ_{i,j}$, static resource capacity $SRC_{i,j}$, and dynamic resource availability $DRA_{i,j}$. $NQ_{i,j}$ describes the neighborhood quality between v_i and v_j . Here, all the QoS metrics are ranging from 0 to 1. Figure 1 shows the simulation of MANET of 50 nodes connected on an ad hoc manner.

Let $s \in V$ be a multicast source and $D \subseteq V - \{s\}$ be a set of destinations. A multicast tree $T(s, D) \subseteq G$ is a tree rooted at s and reaching all of the destinations in D . The QoS of a path on T from s to a destination $v_t \in D$, denoted as $TC(PT(s, v_t))$, is $TC(PT(s, v_t)) = \sum_{(i,j) \in PT(s, v_t)} TC_{i,j}$. Then, the QoS-constrained minimum tree problem is to find a maximum cost multicast tree $T^*(s, D)$ such that $Qos(PT^*(s, v_t)) > \delta, \forall v_t \in D$, where δ is the overall allowable QoS from s to a destination $v_t \in D$. Once $T^*(s, D)$ is found, each node on T^* adjusts its transmission power properly to transmit data packets along the tree.

Challenges: The summary of the major challenges to provide QoS guarantee in the mobile ad hoc network is discussed in this section.

- The wireless communication channel present in the MANET is susceptible to bit error due to the interference from other transmissions, thermal noise, shadowing, multi-path fading effects, etc. This reduces the link lifetime of the nodes.
- The mobility of the nodes in the MANET is another challenge in the QoS guarantee afford. As the topology of the mobile node changes frequently, the updating of the topology information in the data packets are to be done frequently. In addition to the topology updating, the mobility of the nodes creates problem in routing protocol function. Because of the unpredictable nature of the mobile nodes, the routing information will always be stale and routing will be inefficient or could even fail completely.
- The routing protocol with QoS guarantee over every possible constraints of the MANET is the main challenge. If one of the QoS metric is guaranteed by the routing protocol, another metric cannot be fulfilled.
- The route selection in the MANET is also a challenge [4]. From the available path between the host nodes, the best path selection must be done with evaluation of the different QoS metrics. The path selected must have communication nodes with reduced delay, distance within the transmission range, increased link lifetime, limited bandwidth, etc.

Figure 1: Simulation of MANET of 50 Nodes.

4 Proposed SLAQR Routing Protocol: EGA-Based Stable and Load-Aware QoS Routing Protocol for MANET

This section presents the proposed SLAQR protocol using EGA for MANET. In this proposed work, we consider the protocol that provides the best result for the metrics like packet delivery ratio, bandwidth utilization, controlling the message overhead, link reliability, and energy efficiency. This paper enhances the GA-based routing algorithm by using exponential function. In GA-based routing algorithm, it modifies the fitness function by incorporating the metrics like the node's static resource capacity, dynamic resource availability, neighborhood quality, and link quality in such a way that it satisfies a set of QoS requirement. The present research paper has given preference for dynamic aspects of the node while determining its performance in the network. Mobile routing backbone, in such condition, evolves time depending on the traffic distribution, congestion present in region of network, and the load of each node. By implementing this method, QoS values are minimized on links from source to destination, increasing the possibility for the path to satisfy the given QoS requirement and hence overcoming the MCP problem. Figure 2 shows the block diagram of the proposed SLAQR protocol.

4.1 Proposed EGA

This section presents the proposed EGA by modifying the GA with exponential function. GA [9] is a popular search algorithm widely applied for various routing protocols and, recently, it was used in Refs. [6, 18, 23] for routing. The reason for selecting GA is that (i) the procedure of GA is simple, so it would require less computational time; (ii) the finding of multiple paths is possible even though the multiple QoS constraints are incorporated with limited time; (iii) due to mutation operation, it is able to provide small alterations in the final stage to obtain better results; (iv) the number of parameters to be fixed are very few; and (v) it uses probabilistic selection rules, not deterministic ones. GA works on the process of deriving the optimal solution from a solution that is generated randomly. The randomly generated solution is referred here as a population that is filled with chromosomes that consist of random paths. Even though the paths are random, they are supposed to be valid paths, where the chromosomes consist of a sequence of nodes that are in the path from the sender to the receiver. The number of chromosomes that are generated depends on the population size.

Figure 2: Block Diagram of the Proposed SLAQR Protocol.

Initialization: At first, GA initializes P number of solutions randomly. Here, every solution is referred as chromosome. Every chromosome is indicated as a vector consisting of n number of values. n is the number of nodes.

Finding of fitness of chromosomes: Each chromosome in the population is associated with a fitness value that is calculated using a fitness function. This value indicates how good the solution is for a particular chromosome. This information is then used to pick the chromosomes that will contribute to the formation of the next generation of solution. The fitness value is computed using a fitness function. The fitness function is highly dependent on the problem to be solved.

Crossover: The first genetic operation done to the chromosomes in the mating pool is crossover. The idea behind crossover is to create an information exchange between two chromosomes. Nodes, which are commonly involved in the two chromosomes, without positional consistency, are mainly determined as the potential crossover point. Later, a node is randomly selected and the location of that node becomes a crossing point of each selected chromosome. By doing so, the algorithm will explore new paths and hopefully be able to find better paths in the process.

In order to perform crossover, two chromosomes from the mating pool is selected using the selection operator. These two chromosomes will become the parent chromosomes. In iteration, a pair of parents can only be selected for crossover once. To ensure that the paths generated by the crossover operation are still valid paths, the two chromosomes selected must have at least one common node other than the sending and receiving nodes. If more than one common node exists, one of them will be randomly chosen with equal probability. The chosen node is called the crossover point. For example, assume that we have the following parent nodes:

Parent chromosome 1: [S N1 N2 N3 N4 **N5** N6 N7 D]

Parent chromosome 2: [A N8 N9 N10 **N5** N11 N12 D]

It is observed that S and D are the source and destination nodes, respectively. In this example, the common node is N5. Therefore, crossover operation will exchange the first portion of chromosome 1 with the second portion of chromosome 2, and vice versa. As a result, the child chromosomes below will be generated. These two chromosomes would then become new members of the population.

Child chromosome 1: [S N1 N2 N3 N4 **N5** N11 N12 D]

Child chromosome 2: [A N8 N9 N10 **N5** N6 N7 D]

Mutation: Apply a mutation operator on the chromosomes in the mating pool. Each chromosome has a certain probability of being mutated. The mutation result must not be the same as any of the chromosomes in the current population, or else it would be ignored. Replace the worst chromosome produced by the genetic operators (crossover and mutation) with the best chromosome in the previous population.

Exponential order-based new solution: The chromosome replaced with the mutation operation is taken further to generate a new solution based on the exponential order-based process. The reason behind the incorporation of exponential order-based process in GA is that (i) it can provide the reliable solution; (ii) exponential weighting leads to quick finding of routing paths; and (iii) the diversity of the solution can be improved. Here, chromosome is multiplied with the exponential function, and the gene values within the chromosome are sorted. From the sorted results, index values are taken as a new chromosome. Let us assume that C is the chromosome for which we want to do an exponential order-based process. We know that C is a vector having integers, which are the identities of the nodes. The number of nodes in chromosome C is indicated as n . To generate a new solution (new paths), chromosome C vector is multiplied with the exponential function that will generate a new vector of size n . This new vector C_{new} is then sorted in ascending order and the index values are taken as a new solution, which is the new path generated by the exponential order search.

For this new chromosome, the fitness function is computed, and if the fitness is greater than the previous value, the new one is replaced with the older one. By implementing this method, we are maximizing QoS values on links from source to destination and increasing the possibility for the path to satisfy the given QoS requirement, and hence we can overcome the MCP problem.

Termination: The above process is repeated for t number of iterations, and the chromosome having the better fitness value is considered the discovered path for the source.

4.2 Designing of Fitness Function

The fitness of every chromosome is computed based on the QoS metrics of every link connected to two different nodes. Each node has different communication and processing characteristics. Hence, this approach focuses on node classification, where mobile nodes can be either QoS routing nodes, simple routing nodes, or transceiver nodes. Nodes have limited energy, and they do not have enough battery energy to support the added burden of routing packets for which the links connecting them to their neighbors are not stable enough. In the route discovery process, four QoS support metrics are used to differentiate nodes in the network and identify the ones that can take part. These metrics are computed for pairs of nodes or the links. Based on the node connectivity, the fitness function for the chromosome is computed using Eq. (1):

$$\text{Fitness} = \frac{1}{L} \sum_{i=0}^L TC_i, \quad (1)$$

where TC_i represents the cumulated link quality on link i and L represents the number of links based on the route suggested by the chromosome. The cumulated link quality metrics for every link is computed based on various parameters like the node's static resource capacity, dynamic resource availability, neighborhood quality, and link quality in such a way that it satisfies a set of QoS requirement. Each parameter is assigned with a weight. These weighed parameters are combined into a single function, and it is calculated using Eq. (2):

$$TC = \alpha * \text{SRC} + \beta * \text{DRA} + \lambda * \text{LQ} + \delta * \text{NQ}, \quad (2)$$

where SRC is the static resource capacity, DRA is dynamic resource availability, NQ is neighborhood quality, and LQ is link quality.

Static resource capacity (SRC): The size of packet queues P_{queue} (MB), the speed of its CPU P_{CPU} (GHz), the power of the battery M_{battery} (mW), and the maximum available bandwidth B_a (kbps) are defined as the static resource capacity (SRC) of a node. The SRC is calculated using Eq. (3):

$$\text{SRC} = \gamma * P_{\text{queue}} + \lambda * P_{\text{CPU}} + \beta * M_{\text{battery}} + \alpha * B_a, \quad (3)$$

where γ, λ, β , and α are node characteristics that are weighted, and their sum is equal to 1.

Dynamic resource availability (DRA): This represents the current load of the node in resource usage. Even if a node possesses the required capacity, it may not provide the desired service if its resources are already allocated to other connections. Hence, this metric can help guide the route discovery process toward less congested nodes where resources are available. The most essential component is the node's remaining battery life followed by the available bandwidth in DRA. For example, if a node has no energy left, even though other resources may be available, it will not be able to provide the service required by a connection. Hence, the weights in the DRA metric are not in the same sequence as in the SRC metric; their dynamic significance to the protocol is more different than their static significance. Usage rate (UR) is used to determine their values and, it is calculated using Eq. (4):

$$\text{UR} = \frac{\text{quantity of the resource that is being used}}{\text{available quantity for the resource}} * 100. \quad (4)$$

By considering the same characteristics as for the static resources capacity metric, such as queues, CPU, battery, and bandwidth, with the difference that exploit the usage rate to determine their values, the DRA is calculated using Eq. (5):

$$DRA = 100 - (\gamma * UP_{queue} + \lambda * UP_{CPU} + \beta * UM_{battery} + \alpha * UB_a). \quad (5)$$

Neighborhood quality (NQ): This indicates the number of nodes in its neighborhood that are able to forward packets, or in other words, that can be routers. The higher the value of this metric, the higher the probability that a node in this neighborhood can be selected to take part in a route.

Link quality (LQ): Link quality is defined as the power of the signal received by a mobile node. This component is used to refine the estimate of link lifetime. Each time a packet is received by the link layer, it is possible to measure the power of the signal that transmitted it. The closer the power of the signal gets to its nominal power, the higher is the quality of the link connecting the nodes. However, the quality of the signal depends greatly on the propagation environment. Hence, the power of the radio signal received by a node at a distance r of the transmitter node can be modeled by Ref. [8]. Equation (6) provides the link quality:

$$LQ = \frac{P_m}{r}, \quad (6)$$

where P_m is the measure of power and r is the distance separating them. P_m is a constant between a pair of transmitter-receiver. In practical terms, P_m is equal the nominal value of the transmission card used; this value may differ between cards.

4.3 EGA-Based Routing Protocol

Initialization: A communication network is simulated as a directed graph $G(V, E)$, where V is the set of nodes representing the routers and E is the set of edges representing the links that connect between the routers. For a network supporting multiple QoS metrics, each edge (i, j) is associated with four independent metrics each having a numerical value from 0 to 1. The values of static resource capacity, dynamic resource availability, neighborhood quality, and link quality are also initialized.

EGA algorithm for route discovery: In this algorithm, population is initialized. Each chromosome contains a sequence of positive integers, which in turn represents the ID of the nodes, which lies on the route. The location of each chromosome signifies the position of a node in the route. A cross-operator function is applied for several times to create new children for the new population (where m is the population size). The parents are selected using the selection operator. Each pair of parent chromosome can only mate once, and the children produced are only accepted into the new population if they are not similar to the previously produced children. Again, a new exponential order-based process is performed to generate a new solution. This is done to diversify the search and to discourage convergence. This step is repeated for t number of iterations, and the better route is taken for broadcasting.

Dynamic updating of QoS and termination: Once we identify the routes for every node, communication among the nodes happens. For every byte of data transfer, QoS parameters for every node are updated using the network model and the route discovery may happen again based on the updated parameters. The algorithmic description of the SLAQR protocol is given below.

Algorithm for SLAQR-Based Route Discovery:

Step 1: Start
 Step 2: Define SRC = static resource capacity
 DRA = dynamic resource availability
 NQ = neighborhood quality
 LQ = link quality
 M = population size
 TV = threshold value
 Step 3: Randomly initialize the initial population
 Step 4: Calculate the SRC, DRA, NQ, LQ
 Step 5: Calculate the fitness function for each chromosome

Step 6: Create the mating pool, which consists of all the chromosomes in the current population
 Step 7: Apply the crossover operator several times to create m new children for the new population
 Step 8: Apply a mutation operator
 Step 9: Apply an exponential order-based process
 Step 10: If (fitness value < TV), then
 Replace the worst value with the best value using the crossover operation, and
 Repeat maximum paths found
 Step 11: End

5 Simulation-Based Result Analysis

This section presents the simulation of MANET and the experimental results of the proposed SLAQR protocol. Here, parametric analysis and comparative analysis are also performed.

5.1 Simulation Setup

The performance of the proposed SLAQR protocol is evaluated using NS-2 simulation, and the graph is plotted using MATLAB. A network, which is deployed in an area of 1250×1250 m, is considered. IEEE 802.11 MAC layer is used for its reliability. Table 1 summarizes the simulation parameters used.

5.2 Convergence Analysis of the EGA Algorithm

Figure 3 shows the convergence analysis of the proposed EGA algorithm in route discovery. Here, the graphs are plotted for various numbers of nodes ranging from 20 to 80. The iteration versus the fitness function is plotted as a graph. Figure 3A shows the convergence graph for the population size of 10. From the figure, we understand that the fitness function is higher for every iteration if the number of nodes is fewer. This concludes that the proposed EGA algorithm finds the routes in shorter iteration if the number of nodes is fewer. When the number of nodes is fixed to 20, the maximum fitness of 0.9 is reached at the 86th iteration. When the number of nodes is fixed to 80, the maximum fitness of 0.9 is reached at the 90th iteration. Similarly, Figure 3B shows the convergence graph of the proposed EGA algorithm for different number of nodes. Here, better performance is obtained when the number of nodes is fixed to 60. For the node count of 80, the algorithm took 93 iterations to reach the maximum fitness value of 0.9. This convergence analysis proved that the proposed

Table 1: Simulation Parameters.

No. of nodes	20, 40, 60, 80, and 100
Area size	1250×1250
Mac	IEEE Mac/802_11
Speed	10, 20, 30, 40, and 50 m/s
Traffic source	CBR
Packet size	512 bytes
Antenna	Omni Antenna
Propagation	Two-ray ground
Radio model	As like [1]
Channel model	Rayleigh channel
Mobility model	Random waypoint
Simulation time	300 s
Rate	200, 400, 600, 800, and 1000 k/b

Figure 3: Convergence Analysis.
(A) $p = 10$. (B) $p = 20$.

algorithm requires only 90 iterations to reach the maximum value. This proved that the proposed algorithm ensures the capability of speedy convergence due to the exponential order search introduced in the paper.

5.3 Performance Analysis Based on Nodes

This section shows the performance analysis of the proposed SLAQR protocol with the other three protocols like GAQR [30], QMRB-AODV [10], and EISGA [12]. In this analysis, the number of nodes are varied from 20 to 100, and three metrics like average packet delivery ratio, packets received, and average delay are computed. Figure 4A shows the delivery ratio of four techniques for different numbers of nodes. From the graph, the delivery ratio of the SLAQR protocol obtains the value of 0.9685 when the number of nodes is equal to 100. This value shows the highest value as compared with other protocols. Here, GAQR obtains the value of 0.4064, which is less compared with the proposed protocol. Similarly, QMRB-AODV obtains the value of 0.3903 and EISGA obtains the value of 0.3995. We can conclude that the delivery ratio of our proposed SLAQR approach is 58% higher than that of the GAQR approach. Figure 4B shows the throughput of four techniques for different number of nodes. Here, the proposed SLAQR obtains the throughput of 23,822 as compared with 10,256 that is obtained by GAQR. We can conclude that the throughput of our proposed SLAQR approach is 56% higher than that of the GAQR approach. Figure 4C shows the performance analysis of the routing protocols in terms of delay. When analyzing the graph, the proposed SLAQR shows the minimum delay as compared with the other protocols. When the number of nodes is fixed to 100, the proposed SLAQR shows the delay value of 0.2980, which is less as compared with 10.4534, 10.4569, and 10.3266, which are obtained by GAQR, QMRB-AODV, and EISGA. From the delay graph, we can conclude that the delay of our proposed SLAQR approach is 97% less than that of the GAQR approach. For the various numbers of nodes, the proposed SLAQR outperforms in terms of delivery ratio, throughput, and delay as compared with the existing protocol. This ensures that the scalability issues (various number of nodes) are effectively handled by the proposed exponential order search process that is introduced in this paper.

5.4 Performance Analysis Based on Speed

This section shows the performance analysis of four different protocols, such as SLAQR, GAQR, QMRB-AODV, and EISGA, using delivery ratio, throughput, and delay for the speed of node mobility, which is varied

Figure 4: Performance Based on Nodes.
(A) Delivery ratio. (B) Throughput. (C) Delay.

as 10, 20, 30, 40, and 50 m/s. Figure 5A shows the graph of delivery ratio for the different speed values. When the speed is fixed to 10 m/s, SLAQR, GAQR, QMRB-AODV, and EISGA obtain the values of 0.8542, 0.7020, 0.7105, and 0.6413, respectively. This indicates that the proposed SLAR shows better performance than the other protocols. Similarly, better performance is achieved by the proposed SLAQR protocol for all the various speeds of measurements than the existing protocols. Figure 5B shows the performance of the proposed SLAQR protocol for the various speed values using throughput. From the results, SLAQR, GAQR, QMRB-AODV, and EISGA obtain the value of 15,460, 11,708, 12,934, and 12,129 when the speed is fixed to 10 m/s. Also, we notice that the delay is decreased when the speed is increased for all the four routing protocols. From the graph, we can derive that the proposed SLAQR protocol shows the top performance for all the various speed measurements. Figure 5C shows the delay of the SLAQR, GAQR, QMRB-AODV, and EISGA techniques for different speed scenarios. The delay value reaches maximum when the speed of light is 50 m/s. In this speed, SLAQR, GAQR, QMRB-AODV, and EISGA obtain the value of 16.84, 29.16, 18.51, and 27.01, respectively. From these results, we conclude that the proposed SLAQR outperforms the existing protocols by reaching better performance for various values of speed. This also ensures that the proposed SLAQR protocol is adaptable to various speeds of packet transmission as compared with the existing protocol due to the faster identification of multiple paths.

Figure 5: Performance Based on Speed.
(A) Delivery ratio. (B) Throughput. (C) Delay.

5.5 Performance Analysis Based on Rate

This section shows the performance analysis of the proposed SLAQR protocol with the other three protocols based on rate. In the second experiment, the packet sending rate is varied as 200, 400, 600, 800, and 1000 k/b, and three metrics, like average packet delivery ratio, packets received, and average delay, are computed. Figure 6A shows the delivery ratio of four techniques for different numbers of packet sending rate. From the graph, the delivery ratio of the SLAQR protocol obtains the value of 0.9116 when the rate is equal to 200 k/b. For the greater nodes, the delivery ratio is less. This shows the highest value as compared with the other protocols. Here, GAQR obtains the value of 0.7422, which is less compared with the proposed protocol. Similarly, QMRB-AODV obtains the value of 0.6922 and EISGA obtains the value of 0.6944. We can conclude that the delivery ratio of our proposed SLAQR approach 18.58% higher than that of the GAQR approach. Figure 6B shows the throughput of four techniques for different values of rate. Here, the proposed SLAQR obtains the throughput of 16,625 as compared with 11,707 that is obtained by GAQR. We can conclude that the throughput of our proposed SLAQR approach is 29.5% higher than that of the GAQR approach. Figure 6C shows the performance analysis of the routing protocols in terms of delay. When analyzing the graph, the proposed SLAQR shows minimum delay as compared with the other protocols. When the rate is fixed to 200 k/b, the proposed SLAQR shows the delay value of 3.0572, which is less as compared with 5.8616, 4.9018, and 4.8724 that are obtained by GAQR, QMRB-AODV, and EISGA, respectively. From the delay graph, we can

Figure 6: Performance Based on Rate.
(A) Delivery ratio. (B) Throughput. (C) Delay.

conclude that the delay of our proposed SLAQR approach is 47.8% less than that of the GAQR approach. By varying the rate of transmission, the proposed SLAQR shows better performance than the existing algorithms. This proved that the proposed SLAQR is adaptable to various packet rates due to the significance of multiple constraints considered in the proposed algorithm.

6 Conclusion

This paper presented a new EGA-based SLAQR protocol for routing in MANETs. In this work, EGA was newly developed to find the optimal routes from the random paths. Again, the fitness function was modified by incorporating metrics like the node's static resource capacity, dynamic resource availability, neighborhood quality, and link quality in such a way that it satisfies a set of QoS requirement. Finally, the new fitness function and EGA algorithm is effectively combined and applied to MANET simulation to find the optimal paths. The results of convergence for the EGA algorithm is plotted and discussed. Also, the performance of the proposed protocol is analyzed with three existing protocols, namely GAQR, QMRB-AODV, and EISGA, using packet delivery ratio, throughput, and delay. From the results, we proved that the proposed SLAQR protocol outperforms the GAQR protocol by showing the improvements of 58%, 56%, and 97% in delivery ratio, throughput, and delay. In the future, the protocol can be improved by adding more security features for secure transmission of packets.

Bibliography

- [1] M. Balachandra, K. V. Prema and K. Makkithaya, Multiconstrained and multipath QoS aware routing protocol for MANETs, *Wireless Netw.* **20** (2014), 2395–2408.
- [2] C. T. Calafate, M. P. Malumbres, J. Oliver, J. C. Cano and P. Manzoni, QoS support in MANETs: a modular architecture based on the IEEE 802.11e technology, *IEEE Trans. Circuits Syst. Video Technol.* **19** (2009), 678–692.
- [3] P. A. Chaparro, C. T. Calafate and J. C. Cano, Assessing the best strategy to improve the stability of scalable video transmission in MANETs, in: *Proceedings of Wireless Communications and Networking Conference (WCNC)*, pp. 2083–2088, 2011.
- [4] S. Chatterjee and S. Das, Ant colony optimization based enhanced dynamic source routing algorithm for mobile ad-hoc network, *Inform. Sci.* **295** (2015), 67–90.
- [5] H. Cheng, J. Cao and X. Fan, GMZRP: geography-aided multicast zone routing protocol in mobile ad hoc networks, *Mob. Netw. Appl.* **14** (2009), 165–177.
- [6] C. Contreras-Bolton, G. Gatica, C. R. Barra and V. Parada, A multi-operator genetic algorithm for the generalized minimum spanning tree problem, *Expert Syst. Appl.* **50** (2016), 1–8.
- [7] P. Deepalakshmi and S. Radhakrishnan, QoS routing algorithm for mobile ad hoc networks using ACO, in: *Proceedings of International Conference on Control, Automation, Communication and Energy Conservation*, 2009.
- [8] M. Gerhartz, C. de Waal, M. Frank, P. Martini and P. James, Strategies for finding stable paths in mobile wireless ad hoc networks, in: *Proceedings of the 28th Annual IEEE Conference on Local Computer Networks (LCN'03)*, pp. 130–139, 2003.
- [9] D. E. Goldberg, *Genetic Algorithms in Search, Optimization and Machine Learning*, Addison Wesley, Reading, MA, 1989.
- [10] G. I. Ivascu, S. Pierre and A. Quintero, QoS routing with traffic distribution in mobile ad hoc networks, *Comput. Commun.* **32** (2009), 305–316.
- [11] M. Jahanshahi, M. Dehghan and M. R. Meybodi, LAMR: learning automata based multicast routing protocol for multi-channel multi-radio wireless mesh networks, *Appl. Intell.* **38** (2013), 58–77.
- [12] P. Karthikeyan and S. Baskar, Genetic algorithm with ensemble of immigrant strategies for multicast routing in ad hoc networks, *Soft Comput.* **19** (2015), 489–498.
- [13] P. Karthikeyan, S. Baskar and A. Alphones, Improved genetic algorithm using different genetic operator combinations (GOCs) for multicast routing in ad hoc networks, *Soft Comput.* **17** (2013), 1563–1572.
- [14] Z. Liu, M. Z. Kwiatkowska and C. C. Constantinou, A biologically inspired QoS routing algorithm for mobile ad hoc networks, *Int. J. Wireless Mob. Comput.* **4** (2010), 64–75.
- [15] A. Martirosyan, A. Boukerche and R. W. Nelem Pazzi, Energy-aware and quality of service-based routing in wireless sensor networks and vehicular ad hoc networks, *Ann. Telecommun.* **63** (2008), 669–681.
- [16] R. Mylsamy and S. Sankaranarayanan, A preference-based protocol for trust and head selection for cluster-based MANET, *Wireless Pers. Commun.* **86** (2016), 1611–1627.
- [17] M. Obaidat, M. Ali, I. Shahwan, M. S. Obaidat and S. Obeidat, QoS-aware multipath communications over MANETs, *J. Netw.* **8** (2013), 26–36.
- [18] Y. B. Park, J. S. Yoo and H. S. Park, A genetic algorithm for the vendor-managed inventory routing problem with lost sales, *Expert Syst. Appl.* **53** (2016), 149–159.
- [19] S. Pathak and S. Jain, A novel weight based clustering algorithm for routing in MANET, *Wireless Netw.* (2015), 1–10. Available at: <http://link.springer.com/article/10.1007/s11276-015-1124-8>.
- [20] M. M. Qabajeh, A. H. Abdalla, O. O. Khalifa and L. K. Qabajeh, A survey on scalable multicasting in mobile ad hoc networks, *Wireless Pers. Commun.* **80** (2015), 369–393.
- [21] F. Qin and Y. Liu, Multipath based QoS routing in MANET, *J. Netw.* **4** (2009), 771–778.
- [22] Z. Rezaeifar, F. Hendessi, B. S. Ghahfarokhi and T. A. Gulliver, A reliable geocast routing protocol for vehicular ad hoc networks, *Wireless Pers. Commun.* **83** (2015), 281–295.
- [23] F. G. Tari and Z. Hashemi, A priority based genetic algorithm for nonlinear transportation costs problems, *Comput. Ind. Eng.* **96** (2016), 86–95.
- [24] V. Thilagavathe and K. Duraiswamy, Adhoc on demand multipath reliable and energy aware quality of service routing for mobile adhoc networks, *J. Comput. Sci.* **8** (2012), 181–186.
- [25] Y. L. Wang, M. Song, Y. F. Wei, Y. H. Wang and X. J. Wang, Improved ant colony-based multi-constrained QoS energy-saving routing and throughput optimization in wireless ad-hoc networks, *J. China Univ. Posts Telecommun.* **21** (2014), 43–53.
- [26] A. K. Yadav and S. Tripathi, DLBMRP: design of load balanced multicast routing protocol for wireless mobile ad-hoc network, *Wireless Pers. Commun.* **85** (2015), 1815–1829.
- [27] R. Yadav, S. Yadav, A. Yadav and S. Bhardwaj, QoS multipath path routing in MANET, in: *IJCA Proceedings on National Workshop-Cum-Conference on Recent Trends in Mathematics and Computing*, no. 3, 2011.
- [28] S. S. Yau and W. Gao, Multi-hop clustering based on neighborhood benchmark in mobile ad-hoc networks, *Mobile Netw. Appl.* **12** (2007), 381–391.
- [29] D. Yiltas and H. Perros, QoS-based multi-domain routing under multiple QoS metrics, *IET Commun.* **5** (2011), 327–336.
- [30] S. Yussof and O. H. See, A robust GA-based QoS routing algorithm for solving multi-constrained path problem, *J. Comput.* **5** (2010), 1322–1334.