Performance of QOSRGA Routing Protocol for MANET with Random Waypoint Mobility Model

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Abstract

QoS Routing for MANET possess several challenges that must be addressed. Realistic model must be formulated to ensure the performance study correlated to the real-world application. The paper presents QoS routing protocol for MANET with small population, specialized encoding, initialization, crossovers, mutations, fitness selections and route search using genetic algorithm with multiple constraint. The nodes are mobile and must move randomly. The aim is to find the best QoS route in order to optimize the design of MANET routing protocols. This NP-hard problem is often highly constrained such that random initialization and standard genetic operators usually generate infeasible networks. The effect of maximum node velocity on the protocol performances is done conclusively shows that QOSRGA had a potential to be the protocol for MANET.

Keywords: *QoS Routing, Mobile ad-hoc networks, genetic algorithm, fitness function, performances, Random Waypoint Mobility Model, maximum node velocity*

1. Introduction

Future generations of wireless communication shall witness a form of seamless integration made up of a variety of platform. Incidentally, wireless mobile ad hoc network (MANET) could be an additional component within the LTE (Long Term Evolution) implementation. It would be transporting diverse multimedia applications such as voice, video and data with an additional security feature. Considering the level of information with stringent quality requirement it would be imperative that MANET [1] provides QoS Routing support, in which it could, manages bandwidth-delay [2] constraints and node-connectivity issues. Various mechanism of routing protocols are already available [5, 8], but studies on those protocols [3, 4, 6] showed that some are more susceptible to performance degradation than others. Some reactive protocols, performed better than the proactive protocols. Among the reactive QoS routing protocols proposed in [7, 8, 9], a CDMA/TDMA MAC layer is commonly used to mitigate the interference between different transmissions setup. A very promising approach is to establish multiple paths between source and destination. Hence, it would be wise to design the protocols which would leverage on the availability of multiple paths for the purpose of overall performance improvement. Kumar *et al*. [8] uses genetic algorithm (GA), as the optimization technique in the design of computer networks. The authors considered diameter, average distance, and computer network reliability as the optimization parameters. Coley *et al*. [10] outlined fields of electrical engineering where GA had been applied, such as VLSI routing and communication networks. M. Gen *et al*. [11] produced detailed study of various

GA-based industrial engineering applications such as scheduling, transportation and reliability techniques. R. Elbaum *et al*. [12] used GA in designing LAN with an objective to minimize the network delay. S. Mao *et al*. used GA to optimize the routing problem for multiple description video transmission [13]. There are researchers who applied GA to the shortest path routing problem [14], dynamic channel allocation problem [15] and routing problem [16]. Munetomo [17] proposed GA with variable-length chromosomes, whilst Inagaki [18] proposed GA employing fixed length chromosomes for networking problems. In Section 2, we dwelled on the qualitative details of the GA-based QoS routing. The rest of the paper is organized as follows. Section 3 outlined the issues involved when dealing with QoS route. Section 4 describes the QOSRGA implementation. Next, the Random Waypoint Mobility model was introduced to MANET model. Lastly Section 7 concludes the paper.

2. Quality of Service Routing Using GA (QOSRGA)

2.1 QOSRGA as a Collection of Cooperative Protocols

QOSRGA is a collection of cooperative protocols that have to function in tandem to each other. These cooperative protocols include: the Non-Disjoint Multiple Routes Discovery (NDMRD) protocol, the Node State Monitoring protocol, and a GA-based QoS route selection protocol. The overall implementation of the QoS routing algorithm for MANET is presented and its performance is considered only for mobility issues.

2.2 Non-Disjoint Multiple Routes Discovery (NDMRD) Protocol

The NDMRD [22] is a QoS-Aware protocol since the contents of its Route Reply packet consists of QoS information. It initiates the propagation of Route Request packets towards the destination. The salient feature is that in each node it allows Route Request packet duplication, so that a good number of non-disjoint routes are obtained. Non-disjoint routes are necessary in this work, in order to increase the chances of getting a better solution after the process of crossover and mutation. Route Reply packets then extract QoS information from nodes that make up the route, and are carried to the source node. The protocol caused the accumulation of routes within the Route Accumulation Latency period. The number of Route Request duplicates, and the value of Route Accumulation Latency, are predetermined. These values are chosen in such a way to ensure high throughput performance. Since the consideration of delay and possible congestion, the limit imposed on the two variables results in less QoS information being collected at the source. Hence, the NDMRD protocol produced imprecise information, which is in reality a trade-off with a low throughput performance. The imprecise information, here means that many more Route Reply packets with the QoS information are dropped due to time limitation. Besides this, a *converging storm* phenomena might occur at the destination node, which may reduce the QoS information packets further. The c*onverging storm* means that the destination receives a great number of Route Request packets from the same source, resulting in an buffer overflow.

2.3 Node State Monitoring Protocol

Shared channel networks such as the IEEE 802.11 do not perform well for QoS routing, thus it does not provide a unified view of the medium to all nodes. This issue is addressed, whereby nodes must obtain information about their environment and must react to topology changes. The node captured the network information instantaneously and saved as a Node State. The QoS routing mechanism used resource monitoring for admission control and for

QoS routing enforcement. The information accumulated in the Node State is input to the GA module for the computation of route selection. Hence, the Node State is a viable means to maintain an instantaneous characterization of MANET. A system model and monitoring scheme was developed where it involved monitoring packet arrivals of various types, extracting the Node State information, distributing QoS parameters, and updated regularly. The most important aspect of the Node State is that it can infer node mobility, connectivity and topology variation [25].

2.4 Node Bandwidth Measurement Using NAV

When dealing with QoS routing, the protocol must get accurate information on the consumed and available bandwidth. A method for bandwidth measurement had been proposed using the NAV duration at the MAC layer. By using NAV, not only the instantaneous bandwidth of a node was measured, but also all the neighboring nodes that were within the contention range. An algorithm for determining the bandwidth was designed in two stages, one for calculating channel busy time, and another performed the sampling of the busy time. The method was validated by performing a simulation experiment to compare the true bandwidth setting with the measurement reading. The reading fell reasonably close to the true value. Hence, the technique was appropriate and could be used in the QoS Routing protocol. The measurements was done at the MAC layer in a cycle of 20ms, the output bandwidth value was maintain by the Node State Monitoring protocol [22].

2.5 Node Connectivity Index (*nci*) as a Mobility Metric

A novel mobility metric, ***nci,*** was developed which could indicate the length of time a node is in connection with its single-hop neighbour. It depends on the relative velocity of the node-pair and the power received as a result of the packet arrival. The metric is not an absolute quantity, rather a value for the purpose of comparison amongst the node-pair. The contraction and expansion mobility models were designed where ***npem*** (node pair expansion model) and ***npcm*** (node pair contraction model) were defined. The model used two consecutive packet arrivals to resolve the power due to packet arrival and time associated with the packet transmission and reception. It was shown that the ***nci*** can be used to select the node of longer connectivity time [25].

3. QoS Route Selection Issues

3.1 Low Population Sizing

The population size that ensures a specified quality of solution must be specified accordingly. The problem of choosing an adequate population size for a particular domain has puzzled researchers [32]. If the population size is too small, it is not likely that the GAs will find solutions of high quality. However, if the population size is too large, the GAs will unnecessarily waste processing time leading to unacceptably slow convergence. Harik [32] exploited the similarity between the gambler's ruin problem and the selection mechanism of GA in determining an adequate population size. Here, the effect of population size was investigated by fixing the mutation rate ($\mathbf{P}_m = 0.01$) and changing the population size. The simulation was run for 2000 generation. The minimum cost in each generation was recorded and the average minimum cost C_{AMC} was evaluated over the range from 0 until the 2000th generation. Figure 1 shows the average minimum cost as a function of population for two selection methods, elitism and tournament selection, concentrating on a population size below

100. The results showed that a population size below 100 is appropriate for both the elitism and tournament selection. Hence, a population of 20 chromosomes could be used and still produce good fitness.

3.2 Four Constraints Route Selection Algorithm

QoS route selection algorithm for MANET is an NP-complete problem as it considers two additive or multiplicative metrics, or one additive and one multiplicative metrics [19]. The algorithm should be efficient and scalable. Typically the heuristics solution to this problem could be solved by the following techniques: (1) the ordering of QoS metrics [19]; (2) sequential filtering [20]; (3) scheduling discipline of QoS metrics [4]; (4) admission control techniques [4, 21]; and (5) control theory approach [9]. This paper proposed a Genetic Algorithm approach for selection of multiple constraints routes. The constraints are end-to-end delay, MAC delay, available bandwidth and node connectivity index (*nci*) genetic algorithm. MANET is modeled as a graph $G = \{E, Q(nci, B_{AVA}, D_{E2E}, D_{MaC})\}$ where E is a set of mobile nodes in the network; and Q is a set of QoS routing constraints which limit the performance of the network. Each mobile node has a unique identity and moves randomly according to a Random Waypoint Mobility model. A circular plane, radius ***R*** defines a coverage area within which each node could communicate directly to

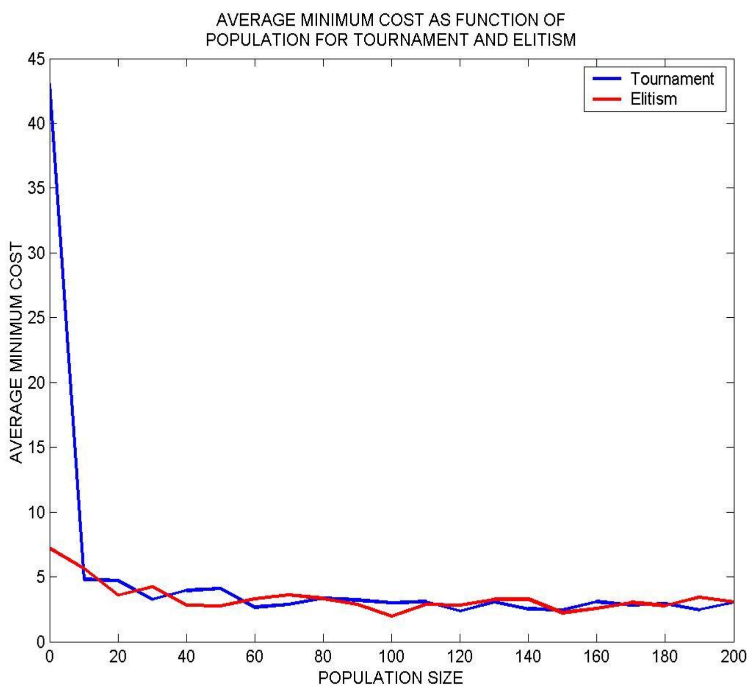

Figure 1. Average Minimum Cost as Function of Population Size for Tournament and Elitism Selection Methods

each other. Every pair of neighbors (***i, j***) , can communicate with each other in both directions. Hence, there exists a connectivity between neighbors ***i*** and ***j*** with an index of ***nci*** [25]. If the pairs are moving towards each other or away from each other, the node pair connectivity index, ***nci*** should be a positive value which describes the quality of connectivity between any two adjacent nodes. The least ***nci*** value indicates good quality connectivity, in which the node pair connectivity time is larger compared to high ***nci*** value. The node connectivity index, ***nci*** is defined as,

$$nci = \begin{cases} a - \left[\dfrac{10^5 \cdot b}{10^5 . c - npem} \right]; & for\ P_2 < P_1 \\ \dfrac{10^5 \cdot b}{10^5 . c + npcm}; & for\ P_2 < P_1 \\ 0\ ; & for\ P_2 = P_1 \end{cases} \quad (1)$$

where ,

$$npem = (1/(t_2 - t_1))\sqrt{((1/P_1) - (1/P_2))} \quad \text{and}$$
$$npcm = (1/(t_2 - t_1))((1/\sqrt{P_2}) - (1/\sqrt{P_1})) \cdot$$

The variable *npcm* and *npem* are positive quantities; *npcm* is due to the node moving toward another neighbor node; *npem* is due to the node moving away from that neighbor node. The values of *npcm* are high positive values and *npem* is low positive values. These two quantities are combined to form a single metric which indicates the quality of connectivity between the two adjacent mobile nodes. A node with *npcm*, indicated that its node pair connectivity time is longer than the node with *npem*. $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$ are the power measured away from the each other's node. During operation, a route, ***R*** is created from source, ***s*** to destination, ***t*** as a sequence of intermediate nodes, such that ***R(s, t)* = {*s,… i, j, k, l, …t*}** without loop. The node pair connectivity index, $\boldsymbol{nci_{(I,j)}}$ associated with a node pair is specified by the following matrix,

$$C = \begin{bmatrix} nci_{0,0} & \cdots & nci_{o,k-1} \\ \vdots & \ddots & \vdots \\ nci_{k-1,0} & \cdots & nci_{k-1,k-1} \end{bmatrix} \quad (2)$$

The node pair connectivity matrix is built at the source, upon receiving the route reply, **RREP** packets from the destination after a time lapse due to route request packet, **RREQ**. The value of ***nci*** changes continually as the topology changes. A connectivity indicator $\boldsymbol{L_{i,j}}$, provides the information on whether the link from node ***i*** to node ***j*** is included in the routing path. It is defined as follows,

$$L_{i,j} = \begin{cases} 1 & if\ \ there\ exist\ \ connectivity\ (i, j)\ . \\ 0 & if\ \ \ otherwise. \end{cases} \quad (3)$$

The diagonal elements of ***L*** must always be zero. Another formulation in describing the MANET topology is node sequence of the routes, such that,

$$N_k = \begin{cases} 1, & if\ node\ N_k \in\ route \\ 0, & if\ \ otherwise. \end{cases} \quad (4)$$

Using the above definitions, QoS routing can be formulated as a combinatorial optimization problem minimizing the constraint effects. The sum of ***nci*** of the selected route should be minimum, since this would be the most preferred route due to the higher probability of being connected longer with next hop neighbors. Then, the formulation statement is to minimize the sum of node connectivity index of the route,

$$C_{k.\{SUM(S,T)\}} = \sum_{j=S}^{T} C_{k,j} \cdot L_{k,j} \tag{5}$$

The sum of ***nci*** of the route ***R(s, t)*** constitutes the cost of the packet transmission process. In this approach, longer connectivity lifetime, indicate the route of least cost.

In many real-life problems, constraints under consideration may conflict with each other. Therefore, a perfect solution that simultaneously considers each constraint is almost impossible. The operation of GA will minimize the sum of node connectivity index of the route, $C_{sum(S,T)}$, subject to the following conditions.

There must be no looping

It ensures that the computed result is indeed an existing path and without loop between a source, ***S*** and destination, ***T*** such that,

$$\sum_{\substack{j=S \\ j\neq i}}^{T} L_{i,j} - \sum_{\substack{j=S \\ j\neq i}}^{T} L_{j,i} = \begin{cases} 1 & if \quad i=S \\ -1 & if \quad i=T \\ 0 & otherwise. \end{cases} \tag{6}$$

Available node bandwidth must be greater than the requested bandwidth

This condition ensures that the node bandwidth can manage the requested bandwidth such that, $B_{AVA,i} \geq B_{REQ}$, and for the whole route, $B_{REQ} \leq min\ (B_S,\ \ldots,\ B_i, B_j,\ \ldots B_T)$, where $\boldsymbol{B_{REQ}}$ is the bandwidth of the transmitted message. The node bandwidth must be greater than the demanded bandwidth. Since the shared medium is being dealt with, CSMA/CA, as the link layer of the mobile ad hoc network, the problem of medium contention among the nodes within the transmission range must be taken into account. Hence, it is necessary to estimate the instantaneous bandwidth available, $B_{AVA,i}$ and bandwidth consumed, $B_{CON,i}$ for the node concerned. Part of the cooperative protocols that are developed, is the Node State Monitoring protocol (NSM), where a method of monitoring bandwidth available and bandwidth consumed is established (5d).

Total delay is a minimum

The link delay and node delay must be considered as follows.

$$D_w \geq \{ \sum_{i=1}^{m} \sum_{\substack{j=1 \\ j\neq 1}}^{|S\rightarrow T|} D_{i,j} \cdot L_{i,j} + \sum_{i=1}^{|S\rightarrow T|} D_j.N_j \} \tag{7}$$

If several routes exist, then the total delay for a route to be selected is the one that is the least.

4. The QOSRGA Implementation

4.1 Encoding and Limited Population Initialization

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 which is equal to the total number of nodes in the network. The information can be obtained and managed in real-time by the Node State Monitoring (NSM) protocol and the non-disjoint multiple routes discovery protocols (NDMRD) [22]. The initial population was obtained by extracting the existing potential solutions from the result of NDMRD protocol [22].

4.2 Fitness of the QoS Parameters Function

Fitness value of each route is based on various QoS parameters: bandwidth, node delay, end to end delay and the node connectivity index, ***nci***. According to M. Gen *et al*. [11], each function is assigned a weight. These weighted parameters are combined into a single function. Fitness function operates to minimize the weighted-sum ***F,*** $F = \alpha.F_1 + \beta.F_2 + \gamma.F_3$ where F_1, F_2 and F_3 are functions that described ***nci***, delay and bandwidth respectively. They are defined as follows,

$$F_1 = \sum^{|s \to t|} C_{ij} \cdot L_{ij} \quad , \tag{8}$$

$$F_2 = \left(\sum_{j=1}^{|S \to t|} D_{ij} \cdot L_{ij} + \sum^{|s \to t|} d_j \cdot N_j \right), \tag{9}$$

$$F_3 = \begin{cases} 1/B_i & if \quad B_i - B_{QOS} > 0 \\ 1000 & if \quad B_i - B_{QOS} \le 0 \end{cases} \quad . \tag{10}$$

The weight-coefficient α , β and γ should be considered as relative emphasis of one function against the others. These values are chosen to increase the selection pressure on any of the three functions. The fitness function ***F*** measures the performance of a specific node state. Having described these QoS parameters, the next consideration is how importance each parameter on QoS routing algorithm. The significance of each parameter is clearly defined by setting appropriate values to α , β and γ in the fitness function that will be minimized by the GA operations. The values of these weighting coefficients were determined based on their equal importance towards the overall QoS Routing performance. By that measure α , β and γ are set to $\mathbf{10^{-3}}$, $\mathbf{10^{-4}}$ and $\mathbf{10^{-3}}$ respectively. For the function that involved bandwidth, the minimum bandwidth must be found for each node and compare this with the demand bandwidth, B_{QOS}. If the minimum bandwidth is less than the B_{QOS} the fitness is set to a high value so that in the selection process it will be eliminated.

4.3 Mobile Nodes Crossover

In this scheme, two chromosomes chosen for crossover should have at least one common gene, except for source and destination nodes. Nodes which are commonly included in the two chosen chromosomes but without positional consistency are first determined as the potential crosspoint. Then, one node is randomly chosen and the locus of that node becomes a crossing point of each chromosome. A simple restoration procedure was designed to eliminate the infeasible chromosomes due to looping. The procedure for crossover operation is follows:

(i) Input a matrix which consists of rows of chromosomes as in Equation 11.

$$ROUTE\_MATRIX = \begin{bmatrix} n_{0,0} & n_{0,1} & n_{0,2} & \cdots & n_{0,k-1} \\ n_{1,0} & \cdots & \cdots & \cdots & \cdots \\ n_{2,0} & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ n_{m-1,0} & \cdots & \cdots & \cdots & n_{m-1,k-1} \end{bmatrix} \quad (11)$$

(ii) If the generated crossover rate is more than the specific crossover rate, then skip the step. If not proceed. Initialize the random number generator and the new route matrix. The population size must be positive and even.

(iii) Consider a pair of variable length chromosomes denoted as parents, V_1 and V_2 , starting from the last chromosome within the population.

(iv) Locate the potential pair of crossing sites.

(v) If more than one pair of crossing sites exists, apply a random number to establish only one particular pair of crossing sites.

(vi) Process the crossover of V_1 and V_2. Two offsprings, V_1' and V_2' are produced.

4.4 Route Mutation

Mutation is used to change randomly the value of a number of the genes within the candidate chromosomes. It generates an alternative chromosome from a selected chromosome. The procedure for the mutation process is outlined below:

(i) Input population matrix (Equation 12) and connectivity matrix (Equation 13).

$$POP\_MATRIX = \begin{bmatrix} n_{0,0} & n_{0,1} & n_{0,2} & \cdots & n_{0,k-1} \\ n_{1,0} & \cdots & \cdots & \cdots & \cdots \\ n_{2,0} & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ n_{m-1,0} & \cdots & \cdots & \cdots & n_{m-1,k-1} \end{bmatrix} \quad (12)$$

$$CONNECTIVITY\ \ MATRIX, \quad L_{i,j} = \begin{bmatrix} l_{1,1} & l_{1,2} & l_{1,3} & \cdots & l_{1,n} \\ l_{2,1} & \cdots & \cdots & \cdots & \cdots \\ l_{3,1} & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ l_{n,1} & \cdots & \cdots & \cdots & l_{n,n} \end{bmatrix} \quad (13)$$

(ii) Choose a parent chromosome ***V*,** from the *POP_MATRIX*, with probability P_m.

(iii) Randomly select a mutation node ***i*** from ***V*,** .

(iv) Generate the first subroute r_1 from source node, ***S*** to node ***i*** by deleting a set of nodes in the upline nodes after the mutation node.

(v) Generate a second subroute r_2 from ***i*** to the destination node ***T***. It is done as follows.

(v-l) Determine node degrees of ***I*** , deg(***i***), neighbors of ***i***. If deg(***i***)=1 and { deg(***i***) } = ***T*** , then terminate the search, since the second subroute consist of

T . If deg(***i***) =1 and { deg(***i***) } # ***T*** , then terminate the mutation process. If deg(***i***) > 1 go to **(v-2)**.

(v-2) Select node {1, 2, 3, … deg(***i***) }. If deg(1)=1 and {deg(1)}=***T*** then second subroute is generated. Proceed with 2 and so on. If deg(1)=1 and {deg(1)}#***T***, proceed with 2 and so on. If deg(1)>1 go to **(v-3)**.

(v-3) Select node { 1, 2, 3, … deg(1) }. If deg(1)=1 and {deg(1)}=***T*** then second subroute is generated. Proceed with 2 and so on. If deg(1)=1 and {deg(1)}#***T***, proceed with 2 and so on. If deg(1)>1 terminate. We search for the second subroute up to two stages so that the effort will not take much processing time.

(v-4) If the number of second subroute generated is more than one, then choose the least hop.

(vi) Combine the first subroute and second subroute forming a new route. Add to the *POP_MATRIX*.

(vii) If any duplication of nodes exists between r_1 and r_2, discard the routes and do not perform mutation. Otherwise, connect the routes to make up a mutated chromosome.

4.5 GA Parametric Evaluations and Preferences

Choosing genetic algorithm parameters such as selection schemes, population size, mutation rate and crossover rate is a very difficult task. Each combination of parameters may produce a variety of outcomes. Haupt *et al* [23] outlined a general procedure for evaluating these parameters.

Crossover and Mutation Probability

Very important parameters for GA implementation are the crossover probability P_c and the mutation probability P_m. These probabilities determine how many times crossovers and mutations occurred within a transmission period. The occurrence of crossover and mutation increases the convergence rate. De Jong [10], tested various combinations of GA parameters and concluded that mutation was necessary to restore lost genes, but should be kept at low rate, avoiding random search phenomenon. Further study by Schaffer *et al*. [24], suggested that the parameters should have these recommended ranges: population size of 20 ~ 30, mutation rate of 0.005 ~ 0.1 and crossover rate of 0.75 ~ 0.95. Another study by Haupt *et al* [23] concluded that the best mutation rate lies between 5% and 20% while the population size should be less than 16. In this paper, where GA operation is done in real time, the value of P_c and P_m is taken to be between 0.4 and 0.9 and between 0.05 and 0.2 respectively. The population size is limited up to the number of routes discovered. The limit is also imposed on the number of generations that is the maximum number of generations to 20. Simulation experiments were run by setting MANET scenario running the protocol, with 20 nodes placed within an area of 1000 meter x 1000 meter. Each node has a radio propagation range of 250 meters and channel capacity of 2 Mbps. Up to 10 sources was initiated transmitting CBR with a data payload of 512 bytes. The investigation concluded that the crossover probability and mutation probability could be taken as 0.7 and 0.1 respectively.

5. Random Mobility Model

5.1 Random Waypoint Mobility Model

Generally, MANETs are studied through simulation and their performance depends heavily on the mobility model that governs the nodes movement. In most cases, the probability distribution of initial locations and nodes velocity differs from the distribution at later stage in the simulation. It is rather true, the probability distributions of both location and speed varies continuously over time, and converge to a *stationary* distribution. At any instant during the simulation period, the distribution of location and velocity is a weighted average of the initial distribution and the stationary distribution, with the weight shifting from the initial distribution to the stationary distribution as the simulation progresses. The distributions of location and velocity normally vary as a simulation progresses, resulted in the performance of the network vary as well. Hence, for the overall performance with respect to velocity, the value of average velocity is taken. Consider the random waypoint mobility model [26, 27]. In this model, each node is assigned an initial location (x_0 , y_0), a destination (x_1 , y_1), and a velocity of *S*.

The points (x_0 , y_0) and (x_1 , y_1) are chosen independently and uniformly in the region of nodes movement. The velocity is then chosen uniformly on an interval (v_0 , v_1), independently of both the initial location and destination. After reaching the destination, a new destination is chosen from the uniform distribution, and a new speed is chosen uniformly on (v_0 , v_1), independently of all previous destinations and speeds. Nodes may pause upon reaching each destination, or they may immediately begin traveling to the next destination without pausing. If they pause, the pause times are chosen independently of velocity and location. Most published simulation results using the random waypoint mobility model, begin with the nodes placed uniformly in the simulation area.

The algorithm can be divided into the following five steps: (1) Select a random destination within the scenario; (2) Select speed (uniform distributed); (3) Move until the destination is reached; (4) Wait (uniform distributed); (5) Go to step one. During the scenario simulation, the algorithm need to be setup with generally typical configuration parameters such as, Start time, Stop time, Minimum speed, Maximum speed and the Pause time.

The specific characteristics of the model are: (1) the average speed; (2) transient phase and (3) the node density. The random waypoint mobility model has some characteristics which have a great impact on the simulation results and should be considered before using the model. The average node speed is NOT the average of the minimum speed and the maximum speed. It is much lower due to the fact that slow nodes require more time than faster nodes to reach the next destination. As a consequence of the next destination selection, the average node speed decreases, especially at the beginning of a simulation. For that reason, the minimum node speed should not be set to zero since a small minimum node speed increases this effect. The transient phase of the model depends on the minimum node speed and the pause time. The pause time should be set to zero and a high minimum speed should be used in order to minimize the transient phase. The nodes are not even distributed by the mobility model. The highest node density is in the center whereas the lowest density can be recognized at the border. This node density distribution results from the next destination selection. A node that moves from one point to another point usually has to move through the center.

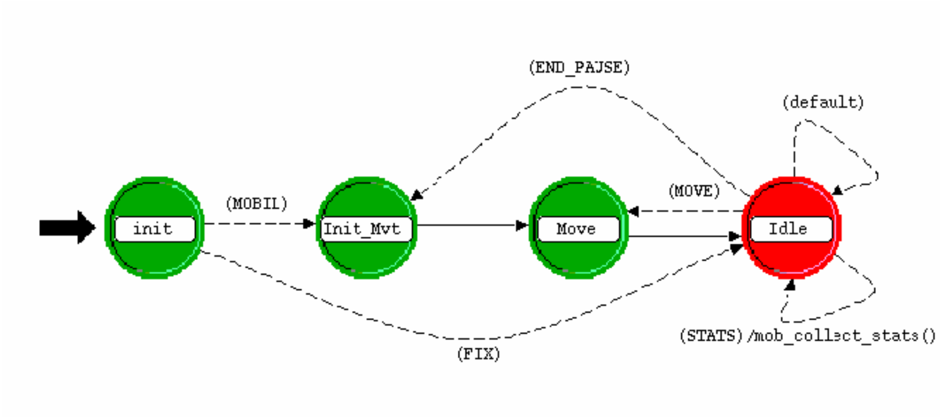

Figure 2: Process Model for Random Waypoint Mobility

As implemented in OPNET [30] models for wireless ad hoc routing protocols, the random waypoint mobility model has the process model shown in Figure 2. The node is at rest, or "pauses", for a random amount of time. Then a random destination position within the specified area is selected, and the node moves toward the destination along a linear trajectory with a randomly selected speed. The process is repeated indefinitely. Thus the parameters of the random waypoint mobility model are the maximum values for the pause time and the speed, and the dimensions of the area in which movement is allowed. It is obvious that an individual node's mobility can be controlled by adjusting the average amount of pause time or the average speed. However, it is not obvious how to predict quantitatively the effect of these parameters in terms of the network connectivity and on the resulting rate of link changes. The Random Waypoint Mobility Model is also a widely used mobility model [28]. In addition, the model is sometimes simplified, by using the Random Waypoint Mobility Model without pause times.

5.2 Mobility and Traffic Models

The random waypoint model was used to model the random movement of nodes. Each node started its journey from a random location to a random destination point with a specific speed. Once the destination was reached, stopped for duration of time, and then calculate another random destination point. Initial angle of motion for every node is set at 0 degree. In this version of Opnet, the random waypoint mobility model was included with the Wireless Module of the Opnet Modeler. It was then configured into the model through the Mobility Profile Definition. It was specified that all the nodes moved within the boundary of the field configuration. The pause time was kept constant at 1 second for all the simulation experiments. This gives consistency in the nodes' movement for all the scenarios. The start time was set to zero until the end of simulation. The only variation within the RWP model was the speed. The speed was configured into a uniform distribution between zero and V_{max}, where V_{max} can be set accordingly. Traffic sources with 512 bytes data packets were CBR in nature. The source-destination pairs are spread randomly over the network and the number of sources was varied to change the offered load into the network. During the lifetime of a flow, a source node continuously generating data packets at the rate determined by the inter-arrival rate. The sending rate was varied according to Table 1, from between 24pps to 292pps. Nodes in all the three protocols maintain an infinite send buffer which contains queued packets. Each node buffered all data packets while waiting for a route. All packets (both data and routing) sent by the routing layer were queued at the buffer until the MAC layer was able to transmit them. Simulations were run for 200 simulated seconds. Each data point represented an average of 10 runs with identical traffic models, but different randomly-generated mobility scenarios by using different seeds to the random number generator. Another interesting aspect of the protocol design was to understand the protocol performance with various parameters.

Table 1. Traffic Sending Rates

Inter Arrival Rate (sec)	Traffic Rate (pkts/sec)	Traffic Rate (kbps)
0.2048	4	20
0.1024	9	40
0.0683	14	60
0.0512	20	80
0.04096	24	100
0.02048	49	200
0.01365	74	300
0.01024	98	400
0.008192	122	500
0.006827	146	600
0.005851	170	700
0.00512	195	800
0.004551	219	900
0.004096	244	1000
0.003724	268	1100
0.003413	292	1200

6. Effect of Maximum Velocity on QOSRGA Performances

Node mobility generally influences the overall performance of the network. The influenced of velocity on the Average Packet Delivery Ratio (APDR) and Average End-to-End Delay (AETED) were investigated. The number of CBR sources was set to five. The simulation was run by varying uniform velocity distribution with mean outcome of V_{max} as 1, 2, 5, 10, 15, 20 and 25 m/s. For stationary nodes, the RWP parameter setting was removed altogether. The source data rates used were 40 kbps and 200 kbps. The aimed of the simulation experiment was to relate the mobility of nodes and its effect on the overall performance of QOSRGA. The results were shown in Figure 3 and Figure 4. Figure 3 shows the APDR against maximum velocity for 40 kbps and 200 kbps. With the increase in velocity, the 40 kbps remained constant at approximately 82%. The performance of the 200 kbps traffic shows a decreasing trend as the velocity increased. It dropped substantially from 78% to 42% at 5 m/s, then to 19% at 20 m/s and improved a little to 22 % at 25 m/s. QOSRGA performed effectively with low source data rate throughout the range of velocities but not with high source data rate. With higher data rate and faster node movement, more packets are dropped due to short node pair connectivity time, that is, high ***nci*** value. Figure 4 shows the average delay against average maximum velocity. With 40 kbps source, the average delay was much less than that with a source of 200 kbps. The 200 kbps source generated more packets and resulted in heavier congestion, and hence produced a greater delay. Nevertheless, it was still below the 100 ms, which was the maximum delay allowed for most multimedia services. The reading also shows a constant trend and not an increasing trend. It was due to the delay reading, which was based on all the packets that actually arrived at the destinations, thus not considering the dropped packets.

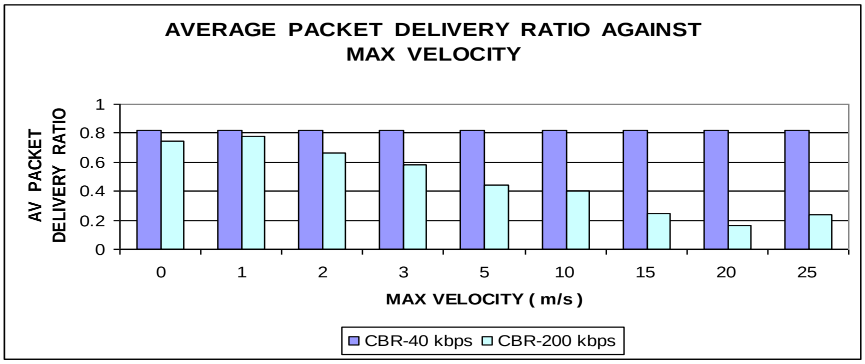

Figure 3. Average Packet Delivery Ratio as a Function of Max Velocity for QOSRGA Protocol with CBR-200kbps and CBR-40kbps

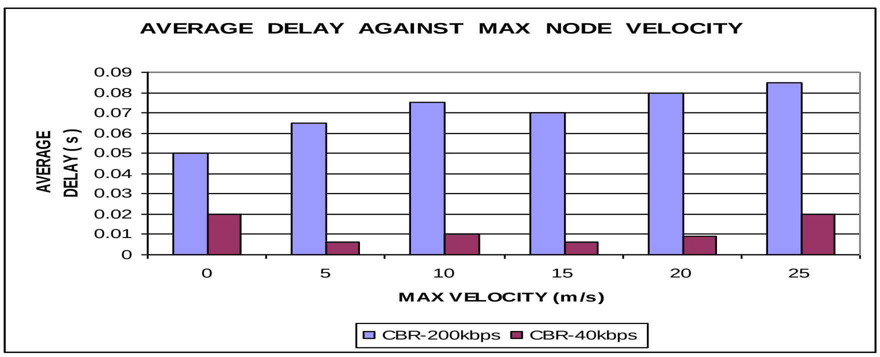

Figure 4. Average Packet Delay as a Function of Max Velocity for QOSRGA Protocol for CBR-200kbps and CBR-40kbps

The second set of simulation experiments varied the velocity for a 40 nodes network and 10 CBR sources. The mobility was varied to see how it affected the different metrics that were measured. The packet sending rate was fixed at 98 pkts/sec (400 kbps). The simulations were run with uniform velocity, where the maximum velocities were 0.5, 1, 1.5, 2, 5, 10, 15, 20, and 25 m/s. The graph of Average Packet Delivery Ratio against node maximum velocity is shown in Figure 5. For high bandwidth sources of 98 packets/sec (400 kbps), clearly QOSRGA consistently performed better than BE-DSR and BE-AODV for all the mobility ranges. Generally, it is 5% to 15% better than BE-AODV and 5% to 30% better than BE-DSR. In QOSRGA, multiple routes were found with the corresponding QOS metrics information B_{AVA}, D_{ETE}, D_{MAC} and ***nci***. The selection of the routes was based on the probable length of time each node pair stay connected, which is indicated by ***nci***. 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 packets back to the source, because of the route caching mechanism of BE-DSR. However routes overlap the existing routes, hence resulting in severe congestion, and it cannot deliver packets along the route. Moreover the stale or outdated routes produce a reply to source with invalid routes. Ultimately, many packets are dropped, resulting in poor BE-DSR performance. In QOSRGA, an aging mechanism is used, hence the stale routes will be replaced.

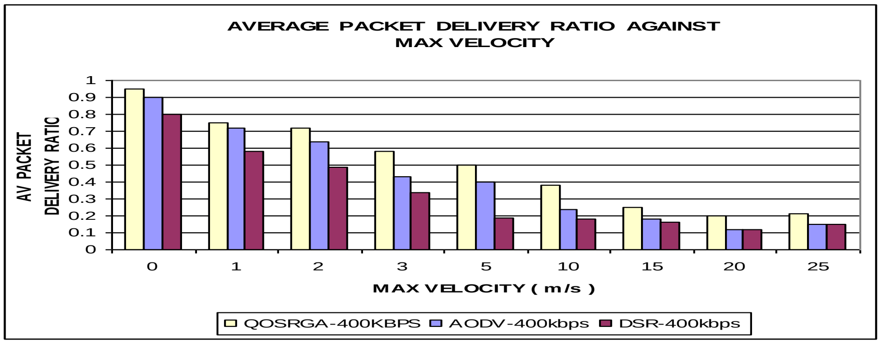

Figure 5. Average Packet Delivery Ratio as a Function of Maximum Velocity Comparing QOSRGA, AODV and DSR.

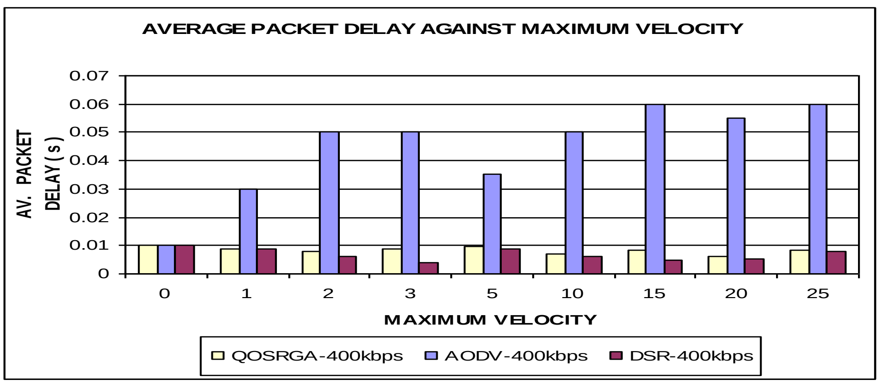

Figure 6. Average Packet Delay as a Function of Maximum Velocity Comparing QOSRGA, AODV and DSR at data rate of 400 kbps

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: (1) Route discovery time, which causes packets to wait in the queue before a route is found; (2) Buffering waiting time, which causes packets to wait in the queue before they can be transmitted; and (3) The length of the routing path. More hops means a longer time to reach the destination node. Figure 6 depicts the variation of the average end-to-end delay as a function of the velocity of nodes.

It can be seen that the general trend of all the 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 means data packets have to wait longer in the queue until a new routing path is found. The delay of BE-DSR is lower than QOSRGA and BE-AODV. However, all the delays incurred by QOSRGA are still less than 0.1 second. This is because availability of cached routes in QOSRGA eliminates route rediscovery latency that contributes to the delay when an active route fails. In addition, when a congestion state 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 the queue.

7. Conclusions

A scheme has been presented for multiple constrained QoS routing protocol for MANET based on Genetic Algorithm. In the proposed scheme of QoS routing, selection of a route was based on node bandwidth availability, short end to end delay and the longest node pair connectivity time indicated by node connectivity index (***nci***). The route selection algorithm was outlined and implemented. The variable length chromosomes represented the routes and genes represented the nodes. The algorithmic process was initialised by introducing a limited population, accumulated during the route discovery by the Node non-Disjoint Multiple Route Discovery (NDMRD) protocol. The fitness calculation was done using the weighted sum approached, combining the entire objective functions into a single objective. The scenario used the Random Waypoint Mobility model for ensuring that the nodes movement in a random fashion. The performance study was done to study the effect of maximum node velocity on the average packet delivery ratio and delay. The performances indicated that the protocol is feasible for a reasonable node velocity with random mobility model.

References

[1] C. E. Perkins and P. Bhagwat, "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers", *Computer Communications Review*, vol. 24, Issue 4, **(1994)** October, pp. 234-244.

[2] J.L. Sobrinho and A.S. Krishnakumar, "*Quality-of-Service in Ad Hoc Carrier Sense Multiple Access Wireless Networks*", JSAC, vol. 17, no. 8, **(1999)** August, pp. 1353-1368.

[3] P. Mohapatra, J.Li and C.Gui, "QoS In Mobile Ad Hoc Networks", *IEEE Wireless Communications*, vol. 20, **(2003)** June, pp. 44-52.

[4] 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", *Journal PADC*, vol. 60, **(2000)**, pp. 374-406.

[5] C. R. Lin and M. Gerla, "Asynchronous multimedia multihop wireless networks", in *Proc. IEEE INFOCOM*, **(1997)**, pp. 118-125.

[6] D. B. Johnson, D. A. Maltz and Y. C. Hu, "The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks (DSR)", *IETF MANET Working Group, INTERNET-DRAFT*, 2007. Available: http://www.ietf.org/rfc/rfc4728.txt, Last accessed: **(2007)** May 30.

[7] C. E. Perkins and E. M. Royer, "Ad-hoc On-Demand Distance Vector Routing", *Proc IEEE Mobile Computer Systems and Applications*, **(1999)**, pp. 90-100.

[8] Kumar, R.; Parida, P.P.; Gupta, M., "Topological design of communication networks using multiobjective genetic optimization", *Evolutionary Computation, 2002. CEC '02, Proceedings of the 2002 Congress on*, vol. 1, **(2002)** May 12 – 17, pp.425-430.

[9] 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.

[10] D. A. Coley, "*An Introduction to Genetic Algorithms for Scientist and Engineers",* World Scientific Publishing, Singapore, **(1999)**.

[11] M. Gen and R. Cheng, "*Genetic Algorithms and Engineering Optimization",* Wiley-Intersciences Publication, Canada, **(2000)**.

[12] R. Elbaum and M. Sidi, "Topological Design of Local Area Networks Using GA", *IEEE/ACM Transactions on Networking*, vol. 4, **(1996)** October, pp. 766-778.

[13] S. Mao, Y. T. Hou, X. Cheng, H. D. Sherali and S. F. Midkiff, "Multipath routing for multiple description video in wireless ad hoc network", *IEEE INFOCOM2005*, **(2005)**.

[14] Y. Leung, G. Li and Z. B. Xu, "A genetic algorithm for the multiple destination routing problems", *IEEE Transactions on Evolutionary Computation*, vol. 2, **(1998)**, pp. 150-161.

[15] S. H. Wong and J. Wassell, "Dynamic channel allocation using a genetic algorithm for a TDD broadband fixed wireless access network", in *Proc. IASTED International Conference in Wireless and Optical Communications, July 17-19, 2002, Banff, Alberta, Canada,* **(2002)**, pp. 521-526.

[16] N. Shimamoto, A. Hiramatus and K. and Yamasaki, "A dynamic routing control based on a genetic algorithm", in *Proceedings of the IEEE International Conference on Neural Networks,* **(1995)**, pp. 1123-1128.

[17] M. Munetomo, Y. Takai and Y. Sato, "A migration scheme for the genetic adaptive routing algorithm", in *Proceeding of the IEEE International Conference on Systems, Man, and Cybernetics*, **(1998)**, pp. 2774-2779.

[18] J. Inagaki, M. Haseyama and H. and Kigajima, "A genetic algorithm for determining multiple routes and its applications", in the *Proceedings of the IEEE International Symposium on Circuits and Systems,* **(1999)**, pp. 137-140.

[19] J. C. Z.Wang, "Quality of Service Routing For Supporting Multimedia Applications", *IEEE JSAC,* vol. 14, **(1996)**, pp. 1228-1234.

[20] 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)**.

[21] G. S. Ahn, A. T. Campbell, A. Veres and L. H. Sun, "Supporting Service Differentiation for Real-Time and Best-Effort Traffic in Stateless Wireless Ad Hoc Networks (SWAN)", *IEEE TMC*, vol. 1, **(2002)** July-September, pp. 192-207.

[22] J.Abdullah, "The Design of QOSRGA Protocol Employing Non-Disjoint Multiple Routes in MobileAd Hoc Networks*", Proc. Of The MMU International Symposium on Information and Communication Technologies*, (M2USIC2007), ISBN: 983-43160-0-3, **(2007)** November 19-20, PJ Hilton, Petaling Jaya, Malaysia.

[23] 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, **(2000)**, pp. 1034-1037.

[24] 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.

[25] Abdullah, J. and Parish, D. J., "Node connectivity index as mobility metric for GA based QoS routing in MANET", *In Proceedings of the 4th international Conference on Mobile Technology, Applications, and Systems* (Singapore, September 10 – 12, 2007), Mobility '07. ACM, New York, NY, **(2007)**, pp. 104-111.

[26] Johnson, D., and Maltz, D., Dynamic source routing in ad hoc wireless networks, In *Mobile Computing, T. Imelinsky and H. Korth, eds*, Kluwer Academic Publishers, **(1996)**, pp. 153–181.

[27] Broch, J., Maltz D., Johnson, D., Hu, Y., and Jetcheva, J., Multi-Hop wireless adhoc network routing protocols; *Proceedings of the ACM/IEEE International Conference on Mobile Computing and Networking* (MOBICOM '98), **(1998)**, pp. 85–97.

[28] P. Johansson, T. Larsson, N. Hedman, B. Mielczarek, and M. Degermark, Routing protocols for mobile ad-hoc networks - a comparative performance analysis, In *Proceedings of the ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM)*, **(1999)**, pp. 195–206.

[29] J.Abdullah and D.J.Parish, "*Effect of Mobility on the Performance of GA-based QoS Routing in Mobile Ad Hoc Networks",* for the ICIAS 2007, IEEE International Conference on Intelligence & Advanced Systems, **(2007)** November 25-28, Kuala Lumpur, Malaysia.

[30] G. Harik, E. Cant˘u-Paz, D. E. Goldberg, and B. L. Miller, "The Gambler's ruin problem, genetic algorithms, and the sizing of populations", *Evol. Comput.*, vol. 7, no. 3, **(1999)**, pp. 231–253, 1999.