Node Connectivity Index as Mobility Metric for GA based QoS Routing in MANET

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ABSTRACT

The objective of this paper is to propose a unique connectivity index, ***nci*** which indicates the quality of route when nodes move randomly. The most reliable route is then chosen using GA route selection mechanism. The node mobility model is introduced and shows that there exists upper bound for velocity in order to achieve reliable wireless communication. The ***nci*** is then derived based on contraction and expansion model. It is then utilized as one of the fitness variable in our multi objectives GA-based QOS Routing protocol. It has been observed that the performances of our protocol QOSRGA on velocity scenario are better than the BE-DSR routing protocol.

Categories and Subject Descriptors

H.5.3 [**Information Interfaces and Presentations**]: Groups and Organization Interfaces – *Collaborative Computing, Computer-supported Cooperative Work, Synchronous Interaction.*

General Terms

Algorithms, Measurement, Performance, Design, Experimentation

Keywords

MANET, QoS Routing, node connectivity index, Genetic Algorithm, Performance Evaluations, Mobility Models, Contraction and Expansion Models

1. INTRODUCTION

The vision of MANET is characterized by mobile, lightweight and personalized computing devices, being collaborative in nature towards a self-establishing network. When network topology changes due to node mobility, three node-pair scenarios are possible; least-connected, highly-connected or breaking-up. The changes in the set of links of a node affect not only the nodes' ongoing communication, but may impede the communication of other nodes. As the capacity and communicating ability of MANET are dependent on node connectivity, it is important to understand how node connectivity behaves in a MANET. Routing protocols may cause rerouting in response to the variation of quality of node connectivity. The resultant routes may alter the traffic distribution in the network, causing congestion at some nodes while less traffic at other nodes. The network dynamics thus, require a mobility metric which can quantify the node movements and eventual relationship with the neighbors. The final outcome would be how reliable the nodal communication is. The stable and durable routes are selected based on the connectivity criteria from a node to its neighbors and successively in pairs towards the target nodes. QoS routing is the mechanism to find a feasible route which has overall excellent connectivity criteria from amongst the routes discovered. For effective performance of QoS routing protocols, it requires a node connectivity metric that can accurately capture the networking dynamics. Effectively it indicates the resulting performance of our GA-based QoS routing protocol. Such a metric could provide feedback information which shows the quality of node connectivity. The connectivity metric must be applicable to a real mobile network with real nodes. Our first step is to define a set of requirements that must be met to enable effective function of QoS routing protocols. The metrics should be (1) able to compute in a distributed environment, (2) able to adapt a locally measured performance, (3) a numerical quantity which indicates the quality of node-pair connectivity, (4) capable of processing in a real time implementation. Ultimately, the metric should quantitatively describe the dynamic of the nodes such that it can be of use in the route discovery and selection process to choose the most reliable, longer duration and stable routes. It can also be use to select the cost-effectiveness of the longer duration and stable routes. Lastly, it is expected to generate the available QoS routes. The rest of the chapter is organized as follows. Section 2 outlined the related work on node connectivity. Section 3 described in detail the node connectivity metric, where the node mobility is characterized by the expansion and contraction model. Section 4 introduced and described in detail the node connectivity index including performance evaluations. Section 5 illustrates the derivation of ***nci***. Section 6 describes the underlying network model. Section 7 introduces our QOSRGA protocol and Section 8 describes the performance evaluations.

2. RELATED WORK

Route reliability issues have been addressed in several works. In the Associativity-based Routing [1], the association stability of the links is accounted when choosing routing paths. It attempts a measure of goodness using associativity ticks which indicates how stable a route is. The Signal Strength Adaptive protocol [2] further considers the signal strength in choosing the good paths. With the Route-Lifetime Assessment Based Routing protocol [3], a parameter called affinity is defined to characterize the signal strengths and stability of a route. An AODV [7] tries to pre-empt

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a link failure by using periodic hello packets and propagating failure messages to source using the route. Pre-emptive routing [4] is an enhancement to DSR that enables nodes to estimate the time to link failure and propagate route failure information in advance. All these mechanisms suffer from the fact that they are local to the node and not necessarily good strategy for the whole route. An attempt to view the whole route was done by [5] using some kind of mobility prediction. This requires global clock synchronization and a positioning system for the network. These mechanisms do not capture aspect of the relative velocity for the route.

3. NODE CONNECTIVITY METRIC

3.1 Characteristics of Node Movements

The main challenge of QoS routing in mobile ad hoc networks is to handle the topology changes appropriately. The performance of a protocol is greatly determined by its ability to adapt to these changes. Hence, it would be useful to have metrics that characterize the effect of mobility on the connectivity of node pair. We need to define a few mobility characteristics that affect the connectivity metrics. These are the link lifetime, route lifetime, the number of link changes, node degree and route availability. Link lifetime is the duration of connectivity for a single hop node pair. The route lifetime is the duration of full connectivity from source to destination for a certain number of hops. Node degree is the number of neighboring nodes within the transmission range of source node. Link availability is the fraction of time where there exists a connection between two neighboring nodes. We would like to consider a metric in terms of a single positive value as node-pair connectivity index, to be incorporated into the route selection algorithm. The metrics are all culminated from the effect of mobility with certain velocities. The velocities of nodes within MANET have the characteristics of spatial and temporal dependence. Spatial dependence is the extent of similarity of the velocities of two nodes that are within the transmission range. Temporal dependence is the extent of similarity of the velocities of a node at two time instances that are not too far apart. Relative velocity is the velocity difference between a pair of nodes. Node pairs moving towards each other and node pairs moving apart, experience higher relative velocity. Node pairs moving along side each other or moving in the same direction experience low relative velocity. We choose the relative velocity to impact on our QoS routing algorithm since it is governed by the strength of connectivity between any set of node pairs within the route. The strength of connectivity between the node pair can be derived from the fact that node-pairs may be moving towards each other in a contraction model or they may be moving away from each other in an expansion model.

3.2 Contraction and Expansion Mobility Model

Ideally the contraction model emulates the movement of mobile nodes towards a logical centre from all directions. In practical scenarios, at $t = 0$, a node may enters another node's transmission range at an angle and move in a direction not towards the other node. Contraction and expansion rates increase as velocity increases. This results in a node reaching the boundary of transmission range after short time duration. Consequently this affects the node connectivity time, route lifetime and the quality of node connectivity. If the movement pattern of the nodes is away from each other, than it is expansion model. Ideally, if at $t = 0$, a node is within a transmission range of the other node, then it moves away from the centre to the edges. In a practical scenario, the mobile nodes may move away from each other at an inclination angle. Incidentally, the starting point of the node is within the transmission radius, in contrast to the contraction model.

3.3 Hybrid Model Characteristics

In this mobility model, the movements of a node may switch from a contraction to an expansion model. This switch able characteristic is due to the relative distance between the node-pair and the time a node is within transmission range of its neighbor. Initially, the node is in contraction model, having entered the transmission range at an angle of arrival, until it reaches a perpendicular point towards the other node where it enters the expansion model. Finally, the node reaches the edge of the transmission range at a point of departure. Considering the node moves in a straight line motion, at a point in time, the node will exhibit the expansion mobility characteristics. There exists a finite time between the node pair when they will always be in connectivity. The node connectivity time is an important QoS routing parameter for mobile nodes. The connectivity time depends on the angle of arrival and velocity. Figure 1 shows these three models. In hybrid model, the node connectivity time is higher when it is at a particular position within the range for contraction compared to if it were for expansion model.

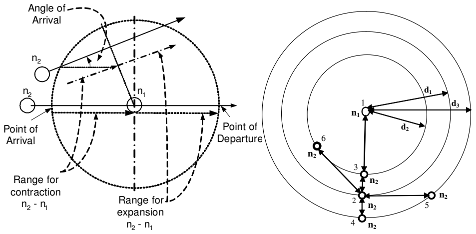

Figure 1 (a) Three Mobility Models (b) *nci* Calculation

4. NODE CONNECTIVITY LIFETIME

4.1 Expected Node Connectivity Time

Consider two nodes ***i*** and ***j***, at time t_1 , when the duration of the node connectivity ***L***(i,j) is the time interval (t_1,t_2) during which the two nodes are within the transmission range of each other. However these two nodes could not be within the transmission range at time $t<t_1$ and also at time $t>,t_2$. Formally, ***L***(i,j)= $t_2 - t_1$ for all values of t , $t_1 \leq t \leq t_2$. We present an analytical model to determine the mean connectivity time of a node-pair. The mean connectivity time of a node pair provides us with the estimated length of residual time the node pair is in contact. It provides us with a lower and upper bound of connectivity time which is useful in ensuring a complete communication session.

The analytical estimates of the node pair connectivity time is obtained using the approach taken by Hong [6], in the cellular network where the expected time of a node residing within a cell is derived. We estimated the connectivity time of a node pair, which is the time where a node is always in contacts wirelessly with the other at a velocity and angle of arrival assumed to be uniformly distributed. We assumed that the transmission range is set at 250m. Next, we assumed that during the connectivity time, the mobile node moves along the specific direction, with uniform velocity. The velocity distribution of different nodes at different time intervals conforms to a velocity profile, with uniform distribution. Figure 1 shows a mobile node, $\boldsymbol{n_2}$ moving in the vicinity of another node, $\boldsymbol{n_1}$ which is assumed to be stationary. In reality, both nodes may be mobile. The mobile node arrives at the boundary of the circular range of the stationary node, at time of arrival, TOA and it keeps on moving until the boundary is reached again, at departure time, TOD. The velocity of the mobile node is assumed to be uniformly distributed between $\boldsymbol{0}$ and $\boldsymbol{V_{max}}$ m/s. The direction of arrival of node $\boldsymbol{n_2}$ is given by $\boldsymbol{\theta}$, the value of which is between $\boldsymbol{-\pi/2}$ and $\boldsymbol{+\pi/2}$. The mobility of the node is then characterized by the velocity *pdf*, $f_v(v)$ and directional *pdf*, $f_\theta(\theta)$. In order to determine analytically the time range when n_2 resides within the range of n_1, the two *pdf* are defined. Velocity *pdf* is given as,

$$f_v(V) = \begin{cases} \frac{1}{V_{\max}} & for \quad 0 \le V \le V_{\max} \\ 0 & otherwise \ . \end{cases}$$

When the mobile node arrives at time TOA and may transverse a distance **X** in any direction with equal probability, the random variable $\boldsymbol{\theta}$, has PDF as,

$$f_\theta(\theta) = \begin{cases} \frac{1}{\pi} & for - \frac{\pi}{2} \le \theta \le \frac{\pi}{2} \\ 0 & elsewhere \end{cases}$$

Consider node $\boldsymbol{n_2}$ from Figure 1, which traverses a distance X, thus, $X=2R\cos\theta$. For node $\boldsymbol{n_2}$ traversing a distance x with time (where $0 \le x \le 2R$) then the density function of X, $F_X(x)=Pr(X \le x)$ Resolving, for $\boldsymbol{F_x(x)}$,

$$F_X(x) = \begin{cases} 0, & for \ x<0, \\ 1 - \frac{2}{\pi} \cdot \cos^{-1}\left(\frac{x}{2R}\right), & for \ 0 \le x \le 2R, \\ 1, & for \ x > 2R. \end{cases}$$

Then the *pdf* of X, $f_x(x) = \frac{d}{dx} \cdot F_X(x)$ is reduced to the form,

$$f_X(x) = \begin{cases} \frac{1}{\pi} \cdot \frac{1}{\sqrt{R^2 - \left(\frac{x}{2}\right)^2}} & for \ 0 \le x \le 2R \\ 0, & elsewhere \end{cases}$$

Node pair connectivity time is defined as the mean time a node is within the transmission range of the other node and both are fully connected. The node connectivity time for the mobile node to travel from the point of arrival to the point of departure, a distance of $\boldsymbol{X}$, with the velocity $\boldsymbol{V}$, generally is given as, $T_{NCT}=X/V$. The *pdf* of the node connectivity time can be found using a standard method shown in [6]

$$f_{NCT}(t) = \begin{cases} \frac{4R}{\pi V_m} \cdot \frac{1}{t^2} \left[1 - \sqrt{1 - \left(\frac{V_m t}{2R} \right)^2} \right] & for \ \ 0 \le t \le \frac{2R}{V_m}; \\ \frac{4R}{\pi V_m} \cdot \frac{1}{t^2} & for \qquad t \ge \frac{2R}{V_m}; \end{cases}$$

The expected mean node connectivity time for the 2-node is given as, $\overline{T_{NCT}} = \int_0^\infty t . f_{NCT}(t) \, dt$. By this equation the mean node connectivity time, T_{NCT} is now a function of velocity. Figure 2 is a plotting of T_{NCT} against velocity. From the plot we can explicitly estimate T_{NCT} for any given velocity. The lower bound and the expected bound of the node connectivity can also be estimated. From the graph we can infer that node connectivity time depends on the velocity of the node. We can obtain the estimate of T_{NCT} for any velocity. There's also a limit to the velocity of each node in the system. For our QoS routing simulation we need only to choose the appropriate velocity. If we choose maximum velocity as 25m/s then we expect the connectivity time would be ~10 seconds.

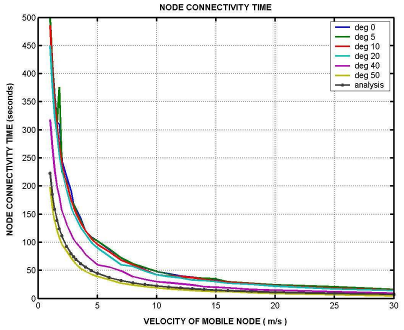

Figure 2 The Node Connectivity Time By Analysis And Simulation

4.2 Connectivity Time through Simulation

Figure 2 shows the T_{NCT} is plotted against velocity. Each reading was taken for a specific angle of arrival. The time difference between the TOA and TOD is taken as the node connectivity time in seconds. Different angles of arrival give a slightly different curve. Low velocity gives higher node connectivity time. The result from Opnet simulation is similar to the one obtained analytically, with a slightly higher connectivity time for a given velocity. Hence we can conclude that Opnet simulation can be used to simulate the node mobility model and extract a suitable node connectivity time. The model can be used to estimate node connectivity time for a given velocity and the maximum time for the purpose of QoS routing implementation. A velocity of 25 m/s gives us about 10s of connectivity duration, whereas velocity of 1 m/s gives us approximately 225s. Hence the velocity which gives a reliable connectivity duration would be between 0.5 m/s (3.6 km/h) and 25 m/s (90 km/h). The velocity of 0.5 m/s depicts a walking scenario whereas the velocity of 25 m/s depicts a car traveling on the highway. We need a metric which can describe the relative difference in connectivity time for different node pairs. By comparing the values from different node pairs, we can select those which have surplus connectivity time left. In the next section we propose a node connectivity index.

5. DERIVATION OF *nci*

5.1 Normalized Relative Velocity

It is not enough to view the network dynamics as having nodes connected or unconnected, but rather how long the connection will last. The longer the connection the better it contributes to the reliability and stability of the whole route. It is proposed to derive a metric which describes the dynamicity of the mobile nodes. In order to compute this metric, the connectivity between two adjacent nodes must be measured. Then the connectivity strength of every node pair is computed to produce a positive numerical index. The index can proportionately describe how reliable a route is. Those low speed nodes which have longer duration, and more reliable are represented by a low value index. Stationary nodes produce a zero index. The rate of separation, expanding and contracting measures, between each adjacent pairs of nodes can be estimated by computing the relative velocity.

Consider node n_1 receiving packets from node n_2 in Figure 1. Within the transmission range, node n_2 will always be on the circular disk centered at node n_1. Node n_2 is said to be within the virtual concentric region. The virtual concentric region is a circular region within the node's (i.e n_1) transmission range, where at any instant its adjacent node (i.e n_2) will always be before reaching point of departure. Let t_1 and t_2 be the times at which the last two packets from n_2 were received. We denote the received power from node n_2 when packets have arrived as P_1 (at time t_1) and P_2 (at time t_2). From this there exist two possibilities; that nodes are moving closer when $P_2 > P_1$ and nodes moving further apart when $P_2 < P_1$. Free space path loss propagation model is used [10] hence power received by the receiver antenna due to transmission from transmitter antenna is given as: $P_r = P_t G_t G_r \lambda^2 / (4\pi)^2 d^2 L$ where, P_r is the received power; P_t is the transmitted power; G_t is the transmitter antenna Gain; G_r is the receiver antenna gain; d is the distance between transmitter and receiver; L is the system loss factor and λ is the wavelength in meters. Then power, $P_r = k/d^2$, where $k = P_t G_t G_r \lambda^2 / (4\pi)^2 L$ .In all cases, the node is assumed to move in a linear motion and posses unlimited battery power.

5.2 Contraction and Expansion Model

5.2.1 *Contraction Mobility Model*

Referring to the Figure 1(b), consider nodes moving apart at a constant velocity and in linear motion. Two extreme scenarios may occur, that is, n_2 moves from position 2 to position 4 or from position 2 to position 5. Consider, n_2 moves from 2 to 4; distance = d_3 - d_1**.** Then for worst case scenario $v/\sqrt{k}$ is

$$v/\sqrt{k} = (1/(t_2 - t_1))\sqrt{(1/P_2) - (1/P_1)} \cdot \ \cdot$$

5.2.2 *Expansion Model*

In Figure 1, nodes moving closer with a constant speed in linear motion. Similarly, two scenarios can be used to find the relationship that will deduce the speed of the node. Consider, n_2 moves from 2 to 3: distance = d_1 - d_2, then, The worst case example is, $v/\sqrt{k} = 1/(t_2 - t_1)((1/\sqrt{P_1}) - (1/\sqrt{P_2}))$. From these equations we have the estimates of the node-pair relative velocity normalized by the constant due to antenna and propagation factors. The relative velocity can be used to estimate the aggregate values for all node-pairs that are within the source-destination route.

5.2.3 *Definition of* npem, npcm *and nci*

Definition 1: Consider a route R which consists of a set of nodes, which are in motion with a velocity, ***v*** and with varying angle of arrival, then R= {n_0, n_1, n_2,… n_{n-1} }. For R to be a reliable route, each node must be connected to its adjacent node for the whole period of message transmission. Let E denote the node pairs, (n_j, n_k) such that they are adjacent nodes. If the pairs are moving away from each other, the node pair expansion metric is defined as, $npem = (1/(t_2 - t_1))\sqrt{((1/P_1) - (1/P_2))}$.

Definition .2: Consider a route R which consists of a set of nodes, which are in motion with a velocity, v and with varying angle of arrival, R= {n_0, n_1, n_2,…n_{n-1}}. For R to be a reliable route, each node must be connected to its adjacent node for the whole period of message transmission. Let E denote the node pairs, (n_j, n_k) such that they are adjacent nodes. If the pairs are moving toward each other, the node pair contraction metric is defined as, $npcm = (1/(t_2 - t_1))((1/\sqrt{P_2}) - (1/\sqrt{P_1}))$ .Observe that *npcm* and *npem* are positive quantities but in different directions, *npcm* towards high positive values and *npem* towards low positive values. These two values must be combined to form a single metric to indicate the quality of connectivity between the two adjacent mobile nodes. We note that the node with *npcm* lasts longer than that with *npem*. Hence we need a weighted form of these two values in a single index quantity. This value will indicate a strong connectivity if its value is low and weak connectivity if its value is high. A high value shows that the node is more dynamic and will soon reach the point of departure from the other node's transmission range.

Definition 3: Consider a set E which consists of the node pairs, (n_j, n_k) such that they are adjacent nodes. If the pairs are moving towards each other or away from each other, the node pair connectivity index, ***nci*** is a positive value which describes the quality of connectedness between any two adjacent nodes. The least ***nci*** value indicates a good quality connection, in which the node pair connectivity time is high compared to high ***nci*** value, then ***nci*** is defined as,

$$nci = \begin{cases} 0.25 - \left[\dfrac{1.0\times10^5}{8.0\times10^5 - npem} \right], & for\ P_2 < P_1. \\ \dfrac{1.0\times10^5}{8.0\times10^5 + npcm}, & for\ P_2 > P_1. \\ 0, & for\ P_2 = P_1. \end{cases}$$

5.2.4 *Performance Evaluation of nci*

Various simulation experiments are done to show the viability of ***nci*** as a potential comparative measure to compare the connectedness among all the potential node pairs connectivity. Consider a scenario which consist of two nodes, one stationary and the other is mobile. We position the mobile node at an angle of arrival to the stationary node. Each node produces a periodic node connectivity packet, i.e. CONN packet, which is a one-hop transmission packet design to identify nodes that are within transmission range. Record them and their parameters in a form of a node state. We call it the node state cache. Readings of ***nci*** was taken for various speeds and for various angles of arrival. The results were tabulated for ***nci*** with velocities of 1 m/s, 2 m/s, 3 m/s, 4 m/s, 5 m/s, 6 m/s, 10 m/s and 15 m/s and graphically. For each graph values of ***nci*** for each angle of arrival of 0, 30, 45, 60, 70 and 80 degrees were drawn. For each velocity, the time of departure is less for small angles of arrival. The ***nci*** on the other hand showed that as the time of departure is decreasing, the value of ***nci*** is increasing. For the purpose of data transmission, it would be convenient to choose a node for which ***nci*** is the lowest among the entire neighboring nodes. From the figure, as ***nci*** increases, the expected connectivity time is reduced.

The results of the ***nci*** values for a number of velocities that are obtained are collated and a graph is drawn (Figure 3) to illustrates the effect of velocity on ***nci***. It can be concluded that the greater the velocity, the higher the ***nci***. If there are two node-pairs with different relative velocities, then the one which has the least ***nci*** value will be chosen at that instant as its performance is the best in terms of how long the node-pair connection lasts. Hence this confirms that ***nci*** could be a unique comparative index, to select which node pairs that provides longer node connectivity.

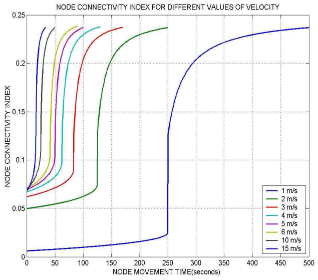

Figure 3 Node Connectivity Index as a Function of Node Movement Time

6. NETWORK MODEL

The underlying topology of mobile ad hoc networks is modeled as a graph $G = (V, Q\{\ nci,\ B_{AVA}, D_{E2E}, D_{MAC}\})$, where V is a finite set of | V | nodes, and Q is a set of QoS parameters that determine the viable QoS connectivity between the nodes**.** Each mobile node $i \in V$ has a unique identity and moves arbitrarily. A radius ***R*** defines a coverage area within which every node can communicate with each other directly. Neighbors of node ***i*** are defined as a set of nodes $i \# j$, which are within radius R and reachable directly from the node ***i***. Every pair of neighbors can communicate with each other in both directions. Hence, there exists a connectivity between neighbors ***i*** and ***j*** with the index of ***nci***. This connectivity constraint may appear and disappear in the ***nci*** matrix every frequently due to node mobility. A route ***P*** from source, ***s*** to destination, ***t*** is defined as a sequence of intermediate nodes, such that $P(s,\ t) = \{s, \ldots\ i,\ j,\ k,\ l,\ \ldots t\}$ without loop. The connectivity constraint, $\boldsymbol{nci}_{(i,j)}$ associated with node pair is transmission cost. It is specified by the connectivity matrix $C = \lfloor nci_{(i,j)} \rfloor$, where $\boldsymbol{nci}_{(i,j)}$ represents the node pair connectivity index. It is described as follows,

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

The connectivity matrix is built at the source, upon receiving the RREP packets from the destination, after a certain latency period of time known as Route Accumulation Latency. The values keep on changing as the topology changes. The protocol also removes the stale values to ensure that the contents remained current. A connection indicator $L_{i,j}$ mapped the connected nodes forming a chromosome. L_{ij} provides the information on whether the link from node i to node j is included in the routing path. It is defined as follows,

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

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

$$N_k = \begin{cases} 1, & if\ node\ N_k \in\ \ route. \\ 0, & \ldots\ldots\ldots\ldots\ if\ otherwise. \end{cases}$$

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

$$C_{sum\,(S,T)} = \sum_{i=S}^{T} \sum_{\substack{j=S \\ j \neq i}}^{T} C_{ij} \cdot L_{ij}$$

The sum of ***nci*** of the route $P(\ s,\ t\ )$ constitute the "cost" of the packet transmission process. In this approach, the "cost" of transmission is due to the lifetime of the node pair connection. The longer the connectivity lifetime, the lower the "cost" of the route is. The node pair connectivity index indicates the estimated length of time a given node pair was in connection. The most important features of ***nci*** are the velocity and position of a node with respect to the other was already inherently considered. The index ***nci*** is a numerical value which represents connectivity time of a node pair. A node has longer connectivity time if its ***nci*** is smaller than the other node pair. Large value of ***nci***, indicate low connectivity between the node pair. The GA algorithm will minimise the sum of node connectivity index of the route, $C_{sum(S,T)}$, subject to the following constraints,

(i) that it must avoid looping. This constraint ensures that the computed result is indeed an existing path and without loops between a source, S and a designated destination, T such that,

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

(ii) that the packet transmission can accommodate the available node bandwidth. This constraint ensures that the node bandwidth, $N_{BW(\ i\ )}$

$$N_{BW(i)} \geq B_{FLOW}$$

$$B_{FLOW} \leq \min(B_s, \cdots, B_i, B_j, \cdots B_t)$$

where $\boldsymbol{B_{FLOW}}$ is the bandwidth of the transmitted message. The node bandwidth must be greater than the demand bandwidth. Generally, for QoS operation to be effective, we have to consider the bandwidth available for the node in question. Since we are dealing with the shared medium, 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 $\boldsymbol{N_{BW\ (\ i\ )AVAILABLE}}$ and $\boldsymbol{N_{BW(\ i\ )CONSUMED}}$, for the node concern. The mechanism for calculating the node bandwidth was outlined in our previous paper. [12]

(iii) that the total delay must be less than the specified delay.

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

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

7. GA-BASED QOS ROUTE SELECTION

7.1 The Design of QOSRGA

QoS routing is a key MANET function for the transmission and distribution of multimedia services. It has two objectives; (1) finding routes that satisfy QoS constraints and, (2) making efficient use of limited resources. The complexity involved in the MANET may require the considerations of multiple objectives simultaneously for routing decision process. We proposed QOSRGA, QoS routing using GA for MANET as single and multiple objectives optimization. The proposed GA technique which is based on source routing, effectively select the most viable routes in terms of bandwidth availability, end-to-end delay, media access delay and the sum of ***nci***. The Non-Disjoint Multiple Routes Discovery(NDMRP) algorithm initially determined a number of potential routes. The returning RREP packets extract the QoS parameters from each node along the routes. GA then operates on this set of routes and the corresponding set of QoS parameters. In our approach the encoding process utilised variable-length chromosomes [9] to represent the $S \rightarrow T$ routes. Each chromosome consists of genes representing the nodes. The crossover operation exchanges partial chromosomes at a random crossing site. Similarly, mutation produces new partial chromosomes into the population of potential solutions. Any infeasible chromosomes were eliminated. All corresponding QoS parameters were then operated by fitness function producing the best QoS route. These triple operations of crossover, mutation and fitness function produced a good quality of route.

7.2 GA-based QoS Route Selection Procedure

The overall function of GA-based QoS route selection is shown in Figure 4. The following steps shows the computational aspect of developing this protocol.

Step 1: A route from source to destination is represented as variable length chromosomes and the nodes within the route as genes. In our procedure the initial routes were not generated randomly, but obtained from the result of NDMRP protocol. By using this approach, we have eliminated most of the infeasible chromosomes.

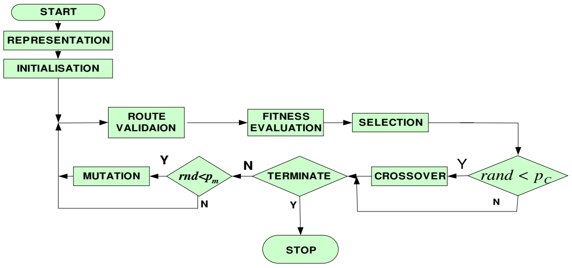

Figure 4 Flow Diagram of GA Process

Step 2: Generate an initial population of chromosomes of size ***k***, from an input matrix ***R*** of routes from source to destination. Matrix ***R*** is of dimension [***m*** x ***k***]. In this case ***m*** is the population size with even value and ***k*** is the number of columns. For each chromosome, the length ***n***, differs, such that $0 \leq n \leq k$.

Step 3: From the matrix ***R***, a node connection matrix ***L***, and node connectivity matrix ***C***, is generated. Node connection matrix ***L,*** provides instantaneous information regarding the state of the network whether it is connected, a ' 1 ' or unconnected, a '0'. Node connectivity matrix ***C***, consists of the node pair connectivity index ***nci***, which indicates the state of node connectivity. The other two matrices generated is the bandwidth matrix ***B,*** and delay matrix ***D***.

Step 5: Route validation and loop free check ensures that the chromosome that is infeasible is further removed.

Step 6: Evaluate the fitness of each chromosome using the fitness functions described below. The fitness function depends on the ***nci***, the end-to-end delay, node delay and node bandwidth.

Step 7: Operate the GA operator on matrix **R**. The operators are the selection function, the crossover function and the mutation function. Additionally the crossover and mutation function depends on the crossover rate, p_c and mutation rate, p_m..

Step 8: Repeat for a number of generations up to 20 or when the solution converged.

7.3 Fitness Computation

Fitness calculation is most crucial in the GA operation, to identify the best route. In our case the least value of fitness constitute the lowest cost and the one that is to be chosen. The fitness value of routes is based on various QoS parameters; bandwidth, node delay, end to end delay and the node connectivity index, ***nci***. Clearly it can be classified as multiple-objectives optimization problem. According to [8], each objective function can be assigned a weight and then the weighted objectives combined into a single objective function. For our MANET QoS routing protocol, the weighted-sum approach can be represented as follows. The fitness function operates to minimize the weighted-sum F, which is given as,

$F = \alpha.F_1 + \beta.F_2 + \gamma.F_3$, where,

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

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

(c)
$$F_3 = \begin{cases} 1/B_i & if \quad B_i - B_{QOS} > 0 \\ 1000 & if \quad B_i - B_{QOS} \leq 0 \end{cases} .;$$

(d) the weight α , β and γ are interpreted as the relative emphasis of one objective as compared to the others. The values of α , β and γ are then chosen to increase the selection pressure on any of the three objective functions.

The fitness function is a weighting function [8] that measures the quality of a specific node state. A fitness function must include and correctly represent all or at least the most important parameters that affect QoS Routing. Having described these parameters, which are the bandwidth, ***nci***, medium access delay and end to end delay, the next issue is the decision on the importance of each parameter on the QoS Routing protocol as a whole. The significance of each parameter is defined by setting appropriate weighting coefficients to α , β and γ in the fitness function that will be minimized by the GA operations. The values of these coefficients were determined based on their equal importance towards the overall QoS Routing performance. The values are $\alpha = 10^{-3}$, $\beta = 10^{-4}$ and $\gamma = 10^{-3}$.

Concerning the function which involved bandwidth, we need to find the minimum bandwidth among the nodes and compare this with the demand bandwidth, $\boldsymbol{B_{QOS}}$. If the minimum bandwidth is less than the $\boldsymbol{B_{QOS}}$, we set the fitness to a high value so that in the selection process it will be eliminated. By doing so we have simultaneously eliminated all the nodes where the bandwidth is limited, the total delay is more than the typical delay and when the node pair connectivity index is high.

8. PERFORMANCE EVALUATIONS

8.1 Performance Metrics

The following metrics [11] are used in scenarios where we vary the velocity to compare QOSRGA with DSR:

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

$$APDR = \frac{\sum_{1}^{TOTAL\ NUM\ NODES} Average\ Number\ of\ Packet Arrived\ at\ Nodes\ Upper\ Layer}{\sum_{1}^{TOTAL\ NUM\ NODES} Average\ Number\ of\ Packet\ Generated\ in\ The\ Nodes\ Upper\ Layer}$$

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

$$ATETED = \frac{\sum_{\forall\ DELIVERED\ PACKETS} (Time\ Of\ Packet\ Arrival_{DESTINATION} - Time\ Of\ Packet\ Sent_{SOURCE})}{\sum_{1}^{TOTAL\ NUM\ NODE} Number\ of\ Packets\ Delivered}$$

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

$$TAT = \sum_{1}^{TOTAL\ NUM\ NODE} \left(\frac{Total\ Number of\ Packets\ Delivered to This\ Node}{Time Taken\ To\ Deliver These\ Packets} \right)$$

8.2 Impact of Node Mobility on Performances

The simulation experiments is done using OPNET Modeler. We vary the velocity for 40 nodes network and 10 CBR sources. The mobility was varied to see how it affects the different metrics that are measured. The packet sending rate is fixed at two rates; 98 pkts/sec (400 kbps) and 4 pkts/sec (20kbps). The simulations were run with uniform velocity where the maximum velocities are 0.5, 1, 1.5, 2, 5, 10, 15, 20, and 25 m/s. In our simulations we limit the velocity up to 25 m/s, since the analysis in Section suggested that the upper bound on the velocity is limited up to 25 m/s which is equivalent to 90 km/h, in order to successfully maintained node connectivity. In most literatures, pause time was used instead of velocity. Each data point is obtained after 10 runs with different seed values for the random number generator.

8.3 Results and Analysis

8.3.1 Average Packet Delivery Ratio

The graph of Average Packet Delivery Ratio against node maximum velocity is shown in Figure 5 Two set of results are obtained, one for CBR sources 4 pkt/s and the other for 98 packets/sec. Consider the 4 packets/sec sources. By comparing QOSRGA and BE-DSR, QOSRGA produced a slightly better APDR. When the mobility is less than 12 m/s, QOSRGA shows a similar reading. When node mobility is more than 12 m/s QOSRGA performed better, in fact 5% better than BE-DSR. For high bandwidth sources of 98 pkt/s, clearly QOSRGA consistently performed better than BE-DSR for all the mobility ranges. Generally, it's 5% to 30% better than BE-DSR. In QOSRGA, it accumulated multiple routes and the corresponding QOS metrics information $\boldsymbol{B}_{\mathrm{AVA}}$, $\boldsymbol{D}_{\mathrm{ETE}}$, $\boldsymbol{D}_{\mathrm{MAC}}$ and ***nci***. The selection of the routes is based on 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 packet back to the source, because of route caching mechanism of DSR. But that routes overlap the existing routes hence resulted in severe congestion and cannot deliver packets along the route. Moreover the stale routes produce a reply to source with invalid routes. Ultimately, many packets dropped resulting poor DSR performance. In QOSRGA, aging mechanism is used, hence the stale routes always been replaced.

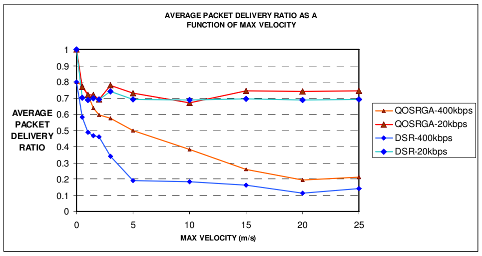

Figure 5 Average Packet Delivery Ratio vs Velocity

8.3.2 Average End to End Delay of Data Packets

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) routes 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; (3) the length of routing path. More hops means longer time it takes to reach its destination node. Figure 6 depicts the variation of the average end-to-end delay as a function of velocity of nodes. It can be seen that the general trend of all curves is an increase in delay with the increase of velocity of nodes. The reason is mainly that high mobility of nodes results in an increased probability of link failure that causes an increase in the number of routing rediscovery processes. This makes data packets have to wait for more time in its queue until a new routing path is found. The delay of BE-DSR is better than

QOSRGA for 98 packets/sec source data. When the source sent 4 packet/sec BE-DSR is better than QOSRGA. When the velocity is more than 5 m/s, the delay in all protocols is maintained at almost the same level. QOSRGA performed badly. This is obvious since, QOSRGA was designed to collect as much information about the network as possible, so that the process of route selection using GA is done based on these imprecise information. But all the delays incurred by QOSRGA are still less than 0.1s which is the delay bound for multimedia signals. This is because availability of node non-disjoint routing paths in QOSRGA eliminates route discovery latency that contributes to the delay when active route fails. In addition, when a congestion occurs in a routing path, the source node can distribute incoming data packets to the other non-disjoint routing paths to avoid congestion. This reduces the waiting time of data packets in queue.

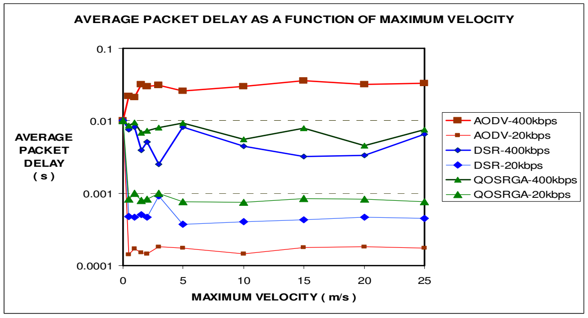

Figure 6 Average End to End Packet Delay

8.3.3 Average Total Throughput

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

9. CONCLUSIONS

In this paper, we have introduced a notion of node pair connectivity in the form of ***nci***. It represents a measure of connectivity and indicates how long the next hop connection would be. We utilized ***nci*** as one of the fitness variable within the GA techniques for QoS route selection. GA will always select a chromosome where the sum of ***nci*** is the least. We compared QOSRGA protocol and BE-DSR whereby we concluded that QOSRGA had a potential as one of the viable QoS routing protocol.

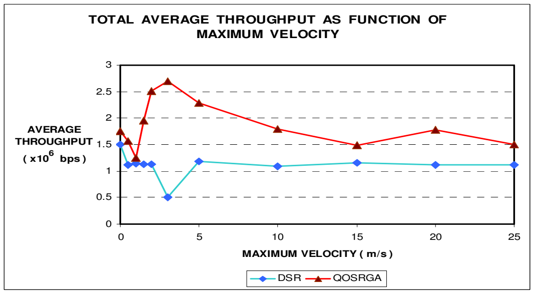

Figure 7 Total Average Throughput

10. ACKNOWLEDGMENTS

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