Special report

Multiple constraints QoS multicast routing optimization algorithm in MANET based on GA

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Abstract

Usually multiple quality of service (QoS) guarantees are required in most multicast applications. This paper presents a multiple constraints algorithm for multicast traffic engineering in mobile ad hoc networks (MANET). The proposed algorithm is a new version of multiple constraints QoS multicast routing optimization algorithm in MANET based on genetic algorithm (MQMGA). The proposed MQMGA can optimize the maximum link utilization, the cost of the multicast tree, the selection of the long-life path, the average delay and the maximum end-to-end delay. Experimental result shows that the approach is efficient, has promising performance in multicast traffic engineering and for evaluating the route stability in dynamic mobile networks.

Keywords: Ad hoc network; Multicast routing; QoS; Genetic algorithm

1. Introduction

A mobile ad hoc network (MANET) is an autonomous system of mobile nodes connected by wireless links. However, there is no static infrastructure, such as base station, as it is in cell mobile communication. In ad hoc network, if two nodes are not within the radio range, all message communication between them must pass through one or more intermediate nodes. All the nodes are free to move around randomly, thus changing the network topology dynamically [1–11]. They are useful in many situations such as military applications, conferences, emergency search, rescue operations and law enforcement. However, the network topology is unpredictable due to mobility of nodes and the limited available bandwidth. These characteristics require a new way of designing and operating this type of networks. Moreover, for such networks, an effective routing protocol adapting to node mobility as well as possible channel error is critical to provide a feasible path for data transmission [1–9].

Multicast is simultaneous data transmission from a source node to a subset of destination nodes in a computer network. Multicasting can reduce the communication cost for sending the same data to many recipients [1,2,4–6,10–15]. Instead of sending via multiple unicast, multicast reduces the channel bandwidth, sender and router processing and delivery delay. In addition, multicast gives robust communication even if the receiver address is unknown or modifiable without the knowledge of the source within the wireless environment.

In the multicast routing problems, a good routing algorithm finds low-cost tree connecting all of the routers that
have attached host members of multicast group and then routes packet along this tree from a source to multiple destinations according to the multicast routing tree [1–4,6,10–15]. Finding the link tree with the minimum cost is known as the Steiner tree problem in graph theory [1,5]. These approaches can be classified into two categories: group-shared tree, where only a single routing tree is constructed for the entire multicasting group, and source-based tree, where a tree is constructed for each individual sender in the group. In general, the former is efficient for large-scale stable networks; and the latter is useful for small-scale dynamic networks. Due to the increasing importance of wireless networks, the source-based tree approach appears to be more attractive. Moreover, multicast routing problems consist of a single QoS constraint [4–6,9,10,13,14,16] or multiple QoS constraints [6,9,11–13]. In wireless networks, multiple-QoS scenario is more promising.

Entropy [17,18] presents the uncertainty and is a measure of disorder in a system. There are some common characteristics among self-organization, entropy, and the location uncertainty in mobile ad hoc wireless networks. These common characteristics have motivated our work in developing an analytical modeling framework using entropy concepts and utilizing mobility information as the corresponding variable features, in order to support route stability in self-organizing mobile ad hoc wireless networks. The corresponding methodology, results and observations can be used by the routing protocols to select the most stable route between a source and a destination in an environment where multiple paths are available, as well as create a convenient performance measure for the evaluation of the stability and connectivity in mobile ad hoc networks.

Considering that genetic algorithms (GA) are suitable for multiple constraints optimization problems [1,6,11–14]. We will present a multiple constraints algorithm for multicast traffic engineering in MANET in this paper. The proposed algorithm is a new version of multiple constraints QoS multicast routing optimization algorithm in MANET based on GA (MQMGA). Results show that the proposed MQMGA can optimize the maximum link utilization, the cost of the multicast tree, the selection of the long-life path, the averages delay and the maximum end-to-end delay.

2. Network model and routing issues

A network is usually represented as a weighted digraph $G = (N, E)$, where $N$ denotes the set of nodes and $E$ denotes the set of communication links connecting the nodes. $|N|$ and $|E|$ denote the number of nodes and links in the network, respectively. Without loss of generality, only digraphs are considered in which there exists at most one link between a pair of ordered nodes.

In $G(N, E)$, considering a QoS constrained multicast routing problem from a source node to multi-destination nodes, namely given a non-empty set $M = \{s, u_1, u_2, \ldots, u_m\}$, $M \subseteq N$, $s$ is the source node, $U = \{u_1, u_2, \ldots, u_m\}$ is a set of destination nodes. In multicast tree $T = (N_T, E_T)$, where $N_T \subseteq N$, $E_T \subseteq E$, if $C(T)$ is the cost of $T$, i.e.

**Definition 1.** The delay of path $p(s, u)$ and the cost of path $p(s, u)$ are

$$D_{p(s,u)} = \sum_{(i,j) \in p(s,u)} d_{ij}$$  \hspace{1cm} (1)

$$C_{p(s,u)} = \sum_{(i,j) \in p(s,u)} c_{ij}$$  \hspace{1cm} (2)

$$B_{p(s,u)} = \min_{(i,j) \in p(s,u)} \{b_{ij}\}$$  \hspace{1cm} (3)

where $d_{ij}$ is the delay of link $(i,j)$, $c_{ij}$ is the cost of link $(i,j)$, $b_{ij}$ is the bandwidth of link $(i,j)$, and $p(s,u)$ is the path from source node $s$ to destination node $u \in U$.

**Definition 2.** The maximum link utilization of tree $T$ is

$$x_m = \max_{(i,j) \in T} \left(\frac{\phi + t_{ij}}{z_{ij}}\right).$$  \hspace{1cm} (4)

where $\phi$ is the traffic demand, $t_{ij}$ is the current traffic of link $(i,j)$, and $z_{ij}$ is the capacity of link $(i,j)$.

**Definition 3.** The cost of multicast tree $T$ is

$$C(T_s) = \sum_{u \in U} C_{p(s,u)}$$  \hspace{1cm} (5)

**Definition 4.** The maximum end-to-end delay of multicast tree $T$ is

$$D_s = \max_{u \in U} \{D_{p(s,u)}\}$$  \hspace{1cm} (6)

**Definition 5.** The bandwidth of multicast tree $T$ is the minimum value of the link bandwidth in the path from source node $s$ to each destination node $u \in U$. i.e.

$$B_s = \min_{u \in U} \{B_{p(s,u)}\}$$  \hspace{1cm} (7)

**Definition 6.** Assume the minimum bandwidth constraint of multicast tree is $B$, the maximum end-to-end delay constraint of multicast tree is $D_s$, given a multicast demand $R$, then the problem of bandwidth, and delay constrained multicast routing is to find a multicast tree $T$, satisfying:

(i) Bandwidth constraint: $B_s \geq B$;

(ii) end-to-end delay constraint: $D_s \leq D$;

(iii) link capacity constraint: $(\phi + t_{ij})/z_{ij} \leq 1$, $\forall (i,j) \in T$.

Suppose $S(R)$ is the set, $S(R)$ satisfies the conditions above, then the multicast tree $T$ which we find is

$$C(T) = \min(C(T_s), T_s \in S(R))$$  \hspace{1cm} (8)
3. Genetic optimization approach

Genetic algorithms are based on the mechanics of natural evolution. Throughout their artificial evolution, successive generations each consisting of a population of possible solutions, called individuals, search for beneficial adaptations to solve the given problem. Mobile ad hoc networks are typically designed and evaluated in generic simulation environments. Genetic algorithms are robust and efficient for global optimization search in complex space.

3.1. Genetic coding for spanning trees

Encoding trees is very important in genetic algorithms for solving tree graph optimization problems because each code should represent a tree. The chromosomes of genetic algorithms are composed of a series of integral queuing and the encoding method based on routing representation, which is the most natural and simplest representing method. Given a source node  and destination nodes set \( U = \{u_1, u_2, \ldots, u_m\} \), a chromosome can be represented by a string of integers with length  \( m \). Fig. 1 shows an example of the proposed encoding method. The first locus in each chromosome is assigned by the source node set to be ‘1’. Each multicast tree extends the source to the set of destinations  \( U = \{4, 5, 7, 9\} \). The routing paths in the example are expressed as follows: the first path is \( (1 \rightarrow 2 \rightarrow 3 \rightarrow 4) \), the second path is \( (1 \rightarrow 2 \rightarrow 3 \rightarrow 5) \), the third path is \( (1 \rightarrow 6 \rightarrow 7) \), and the last path is \( (1 \rightarrow 6 \rightarrow 8 \rightarrow 9) \).

3.2. Fitness function

We also associate each node  with a set of variable features denoted by  \( a_{m,n} \) where node  \( n \) is a neighbor of node  \( m \). Any change of the system can be described as a change of variable values  \( a_{m,n} \) in the course of time  \( t \) such as  \( a_{m,n}(t) \rightarrow a_{m,n}(t+\Delta t) \). Let us denote by  \( v(m, t) \) the velocity vector of node  \( m \) and by  \( v(n, t) \) the velocity vector of node  \( n \) at time  \( t \). The relative velocity  \( v(m, n, t) \) between nodes  \( m \) and  \( n \) at time  \( t \) is defined as  \( v(m, n, t) = v(m, t) - v(n, t) \). Let us also denote by  \( p(m, t) \) the position vector of node  \( m \) and by  \( p(n, t) \) the position vector of node  \( n \) at time  \( t \). The relative position  \( p(m, n, t) \) between nodes  \( m \) and  \( n \) at time  \( t \) is defined as  \( p(m, n, t) = p(m, t) - p(n, t) \). Then, the relative mobility between any pair \( (m, n) \) of nodes during some time interval is defined as their absolute relative speed and position averaged over time. Therefore, we have

\[
a_{m,n} = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{p(m, n, t_i) + v(m, n, t_i) \times \Delta t_i}{R} \right| - \left| p(m, n, t_{i+1}) \right|
\]

where  \( N \) is the number of discrete times  \( t_i \) that the velocity information can be calculated and disseminated to other neighboring nodes within the time interval  \( \Delta t \), and  \( R \) is the radio range of nodes. Based on this, we can define the entropy  \( H_m(t, \Delta t) \) at mobile during the time interval  \( \Delta t \). The entropy can be defined either within the whole neighboring range of node, or for any subset of neighboring nodes of interest. In general, the entropy  \( H_m(t, \Delta t) \) at mobile is calculated as follows:

\[
H_m(t, \Delta t) = -\sum_{k \in F_m} P_k(t, \Delta t) \log P_k(t, \Delta t) / \log C(F_m),
\]

where  \( P_k(t, \Delta t) = \left( \frac{a_{m,k}}{\sum_{i=0}^{N} a_{m,i}} \right) \).

In Eq. (10) we denote by  \( F_m \) the set of the neighboring nodes of node  \( m \), and by  \( C(F_m) \) the cardinality of set  \( F_m \). As can be observed from Eq. (9), the entropy  \( H_m(t, \Delta t) \) is normalized so that  \( 0 \leq H_m(t, \Delta t) \leq 1 \) \([17,18]\). Let us present the route stability between two nodes  \( s \) and  \( u \) during some interval  \( \Delta t \) as route stability. We also define and evaluate two different measures to estimate and quantify end to end route stability, denoted by  \( F(s, u) \) and defined as follows, respectively:

\[
F(s, u) = -\sum_{i=1}^{N_s} \ln H_i(t, \Delta t),
\]

where  \( N_s \) denotes the number of intermediate mobile nodes over a route between the two end nodes  \( (s, u) \). We are computing  \( F(s, u) \), and queuing it from the smallest to the biggest, namely,  \( F(s, u_1) \leq F(s, u_2) \leq \ldots \leq F(s, u_m) \), and then the minimum value is the best stability path.

3.3. Selection operations

Selection operation is used to certain or crossover individuals and the selected individual can produce many sub-individuals. Selection operation has two procedures: firstly, computing fitness value, secondly, queuing it from the smallest to the biggest, namely,  \( F(s, u_1) \leq F(s, u_2) \leq \ldots \leq F(s, u_m) \). Then, the minimum fitness value is the best individual. Selecting the best individual as father-individual, the selection probability of each individual is proportional to its fitness value, and the selected probability is higher when the individual fitness value is bigger. If the same chro-
mosomes have been obtained, only one chromosome exists. The rest chromosomes can be canceled.

3.4. Crossover and mutation operator

The genetic algorithm explores all the search space altering the selected components of genetic operators (crossover, mutation) that form new components to be evaluated. MQMGA uses conventional one-point crossover to exchange the chromosomes of the parents. The mutation in MQMGA is performed by selecting a gene at random and replacing it with another random integer between 1 and \( m \). Chromosomes after these operations remain legal Prüfer numbers [11–14]. The crossover operation is governed by crossover probability \( p_c \) and the mutation operation by mutation probability \( p_m \).

In the proposed scheme, two chromosomes chosen for crossover should have at least one common gene (node), but there is no requirement that they be located at the same locus. That is to say, the crossover does not depend on the position of nodes in routing paths. Fig. 2 shows an example of the crossover procedure.

Generally, crossover operation yields illegal offspring on permutation representation in the sense that some nodes may lose while some nodes may duplicate in the offspring. Then repairing procedure is needed to resolve the illegitimacy of offspring [1,11–14]. The topology mutation process is illustrated in Fig. 3.

3.5. Topology repair

The topology repair treats infeasible chromosomes containing lethal genes that possibly form a loop. Often, they are occurred by variation operator (i.e. crossover and mutation). It means that the tree condition is violated, and thus it needs to fix. Note that no chromosome (in the initial population) is infeasible. And note that all the chromosomes regardless of their validity satisfy the QoS constraints because they have already been taken into consideration. Thus, the proposed topology repair always returns better constraint conditions. The proposed method is exhibited in Fig. 4.

4. Simulation experiments

4.1. Simulation model

To conduct the simulation studies, we have used the randomly generated networks on which the algorithms were executed. This ensures that the simulation results are independent of the characteristics of any particular network topology. Using randomly generated network topologies also provide the necessary flexibility to tune various network parameters such as average degree, number of nodes, and number of edges, and to study the effect of these parameters on the performance of the algorithms [19].

Our simulation modeled a network of mobile nodes placed randomly within a 1000 \( \times \) 1000 m area. Radio propagation range for each node of 250 m and channel capacity of 2 Mbps were chosen. There were no network partitions throughout the simulation. Each simulation time was 600 s. Multiple runs with different seed values were conducted for each scenario and collected data were aver-

| Table 1 |
| Simulation parameters |
| Number of nodes | 100 |
| Terrain range | 1000 \( \times \) 1000 m |
| Transmission range | 250 m |
| Speed | 0–10 m/s |
| Node placement | Random, uniform |
| Mobility model | Random way point |
| Propagation model | Free space |
| Channel bandwidth | 2 Mbps |
| Traffic demand | 0.4 Mbps |
| Examined routing protocol | ADMR |
aged over those runs. Table 1 lists the simulation parameters which are used as default values unless otherwise specified. A free space propagation model was used in our experiments. A traffic generator was developed to simulate CBR sources. Each source transmits data packets at a minimum rate of 4 packets/s and a maximum rate of 10 packets/s.

4.2. Simulation results

In order to evaluate the performances of our genetic optimization approach, we simulate the proposed mechanisms using OPNET [20] extended by a complete implementation of IEEE 802.11.

Fig. 5 compares the cost to control information of Cui’s algorithm [6] and MQMGA. We can see that MQMGA’s cost is smaller than that of Cui’s algorithm with the increasing of the scale of the network by extending QoS constraints into Cui’s algorithm, the cost to control information is also increased. But for MQMGA, the growth of cost to control information is lower, and so MQMGA will not incur the flooding storm. Due to the scarcity of wireless ad hoc network resource, MQMGA has apparent advantages in solving ad hoc network multicast routing problems.

Fig. 6 gives a comparison of number of route reconstructions against mobility between Cui’s algorithm and MQMGA. Whenever path error occurs, route reconstruction is needed, and the route number of reconstructions characterizes the route’s stability to some extent. From Fig. 6 we can see that the time of route reconstructions for MQMGA is superior and more stable.

Figs. 7 and 8 compare the success rate to find the path and the data transmission rate under nodes’ changing movement speed for Cui’s algorithm and MQMGA. From Figs. 7 and 8 we can see that when the movement speed of the node increases, the success rate and data transmission rate of MQMGA are still higher than that of Cui’s algorithm, due to the fact that when the movement speed increases for the nodes, the network’s topology structure changes faster. The reason is that QoS multicast tree can select the most stable multicast routing between source node and destination node.

5. Conclusions

We have presented a multiple constraints algorithm for multicast traffic engineering in MANET. The proposed algorithm is a new version of multiple constraints QoS multicast routing optimization algorithm in MANET based on GA (MQMGA). The proposed MQMGA optimizes the maximum link utilization, the cost of the multicast tree, the selection of the long-life path, and the average delay and the maximum end-to-end delay. The performance evaluation of our proposed methods is accomplished via modeling and simulation. The simulation results demonstrate that the proposed approach is an accurate and efficient method for estimating and evaluating the route stability in dynamic mobile networks.

Although the proposed GA provides a conservative tool to solve multicast routing problems with diverse QoS con-
straints in MANET, further elaboration on generalizing
the idea is required.

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