Applying Genetic Algorithm for Optimizing Broadcasting Process in Ad-hoc Network

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Abstract— Optimizing broadcasting process in mobile ad hoc network (MANET) is considered as a main challenge due to many problems, such as Broadcast Storm problem and high complexity in finding the optimal tree resulting in an NP-hard problem. Straight forward techniques like simple flooding give rise to Broadcast Storm problem with a high probability. In this work, genetic algorithm (GA) that searches over a population that represents a distinguishable ‘structure’ is adopted innovatively to suit MANETs. The novelty of the GA technique adopted here to provide the means to tackle this MANET problem lies mainly on the proposed method of searching for a structure of a suitable spanning tree that can be optimized, in order to meet the performance indices related to the broadcasting problem. In other words, the proposed genetic model (GM) evolves with the structure of random trees (individuals) ‘genetically’ generated using rules that are devised specifically to capture MANET behaviour in order to arrive at a minimal spanning tree that satisfies certain fitness function. Also, the model has the ability to give different solutions depending on the main factors specified such as, ‘time’ (or speed) in certain situations and ‘reachability’ in certain others.

Index Terms — MANET, Network, Genetic Algorithm, Optimisatoin, Spanning Tree.

I. INTRODUCTION

A mobile ad hoc network (MANET) is an independent system mobile host (any host can be a router) created on the fly, and connected by wireless links in the absence of a fixed wired infrastructure. The union of these models constitute a communication network formed as a model of an arbitrary communication graph. In MANET, all hosts can move freely without any limitations through the network, where each node can communicate directly with other neighbour nodes within the range of transmission. Generally, successful routing protocols provide devices to send packets to destination nodes with dynamic topologies [1][2][3][4].

Broadcasting MANET is more complex than normal broadcasting in wired network because the nature of MANET is quite different from wired networks. When each host sends a particular message, this message will be received by all its neighbours within a radius range. This is due to the multi-hop structure, dynamic mobility, and decentralized network with no wired link that connects the hosts. The data broadcasting in MANET is important to study, as it is the main method of information distribution in many applications, such as sending an alarm signal to all hosts [5].

Many algorithms are proposed for optimizing broadcast tree and to avoid the problems of redundancy, contention and collision or what is called Broadcast Storm problem. Starting from simplest technique like simple flooding to the most complex technique like minimum spanning tree (MST), it is observed from theory that the minimum spanning tree (MST) [13] could be considered as the best solution. But this solution is not practical due to the high complexity in computing MST and it could result in a NP-hard problem. Therefore, applying this solution is not feasible even with some research studies making some restrictions, such as redesigning central nodes to respond to rebroadcast messages. On the other hand, genetic algorithm (GA) is considered as an attractive solution to tackle a problem that has high complexity and requires optimization. Hence, in this work, a new model based on genetic algorithm to find minimal broadcast tree in MANET with reasonable time has been proposed. Also, this proposed model has the ability to give different solutions according to the main factor for optimization in the network, such as ‘time’ (or speed) in most situations and ‘reachability’ in some other situations.

II. BACKGROUND

Traditionally, simple flooding [6] is considered as a straightforward technique as there is no need for any complex computations. It is easy to implement and is characterized by high reliability. However, this technique harms the resources of the network, such as bandwidth and energy supplies because it suffers from serious problems such as redundancy, contention and collision (also termed as Broadcast Storm problem) due to huge number of retransmitted messages. Hence, this technique has not been used widely, though it could be considered appropriate for some type of mobile networks, especially when the network has high density and mobility, or in some situations where reachability is the main goal as is the case in battlefield survivability [8].

Many algorithms are proposed for optimizing broadcast process in MANET. Williams et al. [9] presented models to
predict retransmission frequency for three protocols, namely Probability Based Scheme, Area Based Scheme and Counter Based Scheme. Chen et al. [10] proposed a way to minimize the number of clusters by combining two known approaches into a new single clustering method that uses connectivity as the primary and lower ID as the secondary criteria, while choosing clusterheads. Some researches, such as Lipman et al in [11], have tried to find minimal spanning tree. They have realized the complexity involved in finding minimum flood tree that has minimum hops. Instead, their proposal uses Localized Minimum Spanning Tree Flooding (LMSTFlood) to reduce redundancy, consumption of energy and average transmission distance. Lim and Kim [12] studied problems of finding minimum flood tree that has minimum hops in great detail, and concluded that the complexity of finding minimum flood tree with minimum hops is an NP-hard problem.

### III. SPANNING TREE TECHNIQUE TECHNIQUES

In the normal static situations, MST does not cause NP-hard problem and can be solved by any simple algorithm, such as the Prim’s algorithm [13]. However, when trying to optimize two or more parameters, or when the cost varies dynamically in MST, complex computations are required, which may lead to NP-hard problem. A typical example of a NP-hard problem is the k-hop minimum spanning tree (K-MST) problem [14], and main types of such spanning trees have been explained by Eppstein [15].

Constructing a source tree needs high attention and it is changed according to what is required to be found, namely, minimum hops, or minimum flood, or even a compromise between them (minimum broadcast tree). Lauer [16] constructed a single source tree depending on the reverse path-forwarding scheme. Richard and Ogier [17] proposed a new protocol called TBRPF to construct reliable multiple source tree that uses the concept of reverse-path forwarding (RPF). The problem in these two techniques is that they have concentrated on minimum hops only, and have not considered the importance of minimum flood.

Indeed, finding a compromise between minimum hops and minimum flood requires a non-aligned treatment of one aspect without compromising with the other, and this means that a random process to construct a source tree, and then a method to develop the cost of tree should be found.

On the other hand, evolutionary algorithms have proved highly efficient in dealing with complex computations that have resulted in NP-hard problems. Knowles and Corne [18] proposed a new method called randomized primal method (RPM) to solve the problem of finding Degree-Constrained Minimum Spanning Tree (d-MST) by genetic algorithm (GA). Also, other researches like Golden [19] have used the ability of genetic algorithm to solve their problems with MST. Elaiwat & Belal [20] have proposed a new model based on creative design to reach to minimal spanning tree. In general, genetic algorithms and evolutionary algorithms are still new approaches in the area of MST and are not used for all types of MST such as in MANETs. Furthermore, the types of MST are renewed and not limited to fixed group in the case of MANETs. Hence, this research study has adopted GA in the proposed model to address the broadcast problem in MANETs.

### IV. GENETIC MODEL (GM)

As mentioned before, finding a minimal broadcast tree could result in a NP-hard problem. This work has been extended from the previous work reported in [7], where the purpose of this work is to improve further and propose a suitable and efficient model that has the ability to find a minimal broadcast tree within reasonable time, thereby making the solution feasible in real-time. The network graph is the input of the model, and a minimal broadcast tree would be the output. The GM gets the network graph dynamically and applies GA operations on it to produce minimal broadcast tree that determines the track of the broadcasting process to be followed. Figure 1 illustrates the GM components of the model.

The GM components contain phenotypes, genotypes, performance to measure the performance of the network, and GA operations that are required to evolve with the structure of the networks. In this model, source tree (phenotype) will be represented as adjacency matrix (genotype), where genes here are cells in the matrix that require one change in adjacency matrix to make it ready. The root node is specified by adding one along the diagonal cells that intersect with its row.
We provide a set novel GA operations based on the inherent characteristics and constraints of MANETs. These operations are, selection, crossover, mutation and reinsertion and in each of these operations the MANET behaviour is captured successfully. These operations are described below with an example MANET.

A. Selection

The proposed model will use Roulette Wheel Selection as it is a simple technique and at the same time gives the needed cover for all the demands of the proposed system.

B. Crossover

Crossover operation between two parents must be between nodes of the same name, and could be applied at any part of the tree. To reflect this in the matrix representation, the steps given below are to be followed:

Step 1 - Make a crossover in the same row number between two individuals, as shown in figure 2.

Step 2 - Find a set of children and descendants so that the chosen row (crossover point) is a parent of them for each individual, as shown in figure 3.

Step 3 - Interchange parts between individuals - figure 4 shows the result of crossover.

Note that the values of row 5 and row 6 have been reset in child two because they have moved to child one. This results in a problem in child one - column four shows that two values are one, with row 1 and row 3. This means that node 4 has two parents, node 1 and node 3, and that does not form a correct tree as it must have only one parent. Hence, it is required to reset one of these values to zero. In this situation, resetting the value in row 3 is better because it is at a higher level than row 1 (node 1 being the root).

C. Mutation

The main role of crossover is to define new children that have mixture of features from parent. But what about small changes or what is called mutation? Mutation is a process that is adopted for making new small changes not related to parents. Mutation operation here can be applied either in parent node or in leaf node. Mutation in the parent node can be done only by adding new child to the parent, while mutation in the leaf node can be done by either adding new child to the leaf node to make it into a parent node, or by deleting that leaf node.

While making mutation by adding new nodes, there are two main rules to be considered. Firstly, this node must not be within the tree. This means that in the matrix, the sum of row and column values should not be 0. Secondly, nodes cannot be added in any manner, as it must be according to network topology. For example, in figure 5, node 3 must be in range of node 4.

D. Reinsertion

After finishing the crossover and mutation steps and arriving at a new generation of offsprings, it must be decided as to which individuals will survive and which will die. According to the fitness function, those individuals with lowest fitness value will die, either from old generation or from new generation, and then both generations are combined with each other. The population size here is fixed and it cannot be increased and therefore the new population contains the best individuals according to the fitness function. Fitness function here has been devised to depend on reachability, redundancy (rebroadcast saving), number of hops and number of intermediates.
VI. EXPERIMENTAL RESULTS

In this work, the proposed GM simulator using Java NetBeans IDE 5.5 has been implemented. As shown in figure 6, the simulator accepts two sets of inputs: 1) environmental parameters such as, number of nodes, their radius, and more importantly the mobility factor for the network, and 2) broadcasting parameters such as, type of broadcasting techniques to be used and the required broadcasting variables. Three techniques, GM (proposed model), simple flooding and minimum spanning tree (MST) have been implemented. All the following results were taken after 50 simulation runs and then the results were averaged where the comparison between the three approaches was done based on the three performance metrics, namely reachability, rebroadcast saving and latency. Figure 7 illustrates that the best reachability results were obtained from the outputs of the simple flooding approaches, since they do not adopt heuristic methods. The proposed model (GM) was relatively rated high for computing reachability as compared to simple flooding and minimum spanning tree. The reachability was computed using formula (1), where \( N_r \) is number of nodes that received messages, while \( N_n \) is the number of nodes in MANET.

\[
\text{Reachability} = \frac{N_r}{N_n} \quad (1)
\]

In figure 8, it is observed that rebroadcast expense of simple flooding is very high, which means that it causes high redundancy in MANET, while minimum spanning tree gives the lowest value for this factor. The GM model is too close to the best one (minimum spanning tree). The factor, rebroadcast expense was computed using formula (2), where \( R_{et} \) is number retransmitted messages and \( N_n \) is the number of nodes in MANET.

\[
\text{RebroadcastExpense} = \frac{R_{et}}{N_n} \quad (2)
\]

Here, latency stands for the execution time of the program for applying a selected approach. It has been established that minimum spanning tree gives the best solution based on reachability and rebroadcast expense factors, but the high complexity of computations (NP-hard problem) makes it take a long time to arrive at an optimal solution. The experimental results have clearly demonstrated the efficiency of the proposed genetic model (GM) as compared to simple flooding algorithm and MST. The simulations show that while reachability of the GM was close to MST and simple flooding, GM outperformed MST with respect to rebroadcast expense and latency factors. It performed quite close to minimum spanning tree in keeping rebroadcast expense very low and relatively close to simple flooding in achieving low latency as well. Our future work entails comparing the proposed GM with other heuristic techniques such as counter based schemes.

VII. CONCLUSIONS AND FUTURE WORK

This work has studied some problems faced by broadcasting process in MANET, such as Broadcast Storm problem on one side and the complexity (NP-hard) on the other that are compromised to reach the best solution. An optimised genetic algorithm using novel GA operations to find minimal broadcast tree without complex computations has been proposed, and at the same time the redundancy of message transmission has been minimised. Recently, GA has been considered as an attractive solution in complex situations like MANET broadcasting problem. Hence, this work has applied GA innovatively to optimize the structure of tree (individuals) and to arrive at minimal broadcast tree as a feasible solution. The experimental results have clearly demonstrated the efficiency of the proposed genetic model (GM) as compared to simple flooding algorithm and MST. The simulations show that while reachability of the GM was close to MST and simple flooding, GM outperformed MST with respect to rebroadcast expense and latency factors. It performed quite close to minimum spanning tree in keeping rebroadcast expense very low and relatively close to simple flooding in achieving low latency as well. Our future work entails comparing the proposed GM with other heuristic techniques such as counter based schemes.
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