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The Shortest-Path Broadcast Problem

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Abstract

Many applications of the communication require a source node to send information to all nodes through a communication network. To support these applications, it is necessary to determine a shortest paths tree of minimal cost to connect the source node to all nodes subject to bandwidth constraint and hop limit on information communication. A genetic algorithm is suitable to solve the presented problem. Therefore, the paper presents a genetic algorithm to solve the minimal cost shortest paths tree problem subject to bandwidth constrained and hop limited. The objective of the proposed algorithm is to search the optimal set of edges connecting all nodes such that the costs is minimized, the bandwidth is constrained and hop is limited. Some examples are provided to illustrate the effectiveness of this algorithm.

Keywords: Computer networks; Broadcast routing, Shortest paths tree; Genetic algorithms.

INTRODUCTION

In computer networks, broadcasting refers to transmitting a packet that will be received by every device in the network [1]. In practice, the scope of the broadcast is limited to a broadcast domain. Broadcasting a message contrasts with unicast addressing in which a host sends datagrams to another single host identified by a unique IP address.

Broadcast is a communication function that a node, called the source, sends messages to all the other nodes in the networks. Broadcast is an important function in applications of ad-hoc networks, such as in cooperative operations, group discussions, and so on. Broadcast routing is finding a broadcast tree, which is rooted from the source and contains all the nodes in the network. The cost of a broadcast is defined as the sum of cost of all the links that transmit the broadcast message in the broadcast tree.

Broadcasting is the process of dissemination of information in an interconnection network, in which the information originated at one node is transmitted to all the other nodes in the network, [11].

The shortest paths tree rooted at vertex s is a spanning tree T of G, such that the path distance from root v to any other vertex u in T is the shortest path distance from v to u in G,[1]. In the case of single link failure, [2], proposed an algorithm to solve the optimal shortest paths tree. When considering multicast tree, [3], the authors presented an algorithm to find the Shortest Best Path Tree (SBPT). Based on labeling techniques, Ziliaskopoulos et al. in [4], proposed an algorithm to solve the shortest path trees. Also, The shortest paths tree problem has been solved by an efficient modified continued pulse coupled neural network (MCPCNN) model, [5].

Heuristic and approximate algorithms for multi-constrained routing (MCR) are not effective in dynamic network environment for real-time applications when the state information of the network is out of date, [6]. The authors in [6] presented a genetic algorithm to solve the MCR problem subject to transmission delay and transmission success ratio. Younes in [7] proposed a genetic algorithm to determine the k shortest paths with bandwidth constraints from a single source node to multiple destinations nodes. Liu et al. in [8] presented an oriented spanning tree (OST) based genetic algorithm (GA) for solving both the multi-criteria shortest path problem (MSPP) and the multi-criteria constrained shortest path problems (MCSPP). Also, in [9] the genetic algorithm is used to find the low-cost multicasting tree with bandwidth and delay constraints.

Shigeo Shioda, [10] proposed a technique for reducing the number of message duplicates during networkwide broadcasting in wired networks. The key feature of his proposal is that each node keeps the information on hop-limited shortest path trees whose roots are within a certain number of hops from each node. When receiving the message, each node generates its duplicates and forwards them to a subset of neighbors, which are on the hop-limited shortest path tree rooted at the message source.

Hovhannes A. Harutyunyan, [11] presented a new heuristic that generates broadcast schemes in arbitrary networks. The heuristic gives optimal broadcast time for ring, tree and grid if the originator is on the corner. Extensive simulations show that our new heuristic outperforms the best-known broadcast algorithms for two different network models representing

Internet and ATM networks. It also allows to generate broadcast time of networks of bigger size because its time complexity, O(|E|), is lower compared to the complexities of the other algorithms.

Younes, [12] presented a minimum delay broadcast routing scheme based on spanning tree algorithm. He presented a genetic algorithm to find the broadcast routing tree of a given network in terms of its links for using it to solve this problem. The algorithm uses the connection matrix of a given network to find the spanning trees, and also is based on the weight of the links to obtain the minimum spanning tree.

The broadcasting tree is a spanning tree if we consider each device a node and each connection as an edge. In [13] the authors analyzed the shortest-path broadcast problem in graphs and digraphs, after proving the NP-hardness of the problem.

The paper presents a genetic algorithm to solve the minimum broadcast tree problem with bandwidth constraint and hop limits. For any link, we define a three-degree vector C_{ij}, B_{ij}, and H_{ij}. where three metrics C_{ij}, B_{ij}, and H_{ij} denote cost, bandwidth, and the number of hop, respectively. Also, given the source (root) node s, then the genetic operations are executed to search the minimum cost paths that construct the minimum cost broadcast tree with bandwidth constrained and hop limited rooted at the source node s.

The rest of the paper is organized as follows: Section 2 presents notations. The problem description in section 3. The connectivity of the netork and path is presented in section 4. Section 5, presents the fitness function. The proposed GA and its components are given in section 6. Section 7 provides the pseudo code of the entire GA. Section 8 shows the illustrative examples. Finally, section 9 presents conclusions.

NOTATIONS

G	A network graph.
N	The number of nodes in G.
E	The number of edges in G.
e_{ij}	An edge between node i and node j in G.
C(e)	The cost of an edge e.
M	The connection matrix of the given network
T_s	The shortest path rooted at node s

THE PROBLEM DESCRIPTION

Usually, a network is represented as a weighted directed graph $G = (N, E)$, 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. We consider the broadcast routing problem with bandwidth constraints from one source node to all-destination nodes. P_T (s, d) represents a path from source node s *to* the destination node $d \in N$ in T. $e(i,j)$ is a link from node $i \in N$ to node $j \in N$. Three non-negative real value functions are associated with each link $e(e \in E)$: cost $C(e)$, available bandwidth $B(e)$, and hop $H(e)$. The link cost function, $C(e)$, may be either monetary cost or any measure of the resource utilization, which must be optimized. The link bandwidth, $B(e)$, is the residual bandwidth of the physical or logical link. The link bandwidth functions, $B(e)$, define the criteria that must be constrained. The link hop is the number of hop i.e $H(e)$=1.

The cost of the path P_T *is* defined as the sum of the cost of all links in that path and can be given by

$$C(P_T) = \sum_{e \in P_T} C(e) \tag{1}$$

The total cost of the tree T is defined as the sum of the cost of all links in that tree and can be given by

$$C(T) = \sum_{e \in E_T} C(e) \tag{2}$$

The bandwidth of the path P_T is defined as the minimum available residual bandwidth at any link along the path:

$$B(P_T) = \min(B(e), e \in P_T) \tag{3}$$

The bandwidth of the tree T is defined as the minimum available residual bandwidth at any link along the tree:

$$B(T) = \min(B(e), e \in E_T) \tag{4}$$

The hop count of the path P_T *is* defined as the number of links in the path and can be given by

$$H(P_T) = \sum_{e \in P_T} H(e) \tag{5}$$

The hop of the tree T is defined as the maximum of the hop count of all paths in the tree and can be given by

$$H(T) = \max_{e \in E_T} H(P_T) \tag{6}$$

Assume the bandwidth constraint and hop limit of broadcast tree is B and H respectively, then, the problem of broadcast routing is to find a broadcast tree T, satisfying:

$$C(T) = \sum_i \min C(P^i{}_T)$$

Where Bandwidth constraint: $B(P_T) >= B$ *and*

Hop limits: $H(P_T) < H$.

THE CONNECTIVITY NETWORK AND PATHS

The connectivity network is a set of nodes that are 2-connected and generated randomly, i.e., all nodes have at least degree 2 is defined as the number of edges incident with node.

The connectivity path is a set of nodes that are 2-connected and generated randomly, i.e., each node is connected to the previous and next node in the network.

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THE FITNESS FUNCTION

1. Compute the bandwidth of the generated chromosome $B\ (P_T)$ according to Eq. 3., and it must be satisfying the following relation:

$$B\ (P_T) >= B$$

2. Compute the hop number of the generated chromosome $H\ (P_T)$ according to Eq. 5., and it must be satisfying the following relation

$$H\ (P_T) < H.$$

THE PROPOSED GENETIC ALGORITHM (GA)

In the proposed GA, each candidate path is represented by a binary string with length N that can be used as a chromosome. Each element of the chromosome represents a node in the network topology. So, for a network of N nodes, there are N string components in each candidate solution x. Each chromosome must contain at least two none zero elements.

Initial Population

The generated chromosome in initial population must contain at least two none zero elements to be a real candidate path. The following steps show how to generate *pop_size* chromosomes of the initial population:

1. Generate a chromosome x randomly.
2. Check if x represents a real generated chromosome, i.e. contains at least two non-zero elements.
3. Check the connectivity of the generated chromosome, if it fails to meet 2-connectivity requirement, discard it and repeat from step 1.
4. Calculate the fitness function of the generated chromosome.
5. Repeat steps 1 to 4 to generate *pop_size* chromosomes.

The objective function

The cost of the candidate path is used as objective function to compare the solutions and find the best one. The cost of the candidate path is calculated when the fitness function is satisfied

Genetic Crossover Operation

In the proposed GA, we use the single cut point crossover to breed a new offspring from two parents. The crossover operation will be performed if the crossover ratio (Pc=0.90) is verified. The cut point is randomly selected.

Genetic Mutation Operation

The mutation operation is performed on bit-by-bit basis. In the proposed approach, the mutation operation will be performed if the mutation ratio (Pm) is verified. The Pm in this approach is chosen experimentally to be 0.02. The point to be mutated is selected randomly

THE ENTIRE ALGORITHM

The following pseudocode illustrates the use of our different components of the GA algorithm to generate the minimum-cost paths tree of a given network.

Algorithm Find the broadcast tree

Input:

a. Generate a network with number of nodes (maximum number of nodes=50)
b. Check on the generated network, it is connectivity or not according to section 4, if it is not connectivity discard it and goto step a.
c. Generate a cost value C_{ij} for each link randomly in the range of [20, 30].
d. Generate a bandwidth value B_{ij} for each link randomly in the range of [10, 20].
e. Set a hop number H_{ij}=1 for each link.
f. Set the parameters: *B, pop_size, max_gen,* P_m, P_c.

Output:

Minimum broadcast tree.

Begin;

1. For all destination nodes (*Node=2 to N*) {
2. Generate the initial population according to the steps in Section 6.1.
3. *gen* =1.
4. *Min-Cost=1000;*
5. **While** (*gen < = max_gen)* **do**
6. **{**
7. **P=** 1
8. **While** (*P <= pop_size*) **do**
9. **{**
10. Apply crossover according to P_c parameter (P_c >=0.90) as described in section 4.3.
11. Apply Mutation as shown in section 4.4.
12. Compute the bandwidth $B(P_T)$ of the candidate path according to Eq. (3).
13. Compute the hop $H(P_T)$ of the candidate path according to Eq. (5).
14. Check $B(P_T)$ and $H(P_T)$; If $B(P_T)$ < B OR $H(P_T)$ > H discard it and continue
15. Compute the cost $C(P_T)$ of the candidate path according to Eq. (1).
16. Check $C(P_T)$; if $C(P_T)$< *Min-Cost* then *Min-Cost=* $C(P_T)$ and save the

candidate path

17. *P ← P+1.*
18. **}**
19. Set *gen =gen + 1*
20. If gen > max_gen then **stop**
21. **}**

22. Save the candidate path for the destination Node that has the minimum cost with bandwidth constrained and hop limited (the shortest path between the root node and the destination node *Node*).
23. }
24. Compute the cost of broadcast tree *C(T)* according to Eq. (2), B(T) according to Eq. (4), and *H(T)* according to Eq. 6.
25. Print all candidate paths which represent the broadcast tree, *C(T), B(T),* and *H(T)*.

End.

EXPERIMENTAL RESULTS

The proposed algorithm is implemented using Borland C++ Ver. 5.5 and the initial values of the parameters are: population size (pop-size=20), maximum generation (max_gen=100), Pc=0.90, and Pm=0.02. The cost and bandwidth matrices of a given network are all randomly generated and H_{ij} =1. Here C_{ij} and B_{ij} is uniformly distributed in the range of [20, 30], [10, 20], respectively. Let the node 1 be source node. We consider two examples, the first is a network of 10 nodes and the second is a network of 30 nodes. In these example, the technique generates the shortest paths tree of the network that find the minimum cost with bandwidth constrained and hop limited. Two Examples are used to test and validate the proposed technique.

Example 1

In this example, let the bandwidth constraint B=12 and hop limit H=3). We illustrate the results of applying the presented GA on an ten (10) nodes network example. The final output of the GA is shown in Table 1.

Table 1: The final output of the proposed algorithm (GA)

The Shortest Path (P_T)	Bandwidth B(P_T)	Hop H(P_T)	Cost C(P_T)
1-6-2	13	2	57
1-3	13	1	21
1-6-2-4	12	3	81
1-6-5	16	2	48
1-6	17	1	28
1-3-7	13	2	43
1-6-8	14	2	51
1-6-9	16	2	52
1-6-10	16	2	48
Output	B(T)=12	H(T)=3	C(T)= 429

.NG=100; Time Taken=3.33 Second

Example 2:

In this example, let the bandwidth constraint B=12 and hop limit H=9). The GA is applied on the network with thirty (30) nodes. The final output of the GA is shown in Table 2.

Table 2: The final output of proposed algorithm (GA).

The Shortest Path (P_T)	B(P_T)	H(P_T)	C(P_T)
1-3-2	15	2	44
1-3	15	1	20
1-18-8-16-6-14-15-4	14	7	167
1-12-18-6-16-13-5	12	6	135
1-16-6	14	2	46
1-17-2-24-5-7	12	5	116
1-17-6-14-21-25-8	12	6	149
1-18-29-23-19-12-2-22-9	12	8	103
1-13-14-29-8-15-20-10	14	7	175
1-15-14-29-28-25-11	13	6	143
1-12	16	1	20
1-13	15	1	27
1-15-14	15	2	49
1-15	15	1	24
1-16	19	1	24
1-17	16	1	25
1-18	18	1	24
1-28-23-12-6-9-15-19	15	7	173
1-18-20	18	2	44
1-16-26-11-2-17-21	15	6	141
1-22	18	1	26
1-16-15-25-3-2-29-23	12	7	163
1-28-2-14-4-15-24	12	6	156
1-28-25	15	2	45
1-17-15-14-24-18-6-11-26	13	8	190
1-15-2-24-7-16-27	12	6	147
1-28	18	1	24
1-12-4-22-18-6-13-24-29	12	8	184
1-22-20-4-3-25-15-30	12	7	169
Output	12	8	2753

NG=100; Time taken: 4317.99 S,

CONCLUSIONS

The paper addressed the minimum broadcast tree problem and presented an efficient GA to solve this problem. The algorithm reads both the connection, cost, and bandwidth matrices of a given network, then search the minimum broadcast tree that construct the minimum-cost paths tree rooted at a given node s with bandwidth constrained. The GA has been applied on three examples, the results proved that the efficiency of the proposed GA. For the future work, the GA can be extended to solve multi-constrained paths tree problem.

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