A new hybrid GRASP with the pilot method for the delay-constrained multicast routing problem

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Abstract—**Multicast routing problem is a well know optimization problem for transmitting real-time multimedia applications in telecommunication networks. As the underpinning mathematical model, the constrained minimum Steiner tree problem in graphs is a well-known NP-complete problem. In this paper we investigate a new hybrid GRASP (Greedy Randomized Adaptive Search Procedure) approach where a pilot method is applied to further enhance the search for the Delay-Constrained Least-Cost (DCLC) multicast routing problem. Experimental results demonstrate the efficiency of the hybrid GRASP algorithm and the contributions of the post-processing pilot method to better solutions in most cases. The proposed GRASP approach is a competitive approach in solving the DCLC multicast routing problem.**

Keywords- GRASP(Greedy Randomised Adaptive Search Procedure); Pilot Method; Multicast Routing

I. INTRODUCTION

Multicast routing is a well know technique which transfers information from a source to a group of destinations simultaneously. The rapid development of numerous multicast network applications (e.g. E-learning, E-commerce, video-conferencing) promotes the requirement multicast routing with certain QoS (Quality of Service) constraints in the underlying computer networks. Different application may have different QoS requirements, such as the cost of the transmission, the end-to-end delay from the sender to destinations, the bandwidth consumption, the delay jitter, the packet lost ratio and the transmission hop count, etc. Multicast QoS routing has received significant research attention in the area of computer networks and algorithmic network theory [1-3]. This paper concerns two of the most important QoS demands, the total cost of the edges in the multicast tree from the source to all the destinations and the end-to-end delay bound for the total delay from the source to any destination in the multicast group.

Multicast routing problems can be modeled as a Minimum Steiner Tree Problem in Graphs (MStTG)[4]. Given an undirected graph $G = (V, E)$, where V is a set of nodes, E is a set of edges, and a subset of nodes $D \subseteq V$, a Steiner tree is a tree which connects all the nodes in D using a subset of edges in E. Extra nodes in $V \backslash D$ may be added to the Steiner tree, called the Steiner nodes. The objective of a MStTG problem is to search a minimal Steiner tree with respect to the total edge costs $c(e)$, $e \in E$, which has been proven to be NP-complete [5]. The Delay-Constrained Least-Cost (DCLC) multicast routing problem can be seen as a delay-constrained Steiner tree, which is also NP-complete [6-8].

In this paper, we investigate a new hybrid GRASP approach by applying a pilot method as the post-processing technique to further improve the search for the DCLC multicast routing problem. To our knowledge, very little attention has been given to the GRASP approach on multicast routing and we know only one exception in [9]. In our previous work, a GRASP with variable neighborhood search approach, namely GRASP-VND, has been proposed and successfully applied to solve the DCLC multicast routing problem [10]. Motivated by the good performance of GRASP-VND, in this paper, we incorporate the idea of applying a pilot method, named GRASP-VND+pilot, to improve the performance of the hybrid GRASP approach. We test the proposed hybrid GRASP algorithm on a set of benchmark Steiner tree problems in the OR library[11]and a group of random graphs. Computational results indicate that GRASP-VND+pilot leads to better results compared with GRASP-VND. In addition, it outperforms other two algorithms, namely a multi-start algorithm of an extended VND search algorithm [12] and the GRASP-CST algorithm [9]. Our proposed GRASP-VND+pilot algorithm has the overall best performance in terms of the average tree cost in comparison with the existing algorithms and heuristics.

The rest of the paper is organized as follows. In section II, we present the problem definition and related work. Section III presents the proposed GRASP-VND+pilot algorithm. We evaluate our algorithm by computer simulations and summarize the obtained simulation results in section IV. Finally, section V concludes this paper and presents the possible future work.

II. THE PROBLEM DEFINITION AND RELATED WORK

A. *The network model and problem definition*

We define a computer network as a connected, directed graph $G = (V, E)$ with $|V| = n$ nodes and $|E| = l$ links, where V is a set of nodes and E is a set of links. For each link $e = (i, j) \in E$, link cost $c(e)$ and link delay $d(e)$ are defined. $c(e)$ is associated with the utilization of the corresponding link's resources. $d(e)$ is related the transmission delay of messages along the link. The computer network is asymmetric, i.e., for link $e=(i,j)$ and link $e'=(j,i)$, it is possible that $c(e)\neq c(e')$ and $d(e)\neq d(e')$. A multicast routing problem includes a source node s and a set of destination nodes D called *multicast groups*, which receive data stream from the source, denoted by $D\subseteq V\setminus\{s\}$.

A path from node u to v is an ordered set of links, denoted by $P(u,v)=\{(u,i),(i,j),...,(k,v)\}$. A multicast tree $T(s,D)\subseteq E$ is a tree rooted at source s and spanning all destination nodes in D. $P(s,r_i)\subseteq T$ represents the path from s to $r_i\in D$ in T. The sum of the delays of all links along $P(s,r_i)$ is the end-to-end delay from s to each destination r_i which is defined as

$$Delay(r_i)=\sum_{e\in P(s,r_i)} d(e), \forall r_i\in D \qquad (1)$$

$Delay(T)$ represents the delay of tree T, which is the maximum delay among all $Delay(r_i)$ from source to each destination, i.e.

$$Delay(T)=\max\{Delay(r_i)\mid \forall r_i\in D\} \qquad (2)$$

$Cost(T)$ is defined as the cost of tree T, which is the sum of the cost of all links in the tree, i.e.

$$Cost(T)=\sum_{e\in T} c(e) \qquad (3)$$

Real world applications can only tolerant a bounded transmitting delay from source to each destination. In this paper, we assume that the delay bound $\Delta=\delta_i$ for all destinations.

Given these definitions, we formally define the Delay-Constrained Least-Cost (DCLC) multicast routing problem as:

The DCLC Multicast Routing Problem: Given a network G, a source node s, a destination node set D, a link cost function $c(\cdot)$, a link delay function $d(\cdot)$, and a delay bound Δ, the objective of the DCST Problem is to construct a multicast tree $T(s,D)$ such that the delay bound is satisfied, and the tree cost $Cost(T)$ is minimized. We define the objective function as:

$$\min\{Cost(T)\mid P(s,r_i)\subseteq T(s,D), Delay(r_i)\le\Delta, \forall r_i\in D\} \quad (4)$$

B. Related work

The multicast routing problem has received extensive studies, and consequently many exact and heuristic algorithms have been developed. Most of these algorithms can be classified as source-based or destination-based multicast routing algorithms. In source-based algorithms, each node has all the necessary information to construct the multicast tree [13-18]. While destination-based algorithms do not require that each node maintains the entire network status information, and multiple nodes participate in constructing the multicast tree [6,14,19, 20].

In recent years, meta-heuristic algorithms such as simulated annealing [21,22], genetic algorithm [23,24], tabu search [25-28], GRASP [9,10], path relinking [29], VNS [12], scatter search [30] and particle swarm optimization [31] have been investigated for various multicast routing problems. A GRASP meta-heuristic hybridized with VNDMR [12], namely GRASP-VND, is proposed in our previous work in [10], which has showed good performance for the solving the DCLC multicast routing problem.

It can be seen from the literature review, although GRASP is an efficient meta-heuristic for optimization problems, little attention has been given to GRASP for solving the multicast QoS routing problem. Motivated by the successful applications of the pilot method in the literature for the Steiner tree problem in Graphs in [32] and the network design problem in [33], we further study a pilot method as a post optimization procedure to improve the performance of our previous GRASP-VND. Our aim is to investigate advanced hybrid meta-heuristics and towards designing more efficient approaches for the DCLC multicast routing problem.

III. THE PROPOSED HYBRID GRASP APPROACH

GRASP (Greedy Randomized Adaptive Search Procedure) is an efficient multi-start meta-heuristic for a wide range of optimization problems [34]. An iteration of GRASP consists of two phases: a construction phase which is used to generate a feasible solution, and a local search phase which is applied to explore the neighborhood of the feasible solution until a local minimum is found. GRASP builds the feasible solution by iteratively creating a candidate list of elements, called the restricted candidate list (RCL), and by evaluating the elements not yet included in the partial solution with a certain greedy function. To further improve the feasible solution generated in the construction phase, a local search is applied to search for better neighboring solutions of the feasible solutions. After a given number of iterations, the best overall solution is kept as the final solution. More detailed descriptions of the GRASP heuristic can be found in [34, 35].

GRASP meta-heuristic is effective and easy to implement and few parameters need to be set and tuned, thus it has been successfully applied to solve a wide range of combinatorial optimization problems [36-38]. Our motivation is to investigate effectiveness a pilot method as the post optimization process to the performance of the hybrid GRASP approach for the DCLC multicast routing problem.

A. The construction phase

In the construction phase of our GRASP-VND+pilot algorithm, we use the same greedy randomized procedure as that in [10] to create the randomized initial solution, which is adopted from the greedy strategy in [9]. The construction phase firstly calculates the shortest path from source to each destination. A parameter α in GRASP is used to select the candidate paths to be included in the RCL.

B. The local search phase

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C. The application of the pilot method

The pilot method may be seen as an intelligent technique to look ahead of possible choices after certain iterations to support better final decision of the options concerned. It is a tempered greedy method by performing repetition of heuristics in order to record the best result before getting to a promising solution. Pilot methods have been investigated for solving various combinatorial optimization problems [32, 33, 40-42], in which some are under different names, for example the rollout method in [41] and [42].

We propose the GRASP-VND+pilot algorithm which is an extension of our GRASP-VND in [10] by applying a pilot method to explore better neighboring solutions after a local optimum has been found by the local search phase. The pilot method is used as an enhancement mechanism, where each pilot includes two procedures:

1) *Shaking process:* During the shaking process, a destination node is randomly selected. Then, a set of back up paths which connect the source and the destination node is generated for the chosen destination by using the *k*-th shortest path algorithm [43]. The pilot shakes the current solution by choosing one path at random from the back up path set to replace the original path from the source to the destination node in the current tree.
2) *Pilot search procedure:* Each pilot searches better solutions by looking ahead more neighboring solutions defined by the pilot heuristic in the pilot search procedure. Our pilot heuristic uses the same operation as the node-based neighborhood structure in VNDMR which is easy to implement and has shown to be effective. The pilot search procedure repeats until no further improvement can be achieved.

In the pilot method, a key factor is the pilot depth, which determines the actual search depth of the pilot method, i.e. the quality of the results and the runtime of the search. In our pilot method, the pilot depth is a given number of iterations of the pilot heuristic. A larger pilot depth may lead to better solutions; however, it usually means longer runtime.

IV. PERFORMANCE EVALUATIONS

We use a multicast routing simulator (MRSIM) implemented in C++ based on Salama's generator [1] to generate random network topologies. More details description of the simulator can be found in our previous work in [10]. All simulations were run on a Windows XP computer with PVI 3.4GHZ, 1G RAM.

In order to compare the performance of GRASP-VND+pilot with other existing algorithms, we tested GRASP-VND+pilot on a group of randomly generated graphs which has been used as benchmark test instances in [10,12,30,31]. After a number of initial tests, the number of iterations is set as 4, α (the parameter for creating RCL) is set as 5 in both GRASP-VND and GRASP-VND+pilot. The pilot depth is set as $t = 5$.

TABLE 1. COMPARISON OF THE AVERAGE TREE COST OBTAINED BY GRASP-VND+PILOT AND SOME EXISTING ALGORITHMS ON THE RANDOM GRAPHS.

Algorithms		*Average Tree Cost*
Heuristics	KPP1 [13]	905.581
	KPP2 [14]	911.684
	BSMA[18]	872.681
GA-based Algorithms	Wang et al. [23]	815.969
	Haghighat et al. [24]	808.406
TS-based Algorithms	Skorin-Kapov and Kos[26]	897.875
	Youssef et al. [25]	854.839
	Wang et al. [21]	869.291
	Ghaboosi and Haghighat [28]	739.095
Path relinking	Ghaboosi and Haghighat [29]	691.434
VNS Algorithms	VNDMR [12]	658.967
	Multi-VND [10]	656.777
Scatter Search Algorithm	SSPR-VND [30]	644.840
PSO Algorithm	JPSO [31]	662.100
GRASP Algorithms	GRASP-CST [9]	669.927
	GRASP-VND [10]	654.520
	GRASP-VND+pilot	650.823

TABLE 2. AVERAGE TREE COST, STANDARD DEVIATION OF THE TREE COST AND EXECUTION TIME OF GRASP-VND+PILOT, SSPR-VND, GRASP-VND AND MULTI-VND ON RANDOM GRAPHS.

Network Size	*Algorithms*					
	GRASP-VND+pilot			*SSPR-VND*		
	Cost	σ	*Time (s)*	*Cost*	σ	*Time (s)*
10	**94.7**	0	0.02	**94.7**	0	0.04
20	**271.1**	1.48	0.15	272.5	2.41	0.31
30	**392.3**	0	0.61	393.5	3.57	1.45
40	**513.6**	0.35	1.59	513.3	0.00	3.52
50	663.8	6.75	3.42	660.8	0.53	9.58
60	754.8	7.08	6.93	748.1	7.03	13.64
70	780.1	3.94	13.84	779.5	5.97	29.61
80	878.9	16.55	31.19	863.3	5.93	66.36
90	1163.7	28.67	52.20	1132	19.35	116.42
100	995.0	5.22	58.38	989.8	3.19	177.45
Avg.	650.8	7.001	16.83	644.8	4.8	41.84

Table 1 shows that GRASP-VND+pilot performs better than GRASP-VND, Multi-VND and GRASP-CST in terms of the average tree cost, which demonstrates the effectiveness of the pilot method proposed in this paper. Table 2 compares the average tree cost, standard deviation and execution time of GRASP-VND+pilot with the best performed algorithm SSPR-VND[30] on each network size of these random graphs are given. We can see that SSPR-VND consumed much longer average computational time (41.84 seconds) than that (16.83 seconds) of GRASP-VND+pilot. GRASP-VND+pilot algorithm obtained so far the second best average tree cost compared with other existing algorithms which shows it is a competitive approach for solving the DCLC multicast routing problem.

V. CONCLUSIONS

In this paper, we investigated hybrid GRASP approaches for solving Delay-Constrained Least-Cost (DCLC) multicast routing problems. To guide the search to better solutions, a new hybrid GRASP-VND+pilot algorithm is proposed by applying a pilot method to further improve the quality of solutions. Experiment results show that the pilot method in GRASP-VND+pilot contributed to better results in most cases compared with previous GRASP-VND algorithm. Our GRASP-VNS+pilot algorithm obtained the second best performance comparing with existing algorithms in terms of average tree cost.

Some interesting future research directions could be explored. In reality, some networks such as wireless ad hoc networks, the topologies of networks are mostly dynamic with nodes leaving and joining the network at various times. The adaptation and extension of the hybrid GRASP approach to the problem of highly constrained and dynamic multicast routing deserve further research.

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