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KATA PENGANTAR

Alhamdulillah, kami kembali hadir ditengah kita para peneliti. Mulai Volume 13, April 2007, kami telah berganti nama dengan nama baru (**Jurnal Sains MIPA,** disingkat **J. Sains MIPA**) dan nomor ISSN baru serta berbagai perbaikan terutama dalam hal penampilan. Sehingga dengan demikian, makalah yang kami terbitkan akan lebih fokus pada bidang Matematika dan Ilmu Pengetahuan Alam secara murni. Hal ini kami lakukan, agar di masa yang akan datang, status akreditasi yang saat ini kami miliki, dapat kami pertahankan. Selain itu kami selalu berupaya dengan sungguh-sungguh agar Jurnal Sains MIPA ini menjadi salah satu jurnal nasional yang sejati, yang mempublikasikan makalah tidak hanya dari wilayah Sumatra, tapi dari seluruh Indonesia, seperti yang kami tampilkan saat ini.

Kami bahagia, karena berhasil menjumpai kembali para penulis dan peniliti secara umum dan peneliti bidang MIPA pada khususnya. Pada edisi ini, kami muat 13 artikel ilmiah dari bidang MIPA. Artikel-artikel yang ditampilkan berasal dari bidang ilmu kimia 2 makalah, biologi 3 makalah, fisika 6 makalah, dan matematika 2 makalah. Kami berharap semoga makalah yang kami tampilkan pada edisi ini menarik bagi para pembaca.

Sebagai wahana komunikasi para peneliti, kami merasa masih sangat kurang dalam banyak hal. Untuk itu, kami dengan tangan terbuka selalu membuka kritik dan saran yang membangun demi kemajuan jurnal ini. Kami juga tetap berharap para peneliti untuk selalu mengirimkan hasil penelitiannya yang terbaru untuk diterbitkan pada jurnal ini, karena tanpa adanya artikel yang bermutu, maka kami tidak dapat hadir di tengah kita tepat waktu. Untuk itu, kami selalu berterima kasih atas kepercayaan para penulis dan peneliti yang mempercayakan jurnal ini sebagai media komunikasinya.

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TABU SEARCH'S DIVERSIFICATION STRATEGY FOR THE DEGREE CONSTRAINED MINIMUM SPANNING TREE PROBLEM

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ABSTRACT

Tabu search's diversification strategy is one of two important strategies in tabu search: intensification and diversification. The Degree Constrained Minimum Spanning Tree (DCMST) Problem is concerned with finding a minimum weight spanning tree T in a weighted graph G (all weights are non negative) with the requirement that the vertices satisfy a prescribed degree restriction in T. This problem arises naturally in communications networks where the degree restriction represents the number of line interfaces available at a terminal. In this paper we will discuss how to implement the diversification strategy for solving the DCMST problems and present the result on some benchmark problems.

Keywords: *minimum spanning tree, tabu search, diversification strategy, degree constrained*

1. INTRODUCTION

Tabu Search is one of the search methods that has been applied successfully for tackling difficult problems in the area of combinatorial optimization including: telecommunication networks[1,2]; vehicle routing problems[3,4], scheduling problems[5], and Degree Constrained Minimum Spanning Tree Problem[6-8].

Tabu Search can be applied directly to verbal or symbolic statements of many kinds of decision problems, without the need to transfer them into mathematical formulations. Nevertheless, it is useful to introduce mathematical notation to express a broad class of these problems, as a basis for describing certain features of Tabu Search. The basic mathematical concepts of Tabu Search are described below.

We use the notation that S is a set of solutions. For a vector $u \in S$ we can define a set $N(u)$, called the neighborhood of u, of solutions that are "close" to u. $N(u)$ is obtained by applying well-defined rules to u. For example, in the context of the DCMST problem each element of $N(u)$ can be obtained from u by a single edge exchange. The iteration number is denoted by k and S_k is the set of available solutions at iteration k. If f is the objective function, the optimization problem can be stated as:

$$\underset{i \in S}{Minimize}\ f(i).$$

Tabu Search begins the same way as ordinary local or neighborhood search. It proceeds iteratively from one solution to another until a chosen termination criterion is satisfied. Each solution is reached from u by an operation called **move.** We note $w = u \oplus m \in S^*$ for the move applied to solution i in order to obtain solution w.

Tabu Search goes beyond local search by employing a strategy of modifying $N(u)$ as the search progresses, effectively replacing it by another neighborhood $N^*(u)$ using a special memory structure which serves to determine $N^*(u)$ *at every iteration*, and hence to organize the way in which the space is explored. Since the structure of the neighborhood depends on the iteration, we use notation $N(u,k)$ instead of $N^*(u)$.

The definition of $N(u,k)$ implies that some recently visited solutions are removed from $N(u,k\text{-}1)$. These solutions are considered as tabu solutions, which should be avoided in the next iteration. Such a memory based on recency will partially prevent cycling. For example, if L_k is a tabu list at iteration k, then the cycles of length at most $|L_k|$ will be avoided.

In order to improve the efficiency of the exploration process, one needs to keep track of not only local information (like current objective function value) but also some information related to the exploration process. This information will be used to guide the move from one solution to another. This systematic use of memory is an essential feature of Tabu Search. The way of assigning certain attributes to the solutions depends on the use of memory structure. In Tabu Search an important distinction arises by differentiating between short-term memory and long-term memory. The foundation of Tabu

Search lies on those two types of memory. Each type of memory has its own special strategies.

In the long-term memory, diversification strategy is one of the possible ways of avoiding being trapped in a local optimum solution and in this paper we will discuss how to implement the diversification strategy in Tabu search in Section 2 and present the results in Section 3. In Section 4 we give conclusions and also will suggest possible future work regarding this problem.

2. MATERIALS AND METHODS

2.1. Lower and Upper Bounds

The heuristics we propose here start by finding a lower bound and an upper bound. The lower bound is just the Minimum Spanning Tree that is constructed from Kruskal's algorithms that can be feasible (in this case optimal solution) or infeasible. The upper bound is a Degree Constrained Spanning Tree (DCST), which is constructed from the modified Kruskal's algorithm. We use the modified Kruskal because it is simple, efficient and yields relatively good results. The modification is that the algorithm checks the degree of the vertices in the edge-inserting process. If there is a degree violation by the insertion of an edge e_i, then the edge e_i is excluded; otherwise it is included in the spanning tree. In brief, the process or algorithm can be stated as follow:

Step 1. Sort the edges in ascending order.
Step 2. Repeat
Select the smallest edge weight.
If in the element subgraph generated both its vertices have degree
at most b-1 (b is the degree bound) and it doesn't create a cycle,
then include this edge
else
Discard this edge.
Until
A DCST is found or all the edges have been examined.

One possible way in the diversification's strategy is simply allows restarting with a new or different feasible solution. In our heuristic, we employ this feature by implementing our heuristic using different feasible solutions. After getting a set of feasible solutions we apply the method as in Caccetta and Wamiliana[7] simply by restarting and record the best solution found using that set of feasible solutions.

The easiest way of generating a feasible solution for the DCMST problem is by using the modification of the greedy algorithms for finding the MST. As we know, for finding the MST, Kruskal 's algorithm is widely used. With a slight modification the method can be used to generate a DCST.

In general, a restarting process with only two initial feasible solutions doesn't really give the search much better options. It is possible that the search will search more regions if there is a set of feasible solutions that can be used for restarting. For this reason, we generate a set of feasible solutions using the idea of the Modified Kruskal algorithm with some changes in edges insertion process.

The set of feasible solutions are generated by introducing a 'range' in the edge insertion process. In the Modified Kruskal algorithm for the DCMST problem, the algorithm always chooses and adds the cheapest available edge to the component of the spanning tree constructed, with regards to the degree requirement whilst avoiding cycles being formed. We select our next edge for consideration from a specified set of edges. We introduce a 'range' as follows: a range of size k means that we consider the next k cheapest available edges and select an edge at random. For example, if we set the range to be 3, then the algorithm will choose one of the three cheapest available edges in the range. Thus it is possible that the cheapest edge is not chosen. Note that k =1 corresponds to the Modified Kruskal's algorithm. A problem with k =1 is that it is possible that earlier (cheap) edges force the selection of very expensive edges later. Our range idea overcomes this problem to some extent. By changing the range, we will possibly obtain different solutions (but feasible) for the same problem.

3. RESULTS AND DISCUSSIONS

We implemented our heuristic using the C programming language on a Silicon Graphic Indy machine, running in 150MHz. In the implementation we do make the assumption that the degree restriction for every vertex is the same.

As in Caccetta and Wamiliana[7], for all vertex orders we run the program using the gap value of 1 % and maximum iteration number as min {0.20n, 50}. The gap is the difference between best solution and lower bound divided by lower bound, n is the order of the vertices For the degree condition, we restrict our implementation only for degree bound 3. We chose this bound, since our early computational work revealed that for degree bound greater than 3 the MST is usually feasible and hence optimal.

3.1. Test Data

We provide results on 180 random problems generated as follows

- Number of vertices range from 10, 50, 100,150, 200 and 250
- The edge weights are generated randomly from uniform distribution from 1 to 1000. .
- For a given *n*, 30 random problems are generated.

For all simulation problems, we use time as the seed when generating a problem (data) and assign that data a name so that next time when we will retest, we use the same data. This is very important step because otherwise we will lose the same data since our seed is time, which will never be the same. In addition to that, we use also some benchmark problems that taken from http://www.iwr.uniheidelberg.de/iwr/comopt/soft/TSPLIB95/TSPLIB

3.2. Computational Results

We present our computational results in tabular form. LB is the lower bound (MST). Note that LB could be infeasible. MK is the brief notation for modified Kruskal heuristics that using 2 feasible solutions, MK_{Range} is Modified Kruskal heuristics which use ten feasible solutions. CW1 is Tabu search heuristics use in Caccetta and Wamiliana[7]. CW2 is a slight modification of CW1. In CW2, all steps in CW1 are adapted and use two feasible solutions, the Modified Kruskal and the Modified Prim as the upper bound. The feasible solution that has the best quality solution will be chosen first as the upper bound. Then, after a certain number of iterations, if the search could not gain a solution within the tolerance specification, we restart the process and use the other feasible solution generated. The best solution is recorded. CW3 algorithm is essentially the same as CW1 algorithm. The only difference is that we now use a larger set of feasible solutions (DCSTs) to restart with. In our computational work, this set of feasible solutions consists of 10 feasible solutions, obtained by using 10 different ranges. We use the same stopping criteria as in Caccetta and Wamiliana[7]: the 'acceptable solution', where the gap lies within 1% of the lower bound; the maximum number of iterations and optimality. In Table 1 we do not present results for CW2 because the results are almost similar with CW1. The following are the results.

3.3. Implementation on Benchmarking Problems

We also tested our algorithm on the three benchmarks problems for the TSP problem obtained from TSPLIB. The following table shows the results; we have included for each of comparison the performances recorded by the various literature heuristics.

Table 1. Table of performance for MK, MK_{Range}, CW1 and CW3

n	Average of 30 problems for each *n*					
	$\frac{MK-LB}{LB}$	$\frac{MK_{range}-LB}{LB}$	$\frac{CW1-LB}{LB}$	$\frac{CW3-LB}{LB}$	Restart (for CW3)	Processing time (in second) For CW3
10	0.098559	0.078281	0.066067	0.046937	2.20000	0.000507
50	0.073348	0.061083	0.061223	0.048921	3.03333	0.277717
100	0.074109	0.0646919	0.065123	0.0579303	4.63333	0.796284
150	0.080862	0.0762818	0.065292	0.0615451	4.733333	2.273435
200	0.077879	0.0706946	0.066724	0.060289	5.33333	6.899522
250	0.091188	0.0746161	0.074507	0.0633300	5.96667	10.556749

Table 2. Results on some benchmarking problems

Algorithm	pr264	att532	rat575
Best TSP solution	49135	27686 (*)	6773
MST	41142	75872	6246
BF2(Deo, Kumar)	41143	NA	6265
BF4(Deo, Kumar)	41143	NA	6265
GA-F(Krishnamoorthy *et al.*)	41142	75981	6250
GA-P (Krishnamoorthy *et al.*)	44344	75981	6397
PSS(Krishnamoorthy *et al.*)	41143	75981	6250
SA(Krishnamoorthy *et al.*)	43438	79046	6393
BB(Krishnamoorthy *et al.*)	41143	75912	6250
BB(Volgenant)	41143	75912	6250
Modified Kruskal	41155	75968	6265
Modified Prim	41143	75991	6263
Tabu(CW2)	41143	75968	6263
Tabu(CW3)	41145	75954	6265

Legend(*) : The att532 TSP result uses integer pseudo-Euclidean distances, so edge distances differ approximately by a factor $\sqrt{10}$.

4. CONCLUSIONS

The computational results show that employing a diversification strategy improves the quality of the solution. For the CW3 algorithm, the processing time significantly increases compared with the CW1 algorithm. However, the quality of the solution shows an improvement. The average improvement in terms of the statistic $\frac{CW3 - LB}{LB}$ is approximately 1% with the highest improvement of 2% occurring when n=10.

One important factor that influences or causes the improvement is the better bound (the upper bound). The bounds generated by the standard Modified Kruskal's algorithm (where the algorithm always chooses the cheapest edge with regard to the degree restriction), may force the solution of more expensive edges in the later stages. By making the search select an edge within the range (not necessarily the cheapest) randomly, helps overcome this problem.

On the three benchmarks problems, the results show that our method performs better than the Simulated Annealing and the GA-P of Krishnamoorthy *et al.* [9]. There is only a slight variation in the performances of CW2 and CW3 over the GA-F and the PSS methods of Krisnamoorthy *et al.*[9].

5. REMARKS AND POSSIBLE FUTURE WORKS

The long term memory feature in the Tabu Search procedure suggests that advantages could be gained through implementation of a diversification strategy. The aim of applying the diversification strategy is to allow the search process to explore other feasible solutions. One possible way to do this is by restarting the process. To incorporate with this we need a set of feasible solutions. In our CW2 and CW3 heuristics we employ this strategy, and the computational results show that these methods improve the quality of the CW1 solution in terms of the statistic $\frac{H - LB}{LB}$ by approximately 0.3% and 1.5 % respectively (Note : H is the heuristics). However, the processing time for CW3 increases, but still it is reasonably fast.

The way of defining the moves in CW1, CW2 and CW3 have inspired us to develop another version that extends the candidate moves. We developed the algorithm that uses all edges in $G\backslash T$ as the candidate moves. In addition, the set of recently dropped edges that are in tabu status are put in different tenure with the recently added edges. Our testing on some problems indicated that this algorithm is sensitive in terms of obtaining different solutions by changing the setting on the tabu tenure and iteration number. However, to find the best pattern (ie. how many iterations to keep in tabu for recently dropped edges and how many for recently added edges) is not easy. There is no best pattern found so far. However, this problem is worthy for further investigation.

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