A Cooperative Parallel Tabu Search and Its Experimental Evaluation

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Abstract

This paper proposes a cooperative parallel tabu search which incorporates with the historical information exchange among processors in addition to its own searching of each processor. We investigate the influence of our proposed cooperative parallel tabu search by comparison with a serial tabu search. We also propose two extensions of the cooperative parallel tabu search which are the cooperative construction of tabu memory and the selection of cooperative partner. Through computational experiment, we observe the improvement of solutions by our proposed method.

keywords: tabu search, cooperative parallel tabu search, combinatorial optimization problem, cooperative partner

1. Introduction

Numerous attempts have been made to solve combinatorial optimization problems in various fields such as telecommunication, scheduling, circuit design, transportation, and so on [1, 2, 3, 4, 5]. Combinatorial optimization problems can be solved in polynomial time in very strict cases, but in many cases they are characterized as NP-hard, that is, up to now no polynomial time deterministic algorithms are found and their nonexistence in generally believed. On the other hand, from the practical point of view, for NP-hard combinatorial problems we need approximated solutions in polynomial time rather than the exact one with consuming vast computation time.

There are several approaches to approximated solving of combinatorial optimization problems, such as greedy method, problem-domain heuristics, Simulated Annealing (SA), Monte Carlo method, Genetic Algorithms (GA), Neural Networks, and Tabu Search (TS) [6, 7, 8]. Particularly, GAs, SA, and TS are focused as new approaches for combinatorial optimization and they are called "modern heuristics" or "meta-heuristics".

Tabu search is founded on ideas proposed by Fred Glover [9]. It is expanded in various points ever since [14, 15, 16]. Some studies consider its memory structure, others investigate searching restrictions. Parallelization of TS is also one interesting topic, since natural parallelism resides in execution of TS. Moreover, parallel processing is implemented with low cost and also very practical since MPUs are getting low price and high performance, multi-thread programming is available on many platforms, and message passing libraries (MPI and PVM) come up to the standard. There are several parallel execution schemes of TS [11, 12].

The objective of this paper is to propose the cooperative parallel tabu search for improving solution quality and accelerating the execution and to investigate effectiveness of the tabu memory reconstruction and the selection of a communication partner on the cooperative operation.

In Section 2, we explain briefly the tabu search. We perform experiments to show the efficiency of our proposed cooperative parallel tabu search in Section 3. Section 4 introduces an extension by the cooperative partner selection of the parallel method. Finally we conclude this paper in Section 5.

2. Tabu Search

TS is a searching technique based on the neighborhood search. The neighborhood search iterates moving the current solution to an adjacent one in which the adjacent solution is normally selected as the one with the best value of the objective function. In TS, to escape or to keep away from the local optima, adjacent solutions are prohibited to be selected if they are *tabu-active*, even though the solutions correspond to the maximum improvement of the objective function. The condition for the tabu-activity is examined based on knowledge obtained in the searching so far. The most fundamental rule to determine the activity is based on *recency memory* (or *short-term memory*) in which movements recently occurred is recorded to avoid selecting the same or similar movement in a short period. This avoidance tries to prohibit from cycling in local space. That is, once a movement takes place, the parameters specifying the movement is characterized as *tabu-active* during some fixed period, named *tabu tenure*. The procedure for a tabu search is shown as follows:

```
procedure Tabu Search;
begin
    generate an initial solution in some way;
    initialize the tabu memories;
    repeat
        calculate the objective value for each
        neighbor;
        pickup a solution candidate according to
        the objective values, the tabu memories
        and the aspiration criterion;
        move the current solution to the selected
        adjacent one;
    until satisfying the termination condition;
end;
```

The aim of parallelization for TS is to carry out its searching as fast as possible using multiprocessors. Since TS can divide its neighbor calculation into n processors, the processors calculate its assigned neighbors in parallel. However the speed-up ratio is not always n using n processors, that is, the grain and the communication overhead affect its parallel processing time deeply.

In [11], a parallel TS is proposed in which the proposed scheme tries not only to establish the speed-up but also to decrease the dependency of the tabu tenure. That is, each processor is assigned different tabu tenure, totally, multiple tabu tenures (the same numbers as the processors) are employed in the parallel searching.

This paper considers to cooperate among processors to improve obtained solutions and speed-up. Moreover we investigate an effectiveness of the tabu memory and the selection of a communication partner when it is cooperation.

3. Cooperative Parallel Tabu Search

We propose a parallel tabu search which is called the cooperative parallel tabu search (cPTS). Each processor stores its own historical information which is explored during the search, e.g., the obtained minimum solution and the tabu memory (short-term and long-term memory). cPTS is to share and use these historical information. We present one scheme here whose base idea is derived from the field of GAs. That is, the obtained best solution at each processor is treated like a chromosome and a crossover operation is performed. We employ in the cooperation the edge recombination crossover (EX), known as a useful operation in GAs for TSP [17]. The feature of EX is to inherit the parents adjacency (gene connection) information to the children. Two new solutions generated by EX are assigned to the processors as new initial solution. The evolution mechanism in GAs may contribute to generate new good quality of solutions. The cooperation is taken place with some intervals during parallel searching.

3.1 Experimental Evaluation

In this section, we examine the efficiency of cPTS through experimental evaluation solving the traveling salesman problem.

The traveling salesman problem (TSP) is one of basic problems in the combinatorial optimization and is well-known as NP-hard. It is to find the minimum cost of Hamiltonian circuit in a complete graph where each node represents a city and each edge is a link between the terminal nodes. The weight on an edge means the travel distance between the corresponding cities. The cost of the tour is the total distance in traversing along the Hamiltonians circuit. Although we assume there exists an edge between any pair of two cities, unconnected pair is also represented by assigning some arbitrarily large value (∞) for the distance.

In the experiment, we choose randomly initial solutions and design a neighborhood structure based on the 2-opt heuristic [13] in which each pair of non-adjacent edges is swapped. The *improved-best* is employed for the aspiration criterion. That is, any move is accepted, even though it is prohibited by tabu restriction, if it makes the current tour-cost less than the best-tour-cost obtained so far.

The problem instances to be solved in the experiment are obtained from the Web site [10], namely, the att48, eil51, berlin52, st70, eil76, and eil101 problems. The number in an instance name represents the city size. Every execution in each problem instance started from the same initial solution and terminated at the 1000-th iteration and the tabu tenure is twenty-five. In this experiment, the cooperative partner of each processor is the neighbor by the identification number. That is, for $i = 1, 3, 5, \cdots$, the partner of P_i is P_{i+1}. The cooperation carries out at each 100 iterations.

Figure 1 indicates searching results by three types of tabu search, the typical serial TS, non-cooperative par-

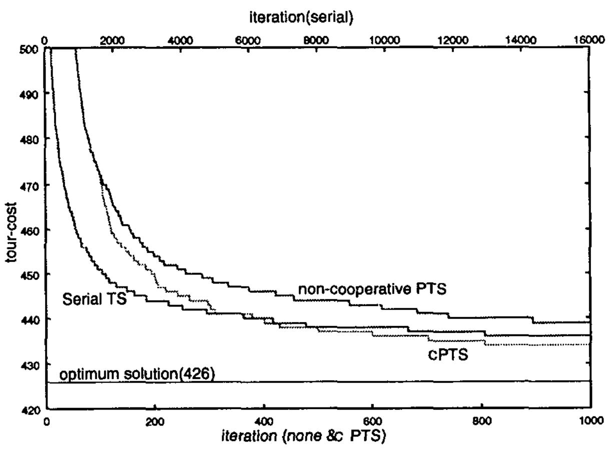

Figure 1: Tour-cost Curves at cPTS and Serial TS in 51-city problem

Table 1: Experimental Results by three types of tabu search

Problem Instance	non≥cPTS	1000 iteration non	1000 iteration cPTS	serial>cPTS		iteration serial best≥cPTS
att48	TRUE	35338	34105	TRUE	(37240)	111
eil51	TRUE	439	434	TRUE	(436)	601
berlin52	TRUE	8375	7835	TRUE	(8757)	110
st70	TRUE	780	724	TRUE	(787)	297
eil76	TRUE	579	565	FALSE	(564)	–
eil101	TRUE	737	685	TRUE	(723)	354

allel TS, and our proposed cPTS on the 51-city problem. The serial TS caries out the searching by one processor. On the other hand, the parallel TSs execute with sixteen processors. The non-cooperative one does not apply the cooperative scheme, that is, it does not use EX operation for comparing with cooperative one. This figure includes three curves and one line. The curves show the average value of the best tour-cost founded by TS among 50 different executions and the horizontal line indicates the optimum solution. The termination of the serial TS is 16000 iterations for the observation. From this figure, our proposed cooperation is effective comparing with the non-cooperative parallel TS. Moreover, cPTS obtained better solutions than the serial TS from 16000 iterations.

Table 1 shows the effectiveness of our proposed cPTS. The first column indicates names of the problem instance and the second , namely "non≥cPTS", shows whether or not the proposed cPTS obtained better or equal solution quality than the non-cooperative one at each iteration. The third and fourth one means the average final tour-cost on each parallel TS. The fifth column shows the comparison between the serial TS and cPTS. "TRUE" means that cPTS is better than the serial, otherwise marked by "FALSE". The number in parenthesis indicates the average final tour-cost on the serial TS. The final column shows the number of iterations (moves) at which the same solution of serial TS is obtained by cPTS.

From the experiment, we found our proposed cPTS obtains better solution quality and can find the equal solution to the serial one quickly.

3.2 Cooperative Construction of Tabu Memory

The information of tabu memory is an important factor in TS. We suppose to use the tabu memory for an additional information in the cooperation. Concretely, each processor records how many swaps were performed for solution movements in the searching in the long-term memory. We propose three cooperative constructions of tabu memory. They can be classified into two types. One is to set new tabu tenures in a short-term memory. The other is to reset a short-term memory to zero. In the cooperation by setting new tabu tenures, two processors which are partner reconstruct the current solution by EX and also replace its own short-term memory by the average/summation values of their short-term memory.

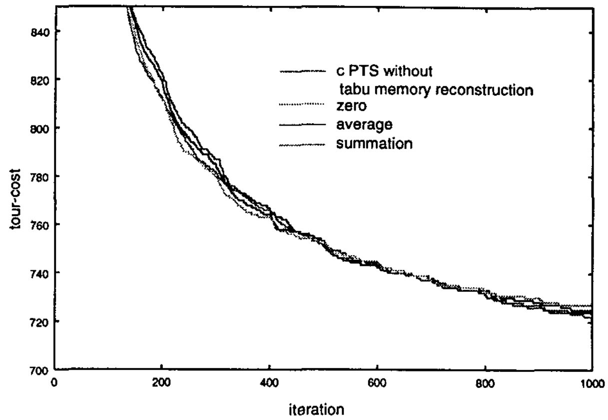

Figure 2: Cooperative construction of Tabu Memory in 70-city problem

While in case of resetting the contents of their short-term memory are cleared.

We investigate the effect of the cooperative construction of tabu memory through experimental evaluation solving TSP. Parameters, restrictions, and the number of times for the experiment each instance are equal to the previous ones. Figure 2 shows one of results and there is four curves, average, summation, zero (clear), and no cooperative construction of tabu memory. We cannot detect remarkable difference from the results.

From the experiment we get our ideas in shape, the cooperative construction of tabu memory cannot produce the remarkable influence in our proposed three patterns.

4. Efficiency of Cooperative Partner

In Section 3, the cooperative partner is selected as the neighbor processor. We propose in this section two partner selections. One is the best-solution, monopolized selection in which each processor cooperates with the processor with found best-solution so far. The other is the tournament selection in which two processors selected randomly and the processor within better solution is selected for the partner.

Figure 3 shows the result of experimental evaluation in 48-city problem. From this figure, the tournament selection obtained better solution than the others quickly.

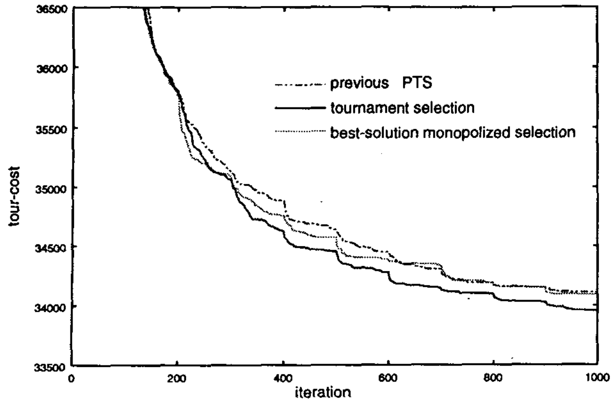

Figure 3: Partner Selection in 48-city problem

The best-solution monopolized selection found good solution among the early iteration but the improvement of the solution cannot observe in the latter. We verified the same observation in other instances.

From this experiment, the tournament selection is useful for selecting the cooperation partner in cPTS. The best-solution monopolized selection exhibits its effectiveness in the early searching but cannot come up to our expectation in the latter. The reason seems to stuck into local optimum by an excess of the cooperation with elite.

5. Concluding Remarks

This paper proposed the cooperative parallel tabu search (cPTS) which includes the historical information exchange among processors in addition to their own searching of each processor. We investigated the influence of our proposed cooperative parallel tabu search by comparison with a serial tabu search. From the results, we verified cPTS is useful approach in a parallelization of TS. We also proposed two extensions of the cPTS which are the cooperative construction of tabu memory and the selection of cooperative partner. We found that the cooperative construction of tabu memory is not available in our proposed scheme. However the selection of partner obtained better solutions than the simple cPTS.

As future works, we need to evaluate more carefully computation and communication costs by experimenting at parallel processing environments and also develop more efficient cooperation using tabu memory and the selection scheme for the cooperative partner.

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