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Development of a traditional transport system based on the bee colony algorithm

Davron Ziyadullaev[1*], *Dildora* Muhamediyeva[2], *Sholpan* Ziyaeva[1], *Umirzoq* Xoliyorov[1], *Khasanturdi* Kayumov[3], and *Otabek* Ismailov[4]

[1]"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, Tashkent, 100000, Uzbekistan
[2]Tashkent University of Information Technologies named after Mukhammad al-Khwarizmi, Tashkent, 100200, Uzbekistan
[3]Tashkent State Transport University, Tashkent, Uzbekistan
[4]Head of the Department for Information Technologies and Communications Ministry of Foreign Affairs of the Republic of Uzbekistan

Abstract. At present, a significant part of optimization problems, particularly questions of combinatorial optimization, are considered NP-complete problems. When solving optimization problems, the neural network approach increases the probability of obtaining an optimal solution. The traveling salesman problem is considered a test optimization problem. This problem was solved using the Hopfield neural network. In solving optimization problems, numerous computation processes and computation time are required. To improve performance and increase the program's speed, there are cases of inappropriate purchase of additional programs and tools, and involvement of additional services. In these cases, parallel computing technologies are used to give an effective result. Based on the developed algorithms, several computational experiments were carried out. The analysis of the obtained results showed that the algorithms of artificial neural networks proposed by us, in comparison with the algorithms created based on Hopfield neural networks, are characterized by low resource consumption and efficiency in terms of high speed. But, it should be noted that if the volume of tasks is very large, neural network algorithms may become less efficient due to longer computation. In such cases, it is usually advisable to use evolutionary algorithms. In particular, the study considers using the bee swarm algorithm for parallel computing technologies. Solving optimization problems using the bee swarm algorithm in parallel computing technologies can be significantly efficient and fast.

1 Introduction

The transport offer includes the infrastructure of all transport systems operating in the study area [1]. The main transport systems in transport models are usually individual transport (passenger or freight) and public passenger transport (public transport). Transport demand

* Corresponding author: dziyadullaev@inbox.ru

quantitatively and qualitatively determines the need of network users to move [1]. The main factors of the transport demand are:

• flow-forming factors, i.e., placement of objects generating movement, such as places of residence, places of employment, places of study, places of cultural and consumer services, etc.;

• behavioral factors, such as population mobility, preferences in choosing methods and routes of movement, etc.

The method of constructing transport models reduces the process of solving the problem of the degree of compliance of the existing transport demand with the existing transport supply, i.e., the problem of the distribution of traffic flows.

When addressing optimization issues, including combinatorial optimization, in many cases, large-scale computational processes, resources, and computational time may be required. In such cases, it is not always possible to achieve effective results by intuitively evaluating the solution to the issue [2]. In solving this issue, a solution close to a global solution can be achieved using parallel computing technology.

Effective results can be achieved using parallel computing technologies to solve the problem posed. Here can participate in the calculation process of several processors. For a specific optimization issue, a neural net system is created on the head processor and sent parallel to the remaining processor. In all processors, the results obtained are again collected in the prime processor and selected among them as a solution with the most optimal value. It turns out that the greater the number of processors, the higher the probability of achieving the optimal solution. But an unreasonable increase in the number of processors does not always count as an effective decision [3].

Today, several applications and libraries have been developed for parallel computing technologies. In these tools, the price/efficiency relationship is optimally established. Based on the developed algorithm, a software tool was developed, which provides for the use of the MRJ library.

Several computational experiments were performed based on the developed algorithms. The analysis of the obtained results showed that our proposed artificial neural network algorithms are more efficient in terms of performance and low computational resource requirements than the algorithms based on Hopfield neural network algorithms. However, it should be noted that in cases where the size of the problem is very large, the efficiency of neural network algorithms may decrease due to multiple calculations. It is usually advisable to use multi-agent heuristic algorithms in such cases.

Today, algorithms based on the properties of natural systems are widely used in science and technology. These include genetic algorithms, evolutionary algorithms, artificial neural networks, bee colony algorithms, ant algorithms, and other similar algorithms [4 - 10].

According to the classical theory of intellectual data analysis, building a system for a specific problem requires building an intelligent system so that the system under construction has all the resources directly necessary to solve the problem. In the theory of multi-agent systems, the opposite principle applies. In such systems, one agent can never provide a global solution, so a set of agents is formed, and an effective relationship establishes a link between them. This means that the solution to an arbitrary problem is obtained from the interaction "services" of several simple agents in a multi-agent system. Many scholars, including R. Brooks, J. Deneburg, L. Stile, and others, have relied on the following in this regard [11]:

- A multi-agent system is a simple and interconnected set of agents;
- Each agent identifies its solutions in the local area and shares the results with other agents;

- Relationships between agents are organized horizontally, i.e., there is no lead agent that can influence other agents;
- There is no clear rule defining the global nature of an agent.

Today, algorithms based on the characteristics of collective, multi-agent systems are widely used in practice and give effective results. Such algorithms include "ant" algorithms, "bee colony" algorithms, and others.

Many optimization problems can be solved in different areas of life. In most cases, it is possible to observe the cases of achieving an optimal solution based on substituting variables within a search field, introducing a specific metric, or a set of rules. There is another way to search for an optimal solution, in which the solution is selected from a combination of unique components derived from finite sets. The main goal is to find the optimal combination of components. Typically, such optimization problems are called combinatorial optimization problems.

Combinatorial optimization is part of the theory of optimization in applied mathematics. It is inextricably linked with operations research, algorithm theory, and complex computational theory. The main task of the problem of combinatorial optimization is to search for the optimal object among a limited set of objects.

The combinatorial optimization problems have been studied since the second half of the 18th century. As combinatorial optimization problems, we can take such problems as the problem of the intelligent transport system, the problem of construction of graphs, and the problem of transport. It is usually necessary to develop a complex algorithm to find an exact or approximate solution to such problems.

We will consider the process of using the bee colony algorithm, which is one of the heuristic methods in solving a problem of such complexity, which belongs to the group of multi-agent algorithms. In solving this problem using the bee colony algorithm, parallel programming technology was used to accelerate obtaining a globally optimal solution.

The problem of the intelligent transport system is one of the problems of complex, difficult-to-solve combinatorial optimization. In general, the problem of the intelligent transport system (traveling salesmen problem, TSP) [12] can be classified as follows: several (n) nodes in a particular area and the paths connecting them are given. The sequence of access to all nodes through these paths should be organized so that the traversed path is the shortest distance relative to the traversed tracks in the sequence of the other variant. Each node can be accessed only once during the entire route. The end of the route must be completed by returning to the first node.

We will consider the solution to the intelligent transport system problem based on the bee colonies algorithm. It should be noted that this algorithm significantly speeds up the process of achieving an optimal solution. As a result of solving the problem, it is necessary to create a sequence of nodes to be followed, and the final function is to represent the distance between them, the total sum of the paths.

Typically in a bee colony (e.g., Apis mellifera local bees), bees perform various functions throughout their lives [13]. In particular, a beehive can contain 5,000 to 20,000 bees. As a rule, adult bees (from 20 to 40 days of age) are the main worker, and reserve beekeepers (foragers). These worker bees periodically perform one of the following three functions: active workers, observer workers, and inactive workers. The number of active, observant, and inactive bees in the total number of bees in the hive is distributed in the same way as approximately 75% active, 10% inactive, and 15% observational bees.

2 Methods

It is known that in a bee colony, bees are divided into three groups: active bees, observation bees, and inactive bees. Initially, the observer bees communicate to the active bees information about the nectars in the immediate vicinity and their quality by observing the environment. Active worker bees fly to the source to collect nectar, study the surrounding nectar, collect nectar, and return to the hive. Observers are looking for a new nectar source around the nest (an area of up to 50 square miles or up to 80 square kilometers).

Many worker bees may not be active at any time. They wait around the entrance. The active or the observant bees coming in front of quality nectar perform a special waggle dance in front of these waiting inactive bees. Studies have shown that bees exchange information with the inactive bees about the source of nectar and its quality using this special dance. Based on this dance, inactive bees receive information about nectar and can replace the inactive state with the active state. In turn, several active worker bees can alternate with inactive bees. The duration of the special dance D_i can be expressed based on the following formula [14]:

$$D_i = d_i A, \tag{1}$$

where *A* is the scale factor; d_i is dances; *i* is quantity indicating the relative usefulness, quality, and quantity of nectar found by the agent.

In the general case, when solving an intelligent transport system, the absolute utility of the nectar found by the i-agent can be calculated by the expression, where - F_i - i - objective function on the path of the i-agent.

Knowing the absolute utility of all the bees in the hive, we can calculate the average utilization of the entire colony:

$$PA_{col} = \frac{1}{n}\sum_{j=1}^{n} PA_i, \tag{2}$$

where n is the number of simultaneously dancing bees.

There are several dancing bees, and based on the information provided by one of them, the other worker bees choose their next new direction. The probability of choosing other worker bees according to the information provided by the *i*-agent can be expressed based on the following formula [15]:

Once the desired nectar has been selected, the worker bee begins to fly in that direction of the nectar. In this case, the path to the nectar includes several nodes. The probability of choosing an active bee from the *i*-core is calculated by the following formula [14]:

$$P_{ij} = \frac{\rho_{ij}^{\alpha} d_{ij}^{-\beta}}{\sum_{j \in J^k} \rho_{ij}^{\alpha} d_{ij}^{-\beta}} \tag{3}$$

where is the cost of the path between nodes i and j - heuristic path distance between nodes i and j; experimentally selected coefficients; - i is the set of all nodes that can be traversed.

The parameter value in formula (3) can be calculated using the following formula:

$$\rho_{ij} = \frac{1 - m\alpha}{k - m} \tag{4}$$

where *k* is the number of all nodes that can be passed through i; m is the advantage of the path, the coefficient of convenience, the value of which can be equal to 0 or 1. In the first iteration, $m = 0$ for all paths.

Typically, active worker bees carry nectar from a specific nectar source until the nectar is depleted. The bee then becomes an inactive bee.

Based on the features of the movement of bees in bee colonies, the "Bee colony" algorithm was developed to solve the problem of an intelligent transport system. This algorithm can be expressed based on the following sequences.

Step 1. Initialization. totalNumberBees - number of bees, numberInactive - number of inactive bees, numberScout - number of watcher bees, maxNumberVisits - number of entries to each node, maxNumberCycles - number of iterations.

Step 2. Search for nectar in the immediate vicinity by observer bees. This determines the coordinates of the nearest nodes and stores the results in the BS matrix.

Step 3. The waggle dance is the dance of the watcher bees. In this case, the most optimal (or closest) of the identified nodes is transferred from the BS matrix to the WG matrix.

The duration of the wagging dance is calculated by the formula (1). Here *A* is the scaling factor; d_i is quantity, indicating the relative utility, quality, and quantity of nectar found by the dancing i-observer bee. In this case, the absolute utility coefficient of the node found by the *i* - observer bee is calculated

$$PA_i = \frac{1}{F_i} \tag{5}$$

where F_i - i - objective function on the path of the bee. Knowing the absolute utility of all the dancing bees in the hive PA_{col} , the average utilization of the entire colony is (2).

Step 4. The probability that the information provided by the i-observer bee will be selected by other worker bees can be calculated based on the following formula:

Once the desired node is selected, the worker bee starts flying toward that node. In this case, the path to a node requires passing through several nodes. The probability of choosing the path of an active bee from the i-th node to the j-th node is calculated by the formula (3).

Based on the WG matrix received from observer bees, worker bees spread the nectar and look for new nectars (parameter values) around this nectar. The found data are entered into the NW matrix.

Step 5. Observer bees transfer nectar based on the WG data and learn the best variable, determining the result that gives the most optimal values. The results obtained are stored in the NV matrix.

Step 6. Formation of an archive of new WG decisions based on the existing matrices NW, NB, WG.

Step 7. If the accuracy reaches E or the number of steps from the maxNumberCycles set is met, then the best, optimal path from WG is determined and, based on the result, a sequence of nodes is printed,

Otherwise, the algorithm is repeated from step 2.

Here BS is a random matrix of observer bees, WG is a decision matrix, best is a matrix of optimal solutions, NW is a matrix of new solutions formed by worker bees based on the decision matrix, NB is a matrix of decisions formed by observer bees and the best solutions.

When solving the problem of an intelligent transport system based on the bee colony algorithm, the main node A is a bee nest, and the remaining nodes are a source of nectar or nutrients. In this algorithm, the shortest paths to each nectar are sequentially calculated, and then the sum of the shortest distances to the found nectar is found. This iterative process continues until all existing nodes and nectar sources have been considered. This condition is as strong as the problem of finding a Hamiltonian cycle in the problem of an intelligent transport system.

Using the bee colony algorithm, it is possible to propose a solution to the problem of an intelligent transport system based on a parallel algorithm. In practice, in some cases, tasks solved on the basis of parallel computing technologies can decrease the effectiveness of the results. Dividing large tasks into several independent parallel parts and loading their calculations on different processors can reduce the time spent solving the problem.

3 Results and Discussion

The solution of the combinatorial optimization problem using the bee colony algorithm based on parallel computing technologies showed that the solution of large-scale optimization problems using this algorithm is quite fast and efficient.

In the question discussed above, we saw that increasing the number of nodes can complicate reaching the optimal solution. In such cases, using the Hopfield network may not give sufficient results, i.e., it may require a lot of time and resources for calculations. In such cases, it may be appropriate to use multi-agent heuristic algorithms.

The combinatorial optimization problem may be suitable for using the bee colony algorithm when the number of nodes is very large.

To speed up the process of reaching the global optimal value, we load the algorithm for solving a specific optimization problem, the problem of an intelligent transportation system, on N processors at the same time. These processors obtain their optimal (local) solutions independently of each other. The main processor collects all the results, and the sequence of nodes with the smallest (min) value among them is selected as the optimal solution. At the same time, an increase in the number of processors increases the probability of finding an optimal solution and leads to an increase in computation time.

We conduct computational experiments based on the bee colony algorithm to determine the shortest path between 2000 nodes (X, Y coordinates [1,2000]). It's about 2000! routes in each option and the viewing status of all options require much computing time and resources. As already mentioned, in this case, the Hopfield neural network is inefficient (Fig. 1).

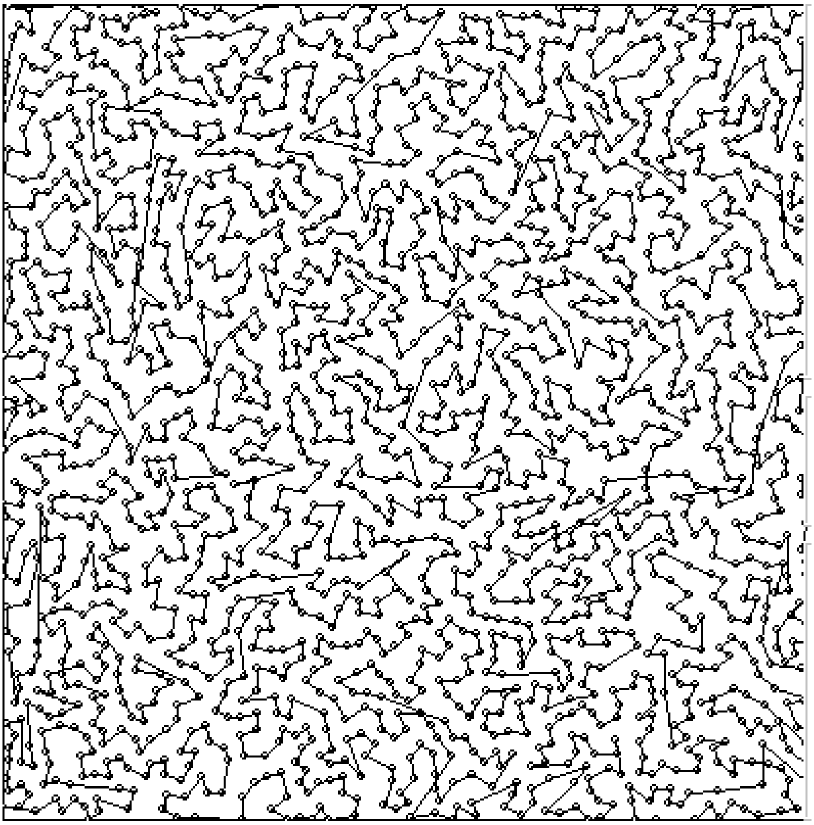

Fig. 1. Solving the problems of an intelligent transport system

The computational experiment results are presented graphically below (fig. 2 and 3).

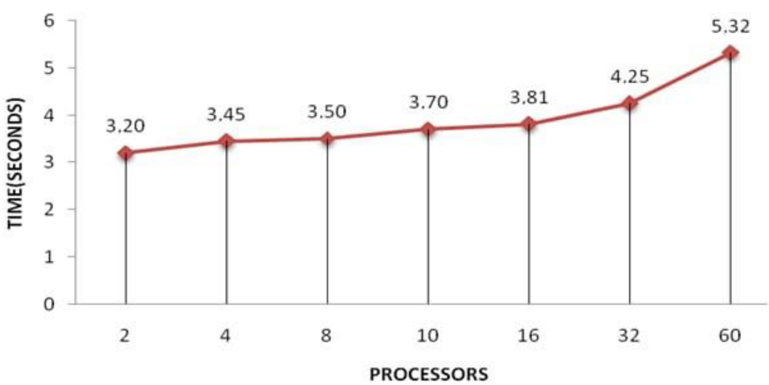

Fig. 2. Dynamics of the dependence of the number of processors on time

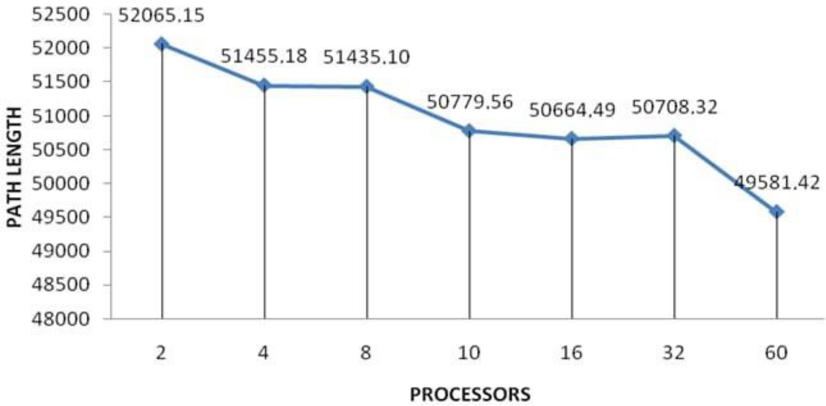

Fig. 3. Graph of the dependence of the number of processors on finding the optimal values

The results of the subsequent analysis showed that the number of processors used to solve this problem improved as the number of processors increased. However, with 32 processors, there was a slight increase in the minimum value in the solution. Although the running time reached a maximum value of 5.32 seconds with 60 processors (processes), in this case, the minimum value of the optimal direction was the lowest - an effective result of 49581.42.

4 Conclusions

When developing transport models, full-scale surveys of routes at key nodes of the transport network were carried out. Part of the observations was obtained in automatic mode with the help of vehicle registration detectors. To collect the rest of the observations, video filming certain network nodes (vertices of the graph) was carried out for several periods. After that, the videos were processed manually; the results were obtained according to the "route observation model". The most informative nodes of the network were selected for the survey.

The clear line is the maximization or minimization of the objective function. However, in many practical cases, it may not be possible to clearly define the decision maker's goal and/or limiting functions but rather to present them in an "ambiguous sense". In such cases, it is advisable to use indefinite linear programming. The work is devoted to studying various models of an indefinite linear programming problem [15-20] and consists of indefinite linear programming, indefinite inequalities, and explicit linear programming problems. Traffic flows are modeled. Models of transport demand and transport supply are built in a detailed form to a specific territory.

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