Application of bionic and immune algorithms for the solution of ambiguous problems of transportation routing

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Abstract. The main objective of the study is to develop efficient methods and algorithms based on the operating principles of the immune system and evolutionary search for further search of a global optimal solution of optimization problems. It is suggested to integrate the modified evolutionary and immune algorithms to solve the set task. Transportation routing is the priority direction in the field of information technologies, industry, transport, and communication systems. Due to increasing demand of enterprises, it is impossible to ensure the efficiency of transport operations without information and software systems for analysis, planning and support of commercial solutions. Therefore, further study of artificial immune systems and algorithms and their integration with genetic algorithms aimed to solve various optimization problems and identify the class of their optimization, for which such systems and algorithms can be applied, as well as to modify the method for new applications, seems quite relevant.

1. Introduction
At present, information resources are highly demanded. In the conditions of unstable telecommunication networks, the transfer of some data to subscribers may seem irrational and be postponed for later period, or even cancelled. Clear restrictions in the majority of modern optimization tasks do not only narrows the search, but also force to make decisions containing elements thus causing the use of unprofitable delivery media. For example, low priority messages will be delivered along overloaded communication channels. Thus, this poses the need for algorithms ensuring the transition from qualitative characteristics to quantitative and vice versa in order to come to adequate solutions in such cases.

In fact, the widespread statement of modern transportation optimization problems means determining some solution satisfying the extreme value of the corresponding objective function. The compliance to the system of set restrictions serves the criterion of correctness of the obtained solution [1]. Another complexity of such tasks is their multidimensionality affecting the objective function and the corresponding restrictions [1].

2. Materials and Methods
Modeling of information transfer implies, inter alia, the use of static and dynamic settings of transportation tasks. The static setting is acceptable, for example, in case of minor changes of parameters influencing the implementation of problem solution and lack of short peak loads. The dynamic setting is caused by the need to correct the implementation of the obtained solution, i.e. adaptation of the solution to hardly formalized factors of the real world. Dynamism also means the reevaluation of the importance of transmitted data. The dynamism of distribution implies the need for variable description of parameters regarding the considered optimization task. Matrix models providing for the study of data flows between different structural elements (departments, services, workplaces) in various segments are
quite suitable for the mathematical description of information flows. Such models are described via a certain set of matrixes, while modeling transformations are made via standard matrix operations [9, 10].

In classical setting, the static transportation task is formulated as follows: there is \( n \) of resource sources and \( m \) of resource consumers. For each source \( i \) the production volume \( (A) \) of a resource \( a[ij]>0 \) is set, and for each consumer \( j \) the volume of consumption \( (B) \) \( b[jj]>0 \) is set. The cost of transfer of a conventional unit of resource between \( i \) source and \( j \) consumer equals \( c[i,j] \). The cost schedule \( C[A,B] \) is set. One shall strive for the minimum total cost [11, 12].

In case of a closed task, the following equality is fair:

\[
\sum_{i=1}^{n} a[i] = \sum_{j=1}^{m} b[j]
\]

In case of practical optimization of distribution of information resources, the optimization task cannot be fully closed due to the need for retransmission of resources under the influence of noises, network collisions, etc.

In practice, as a rule, we deal with nonlinear transportation problems [4]: \( \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij}(x_{ij}) \to \min \), where \( c_{ij}(x_{ij}) \) – costs of transmission \( x_{ij} \) of resource units from \( i \) source to \( j \) consumer.

The weakness of modern adaptation algorithms solving problems with uncertainty of the objective function or the constraint system is the definition of necessary and sufficient degree of correction of the computation process, which ensures acceptable quality and admissible required computing resources [12]. Methods of process modeling in real life are considered promising for the solution of optimization problems [7].

The Artificial Immune Algorithms (AIA) are self-adaptive algorithm algorithms that appeared from the operation schemes of biological immune systems, which use the mechanisms described in theoretical immunology. Possible variations of immune algorithms are used in various research fields and production. Immune algorithms have the same fields of application as bionic systems, but as practice shows, their integration allows receiving the best result for the best operating time of an algorithm. Immune algorithms are considered as antigens – applicants for solutions, and the qualities of candidates of the solution correspond to nearest between antibodies and antigens. The search of possible solutions is similar to the recognition of antigens by immune cells and the immune response within the immune system [1].

The solution of a transportation problem can be obtained with clear initial parameters, but if these parameters have a minor error, then the result will not reach the set accuracy [2]. Therefore, to search the best solution considering the influence of any data and conditions regarding initial parameters, there is a need to apply the integration of bioinspired and immune search. This search implies the use of a variety of natural parameters of the optimization task [3].

Fig. 1 shows the scheme of the integrated search aimed at the best result for the solution of transportation problems based on bionic search (BS). The initial population is formed through Heuristic Algorithms (HA) and cloning of a set of obtained solutions. The integration of BS and HA will give the best solutions, i.e. the obtained solutions considering the adjustment of all parameters are better adapted for external changing environment [4].

With reference to the obtained values of the objective function the sorting of population of solutions is made. As a result of the modified immune algorithm (MIA) we receive a new subset of solutions [5]. The automated adjustment of algorithms taking into account the training of artificial immune algorithm is required for the optimal performance of a hybrid algorithm considering the elements of adaptation and artificial immune algorithms.
3. Results and Discussion

It is suggested to implement the immune algorithm by calculating the objective function justified by the parameters of the optimization task. For the considered case, the algorithm may be based on the subpopulation function. The search procedure covers parallelization of initial population into several subpopulations. Genetic operators of mutation, crossing-over, etc. are applied $j$ times to individuals of each subgroup, then there is an exchange of individuals. The sets of alternative solutions received through cloning of solutions obtained via heuristic algorithms are used to form the initial population. The interaction between EDS and heuristic algorithms ensures the adaptation of sets of parameters and focus on the best solution. The obtained values of the objective function make it possible to sort the solution population. As a result of MIA and MEA a new subset of solutions is obtained. The Dr-aiNet block works with adjustment of the population size of the obtained MIA. With the increase in the population dimension the immune algorithm does not always give 100% result, therefore the development of a hybrid algorithm taking into account evolutionary, genetic and immune algorithms most often gives the best results. The choice of applied evolution model is made in the block of evolutionary adaptation, it allows changing the order of GO and search schemes [6]. The following mechanism of the population sorting is proposed: if the size of the population of chromosomes with the “best” values reaches the set condition, the size of the population remains invariable and if the size of the population of chromosomes with the “best” values is low, the size of the population increases. Thus, the hybrid algorithm maintains a variety and balance of the population, and the proposed mechanism

Figure 1. Scheme of the integrated search for the solution of transportation tasks
gives the chance to regulate the direction of search and to accelerate the convergence of the algorithm, as well as to store the obtained illegal solutions in a file for further analysis [7].

Fig. 2 shows the modified AIA based on the “theory of danger”. This algorithm is based on biological immune systems [8].

After forming the population the algorithm divides the population into two subpopulations with the best and the worst solutions (danger zone). For the first population the subpopulation cloning is carried out. Then the operator of mutation with the set probability is applied to obtained clones-descendants. The parent of clones remains invariable. A new population is formed taking into account the fitness function. The algorithm of single-point mutation with random probability is applied to the second subpopulation.

Subpopulation makes sorting and ranging. All obtained chromosomes form a new population. Then there is an exchange of populations between MIA and MEA, sorting and ranging.

The danger signal may be interpreted as the obtained information on the objective function (set of “bad” solutions getting to a danger zone). Hence, the solutions getting to a danger zone are exposed to stimulations. Taking this into account, it is possible to define the danger signal as the identifier for the benefit of the user. Considering this definition, it is possible to present various scenarios where the danger signal may be useful.

The use of alternative adaptation methods allows intellectualizing the control of the algorithm related to the solution of the optimization problem (in this case a genetic algorithm). This approach allows setting specific control alternatives depending on the algorithm related to the solution of the optimization

Figure 2. Scheme of the modified AIA
problem. The adaptation change realized due to reduction/increase in the number of states corresponding to each alternative allows controlling the delayed action of the immune response.

The modified AIA with the same source data exceeds the quality of solutions obtained by classical methods and simple genetic algorithms at considerable dimensions of a task n>800. The control over the integrated search allows defining the optimum parameters and improving the quality of solutions by approximately 15%-20%.

Now as decoders accurate characteristics of technological processes are, as a rule, used (for example, [13] suggest carrying on-line control of the milling equipment on the basis of accurate detectors, and in work [14] the serviceability check of a bearing). The method based on the theory of danger supplementing the selection of intermediate solutions is used. The principle of a classical theory of danger includes the creation of decoders – object instances describing unacceptable situations. The equivalence of a controlled object against the decoder represents the sign of emergency demanding immediate response. It is suggested to use fuzzy set adjectives describing the compliance of emergency controlled parameter like decoders.

Modern evolutionary methods of optimization of bionic algorithms, such as the Particle Swarm Optimization or the Ant Colony Optimization, adjust the search based on approximation (removal) of agents to the optimum. The supply of such methods with a possibility of immune response allows considering the proximity of an agent to the area of forbidden solutions in the analysis of intermediate solutions.

4. Conclusions
The paper describes the main requirements to mathematical models of chosen indistinct transportation problems and algorithms of their solution. It is shown that for adequate description of the distributive dynamics it is necessary to use complex data structures, while the accounting of internal and external relations of the modelled system requires multidimensional information arrays. The proposed algorithm of immune response is based on the method of alternative adaptation ensuring the intellectual choice from the set of admissible strategies.

Methods of search management are developed:
- change of evolutionary search architecture (interpopulation exchange, set of operators and sequence of their use, criteria for evaluation of solution prospects, etc.);
- change of evolutionary algorithms parameters (quantity of individuals in a population, number of iterations, probability of rejection of individuals, etc.);
- change of the adaptation strategy (quantity of supported alternatives and thus corresponding states, transition mechanisms between states etc.). The scientific novelty of these methods includes the use of the artificial immune system based on the theory of danger, which evaluates the proximity of current solution to the area of “bad” solutions aimed to determine the operating impacts on the computation process.

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