Research on Resource Allocation Method in Universities Based on User Participation

Cong Liu
Computer and Information Management Center, Tsinghua University, Beijing, China
e-mail: lc@cic.tsinghua.edu.cn

Abstract—Resource allocation problem in universities belongs to office automation research issues, which is one of the important businesses for management departments in universities. Aiming at “Just, Fair and Open” principle and purpose of user-oriented resource management, rational allocation by means of informatization and efficient use of resources is certainly an effective way. In this paper, we study the problem of resource allocation method in universities with user participation. A layered reference model of reservation system for university resources is presented. Taking multiple constraints into account, including user satisfaction, resource utilization, user coverage etc., the resource allocation is made much fit to the actual situation, however, the problem complexity increases correspondingly, leading to the adoption of an intelligent algorithm solution. Hence, an improved ant-colony-optimization-based resource allocation algorithm with user participation is proposed. By feasibility analysis of algorithm, it is shown that the proposed algorithm to solve the multi-objective optimization problem with multi-constraint is feasible and valid. As the layered idea of the model is applicable to other system, so it has broad application value.

Keywords—resource allocation; user participation; university office automation; ant colony optimization; optimization problem; multi-constraint; multi-objective

I. INTRODUCTION

Resources are the basis for the development of the colleges and universities and the essential guarantee for higher education quality as well. However, the growth speed of the resources is greatly far away from meeting with the demand for resources needed in the actual situation. With the expansion of colleges and universities, will inevitably lead to the per capita possession of resources reduces relatively. In recent years, university informatization as an important part of the university businesses has been paid more attention with the leaders, teachers and students in the universities. Through the implementation of university informatization, promotion of teaching, research, management and service level and improvement of the university core competitiveness have increasingly become a consensus. Among them, how to manage the university resources (i.e. classrooms, laboratories, instruments or equipments, activity fields, etc.) effectively, improve the resource utilization and grasp the situation of resource usage are the important issues to be resolve urgently for relevant administrative departments in the universities [1].

The problem of resource allocation with user participation is the procedure to allocate the limited resources according to users’ subjective demands, so that make sure the results are conflict-free and reasonable, even have practical effect to meet with some particular needs. We can divide that the task requirements into two categories, i.e. hard constraints and soft constraints. Solving the issue is to obtain the Pareto optimal solution based on the constraints where meets the hard constraints absolutely and satisfies soft constraints as much as possible.

The so-called hard constraints are the conditions as the basis requirements to guarantee conflict-free arrangement among users and resources. By the way, these conditions are generally fixed, which do not vary with the specific circumstances. The following conditions are the hard constraints in the resource allocation, such as,

1) The number of the success reservation for one user during the same time is less than or equal to 1.

2) The number of the users reserving the same resource during the same time is less than or equal to 1.

The so-called soft constraints are optional constraints on the basis of meeting hard ones. These kinds of constraints are some particular requirements in practice or rules to ensure that the assignment is more scientific and rational. It is a measure standard whether the allocation algorithm is good or not, based on the actual usage of the specific resources. The following conditions are the soft constraints in the problem, such as,

1) User satisfaction is as high as possible.

2) Resource utilization is as high as possible.

3) The number of users successfully reserving is as high as possible.

4) The total time of the success reservation for one user during a certain period is less than or equal to the limited time.

5) The total time of the continuous use for one user reserving the same resource is less than or equal to the limited time.

The rest of this paper is organized as follows. In Section II, a layered reference model of reservation system for university resources is presented. Section III describes the introduction of the Ant Colony Optimization (ACO) algorithm. In Section IV, an improved ACO-based resource allocation algorithm with user participation is proposed, which is an implementation mechanism for the core module.
Finally, the paper concludes with a summary of the results and suggests the future works in Section V.

II. LAYERED REFERENCE MODEL

A. Concept model

In fact, the resource allocation is the result set of mappings from users to resources in accordance with certain rules. Reasonable resource configuration to improve resource utilization is to optimize resource allocation, which to obtain an optimal result set of mappings from users to resources according to certain rules. The concept model shown in Fig.1 gives a uniform solution to define, explain, supervise and manage throughout the life cycle of the resource reservation in universities.

![Figure 1. A concept model of the proposed problem](image1)

From the perspective of above model, Resource Manager is a function entity responsible for the control and allocation of users and resources. Rule Service is a function entity to provide corresponding resource rules from the Rule Database which is used to store reservation rules of various types of resources. Authorized Authentication Center is a function entity to issue the identity certificate. Users, i.e. organization or individual user, can reserve resources only through authorized authentication.

B. Layered reference model

A layered reference model of reservation system for university resources is given based on corresponding concept model, which is layered structure and modularity, shown in Fig.2.

The bottom layer is the Hardware Platform, including all kinds of server hardware, print device, etc. The lowest layer of software is the Operating System Platform which can provide a well graphic user interface, application program interface and multi-task mechanism. The Application Software is the upper layer, where its internal structure is modular. The core of this layer is the General Control Module, and its responsibility is for the coordination of the entire system, efficient operations and reasonable resource allocation. In this layer, Human-machine Interface calls for beautiful, simple and easy to use; Resource Management Module is responsible for maintenance management of resources; User Management Module implements user management, and combining Authorization Management Module is realizing the user authentication; Rule Management Module manages a variety of restriction rules for resource usage; Monitoring and management of the reservation system can be achieved by Procedure/Logic Control Module and Algorithm Module; Evaluation/Statistic Module can be used to conduct evaluation and statistics of the resource allocation and usage as convenient for the leadership decision-making. External Interface Module provides all kind of interfaces for MIS system, decision-making system, database system etc., and can exchange information with these systems, so interface functions is convenient for connection and integration with other systems. All above modules are integrated into a complete system, achieving a seamless interface between the module and the smooth upgrading of versions.

![Figure 2. A layered reference model of reservation system for university resources](image2)

III. THE ANT COLONY OPTIMIZATION ALGORITHM

The algorithm that we developed for the stated problem is based on ACO. ACO is a metaheuristic proposed by Dorigo et al. [2]. The inspiration of ACO is the foraging behavior of real ants. In nature, ants initially wander in the field to search food. When an ant finds food, it returns to its colony laying down a pheromone trail, which attracts other ants. Once a pheromone trail is laid down, other ants are likely to follow the pheromone trail. If the ants eventually find food along the trail, they return to their colony reinforcing the pheromone trail. On the other hand, the pheromone evaporates with time. As a result, the amount of pheromone on paths along which many ants transit frequently such as the shortest path become and remain high. In general, it takes a short time until pheromone accumulates on the path, and the majority of ants will follow on the path. It gives the distinction described in Fig.3.

![Figure 3. To illustrate of how real ants can lead to identify the shortest path around an obstacle. Figure from [3]](image3)

ACO has been applied successfully to numerous combinatorial optimization problems including the traveling salesman problem [4], quadratic assignment problem [5], scheduling problems [6], and others. In this paper, we design
a resource allocation algorithm in universities with user participation based on the improved ACO.

IV. AN IMPROVED ACO-BASED RESOURCE ALLOCATION ALGORITHM WITH USER PARTICIPATION

A. Preprocessing Problem

Before describing the actual algorithm, there is number of issues that should be clearly defined. As an important module, the resource allocation algorithm module is required to be connected with other modules smoothly and need to be prepared for pre-processing operation accordingly, including data processing and system settings.

- Rule Management Module. Based on web information system, an administrator manages the reservation rules according to the actual situation, e.g. setting allocation cycle, reservation length constraint in the allocation sub-cycle, timeslots, continuous usage restriction, the maximum number of reservation requirements, etc.
- Resource Management Module. Based on web information system, an administrator manages all the resources, e.g. setting each resource property, which is occupied leading to resource unavailable, etc.
- Human-machine Interface. Based on web information system, obtain all the user reservation requirements within a resource allocation cycle. It is forbidden for one user to successfully reserve more than one resource at the same time. Thus, we check and restrict users to apply invalid requirements in this module, not only to meet the hard constraints 1), but also to improve the performance of the algorithm.
- Evaluation/Statistic Module. Based on Web information system, users can feedback the results of user satisfaction with the history of reservation cases, to facilitate implementation of the algorithm into account.

B. Problem Formulation

We assume that the resources to be allocated are in the same or similar classification having the same reservation rules. In the model of the resource allocation with user participation, there are too many factors to be considered. Due to non-profit nature of the resources in the universities, we do not consider the cost factors such as reservation fees and maintenance costs etc., and leave aside the issue of adjustment after the allocation of resources. Here, it is assumed that users are specific to independent individuals, if there is the reservation for departments, it can be put into the personal mode. Finally, we assume that the timeslots are divided into each unit time and all the length of the allocation sub-cycle is identical except the last one for simplicity.

Here are the notations that are used throughout this paper.

- \( T \) - a set of timeslots, representing the smallest time interval for resource usage, i.e. \( T=\{1,2,\ldots,|T|\} \).
- \(|T|\) - a number of timeslots in the set \( T \).
- \( t \) - a timeslot from the set \( T \), i.e. \( t \in T,0 < t \leq |T| \).
- \( r \) - a resource entity from the set \( R \), i.e. \( r \in R,0 < r \leq |R| \).
- \( D \) - a set of allocation cycles, i.e. \( D=\{1,2,\ldots,|D|\} \).
- \(|D|\) - a number of allocation cycles in the set \( D \).
- \( s \) - a number of allocation sub-cycles.
- \( D_i \) - the \( i \)th allocation sub-cycle, i.e. \( D=\{D_1,D_2,\ldots,D_s\}, D_i \subseteq D,0 < i \leq s \).
- \(|D_i|\) - length of the \( i \)th allocation sub-cycle, i.e. \(|D_1|+|D_2|+\ldots+|D_s| = |D|\).
- \( P \) - a set of reservation users, i.e. \( P=\{1,2,\ldots,|P|\} \).
- \(|P|\) - a number of reservation users in the set \( P \).
- \( p \) - a reservation user from the set \( P \), i.e. \( p \in P,0 < p \leq |P| \).
- \( U \) - a set of resource units, a resource unit is a unique resource/allocation cycle/timeslots combination, i.e. \( U=\{1,2,\ldots,|U|\} \).
- \(|U|\) - a number of resource units, i.e. \(|U| = |R| \cdot |D| \cdot |T| \).
- \( l \) - reservation length constraint, representing the longest time allowing user to reserve in the allocation sub-cycle, usually measured in hour.
- \( T' \) - continuous usage restriction, representing the maximum continuous time limitation for a user usage of a resource.

Definition 1. User Region is the set of users who reserve the same resource unit.

Definition 2. Resource Region is the set of resource units which are in the same allocation sub-cycle.

The model of the resource allocation with user participation is as follows.

In the above model, each grid represents a resource unit, in which the nodes indicate all the users reserving the same resource unit, i.e. User Region. And the area within the dashed box represents a Resource Region. Here, a user can appear in more than one resource unit, but only one user (i.e. node) is selected in each resource unit which satisfying the hard constraints 2). Meanwhile, the number of the successful reservation requirements for one user in a certain resource region cannot exceed \( l \) and the continuous use of a resource for same user cannot exceed \( T' \) either. Thus, a connected graph \( G=(V,E) \) is constructed to express the solution of the problem, where \( V \) represents the set of the successful reservation users in all user region, i.e. the set of the successful user requirements, and \( E \) represents the set of the edges where each edge connects two nodes belong to two
adjacent valid resource units respectively according to certain rules.

Taking description and basic assumption of the problem into account, it can be considered as a multi-constraint and multi-objective programming problem, aiming to optimize the user satisfaction, resource utilization and user coverage (i.e. the number of the successful reservation users), meanwhile satisfy the soft constraints 4) and 5). As the number of the subscribers is usually far greater than the number of the resources, leading to more failed requirements, so it is not obvious to make user satisfaction influence the object function. Thus the mathematical model of the problem is stated as follows.

\[ \text{Maximize}(RU(U)) \] \hspace{1cm} (1)

\[ \text{Maximize}(PC(P)) \] \hspace{1cm} (2)

s.t.

\[ \forall v_a, v_b \in U, m \neq n, v_a \in V, v_b \notin V. \] \hspace{1cm} (3)

\[ 0 \leq RP(p_i, D_j) \leq l, 0 < i \leq s. \] \hspace{1cm} (4)

\[ 0 \leq CU(p_i, U) \leq T'. \] \hspace{1cm} (5)

where \( RU(U) \) is the resource utilization function and \( PC(P) \) is the user coverage function; Formula (4) and (5) satisfy the soft constraints 4) and 5) respectively while formula (3) satisfies the hard constraints 2); Hard constraints 1) and soft constraints 1) are dealt with in the sec. IV. A and later section respectively.

The fitness value of solution is obtained by fitness function \( f \), which is determined by the resource utilization and user coverage. The fitness function is defined as follows.

\[ f = [w_1 \cdot RU(U) + w_2 \cdot PC(P)]. \] \hspace{1cm} (6)

\[ RU(U) = |V|/|U|. \] \hspace{1cm} (7)

\[ PC(P) = N_p/|P|. \] \hspace{1cm} (8)

where \( w_1 \) and \( w_2 \) are two coefficients, representing function weights above respectively, which can be set and adjusted by experiments, but must satisfy \( w_1 + w_2 = 1 \); Formula (7) represents resource utilization, where \( |V| \) is the number of the nodes in \( G \); Formula (8) represents user coverage, where \( N_p \) is the number of the successful reservation users, usually \( N_p \neq |V| \).

C. Algorithm Description

1) Node-based pheromone and heuristic information design

In the process of building a solution, ants need to repeat two basic decision-making processes: 1) select the next resource unit; 2) select one user in this resource unit (i.e. user region) as the successful one. Different from the usual cases, the pheromone \( \tau_{ij} \) and heuristic information \( \eta_{ij} \) are related to nodes, but no longer related to edges, which is more clearly describing the nature of the problem. Heuristic information takes reservation priority and the historical user satisfaction into account, expressed by the following formula.

\[ \eta_j = \gamma \cdot \frac{N_j}{\text{Seq}_j} + r_1 \cdot \gamma \cdot \text{Sat}(j). \] \hspace{1cm} (9)

where \( r_1 \) and \( r_2 \) are two coefficients, representing function weights above respectively, which can be set and adjusted by experiments, but must satisfy \( r_1 + r_2 = 1 \); \( \text{Seq}_j \) represents the requirement order No. for user \( j \); \( N_j \) is the maximum number of the experiments of the user \( j \) requirements in the corresponding allocation sub-cycle; \( \text{Sat}(j) \) represents user \( j \) satisfaction of the historical reservation; \( \gamma \) is a constant and \( i \) is the upstream node of \( j \).

Let the initial pheromone trail as follows.

\[ \tau_{ij} = \frac{1}{C(e)}. \] \hspace{1cm} (10)

where \( C(e) \) is the number of users in the user region \( e \); and \( \tau_{ij} \) represents initial pheromone trail of each node in the user region \( e \).

2) Algorithm improved strategy

The pheromone trail is updated through a fixed amount of information in proportion to change in the traditional ACO primarily, which is prone to stagnation or premature phenomenon. To avoid such cases, this paper uses an improved ACO (MAX-MIN ant system, MMAS [7,8]) for reference under making certain adjustments and modification. The differences between the improved algorithm and the basic algorithm are as follows.

a) Pheromone trails limitation

The size of pheromone trail on each node is limited to a certain range \([\tau_{\text{min}}, \tau_{\text{max}}]\) in order to avoid premature stagnation. Pheromone trail update therefore is completed using the following formula (11). Thus, the search intensification versus diversification may be balanced.

\[ \tau_{ij}(t) = \begin{cases} \tau_{\text{max}}, & \text{if } \tau_{ij}(t) < \tau_{\text{min}} \vspace{0.1cm} \\ \tau_{ij}(t), & \text{if } \tau_{ij}(t) > \tau_{\text{max}} \vspace{0.1cm} \\ \tau_{ij}(t) - \frac{\tau_{\text{min}} - \tau_{ij}(t)}{\tau_{\text{max}} - \tau_{ij}(t)}, & \text{otherwise} \end{cases} \] \hspace{1cm} (11)

b) State transition rule

A set of artificial ants is initially created. Each ant follows three-step, firstly to choose a resource region randomly, secondly to select a resource unit randomly in the chosen resource region, thirdly to pick a node (user) in the selected resource unit according to formula (12).

\[ j = \begin{cases} \arg\max_{q \leq q_s} \frac{[\tau_{ij}(t)]^q - [\eta_{ij}(t)]^q}{M}, & \text{if } q \leq q_s \\ \text{otherwise} \end{cases} \] \hspace{1cm} (12)

\[ p_j = \begin{cases} \frac{[\tau_{ij}(t)]^q - [\eta_{ij}(t)]^q}{\sum_{i \in L} [\tau_{ij}(t)]^q - [\eta_{ij}(t)]^q}, & j \in L \\ 0, & \text{otherwise} \end{cases} \] \hspace{1cm} (13)
where \( q \) is a random number uniformly distributed in \([0,1]\), and \( q_0 \) is a parameter, \( L \) is the available users in the selected resource unit with no violating the constraints yet. The parameter \( q_0 \) determines the relative importance of exploitation versus exploration. In the other hand, with probability \( q_0 \) the ant makes the best possible move as marked by pheromone trails and the heuristic information. \( M \) is a random variable selected according to the probability distribution is implemented by formula (13).

**c) Pheromone update rule**

An alternate strategy of pheromone update is proposed in the algorithm. The pheromone is updated either by the best solution of a given iteration (i.e. *local best*), or by the global best solution (i.e. *global best*). Two kinds of updates are chosen with certain probability. In early iterations, more and more iterations use the *local best* to update pheromones to help obtaining a larger search range. With the increasing of iteration number, more and more iterations use the *global best* to update pheromones to accelerate the process of convergence to the optimal solution.

\[
\tau_{ij} = \begin{cases} 
(1-\rho) \cdot \tau_{ij}^r + Q, & \text{if } j \text{ is in local / global best} \\
(1-\rho) \cdot \tau_{ij}, & \text{otherwise}
\end{cases}
\]

where \( \rho \) is pheromone evaporation rate, \( \rho_0 \in [0,1] \), \( Q \) is the pheromone strength to release, and \( f \) is the fitness value of local or global best solution.

Due to the limited space, the description of the proposed algorithm flow is omitted in this paper.

**D. Feasibility Analysis of Algorithm**

According to the formal description of ACO, the nature of the algorithm is kind of pheromone-mediated, indirectly spreading information of the optimal solution via swarm intelligence, gradually converging approach to solve the optimal solution algorithm, so it is often used to solve various combinatorial optimization problems. As resource allocation with user participation is a multi-constraint combinatorial optimization problem, it is therefore great applicable to solve the problem from the perspective of ACO.

In ACO, pheromones as the medium to exchange and transmit information of the optimal solution indirectly between individuals reflect swarm intelligence, thus ACO has a strong innate parallelism and distributed nature. These features provide a convenience to solve the problem based on ACO, helping to improve search performance.

ACO has a strong ability to find better solutions. As the principle of positive feedback in the algorithm itself, accelerate the evolutionary process, so solving combinatorial optimization problems based on ACO is usually faster. Of course, this feature also makes the ACO for optimal accuracy is not high, often can only find the suboptimal solution. As many applications have real-time requirements, in many cases, it is more important to reduce time than to obtain the optimal solution. Therefore, ACO is more suitable for issues of real-time requirements.

ACO has strong robustness, less demanding on the initial conditions, running without intervention characteristics, which makes the ACO in complex issues easier to control.

**V. CONCLUSION**

Resource allocation with user participation arises not only in universities but also in many application areas, whose method is the key issue that needs to be addressed in such kind of problem, i.e. the multi-objective optimization problem with multi-constraint. The paper analyzes the key issues when they are applied in our problem. Through deep analysis, establish a layered reference model of the problem, and propose an intelligent computational method which derived from nature to implement the Algorithm Module. In the proposed algorithm, the improvement schemes are designed according to characteristics of reservation, allocation method and ACO. Future research topics include extending the framework to support universal resource allocation problem, building a simulation platform and trying to improve the algorithm performance further using cloud computing.

**ACKNOWLEDGMENT**

The author would like to thank Ruiwei Meng for excellent technical support and critically reviewing the manuscript.

**REFERENCES**


