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## An Artificial Immune Algorithm for HHC Planning Based on multi-Agent System

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### Abstract

This paper presents the home health care routing and scheduling problem as the vehicle routing problem with time windows (VRPTW). We propose a dynamic approach for home care planning to ensure the continuity of care for patients. The proposed approach aims to optimize the care plan route of each caregiver according to their skills, availabilities and preferences. We aim also to minimize the violation of time windows in order to maximize patient and caregiver's satisfaction. The optimal plan route is generated with a population-based algorithm which is the Artificial Immune Algorithm (AIS). A multi-agent approach is used to ensure communication and coordination between the different actors.

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**Keywords:** Home Health Care; routing and scheduling problem; Vehicle Routing Problem with Time Window(VRPTW); Artificial Immune Algorithm (AIS); Multi-Agent System (MAS).

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## Introduction

Home Health Care (HHC) offers support and care services such as medical, paramedical and social services for patients with clinical diseases in the comfort of their homes. Several services are provided by caregivers depending on the patient's needs. They can be nurses, auxiliary nurses, doctor or treating physician [1]. This Home Health Care is a new alternative to traditional hospitalization that can lead to a reduction in the congestion of hospitals and to improve the life condition of patients. Recently, HHC has experienced rapid growth in different countries and its organization involves many complex issues which are classified into three main problems [2]: the assignment problem, the partitioning problem and the routing and scheduling problem. In this paper, we focus on the routing and scheduling problem, which is considered the major issue studied in the literature. The aim is to design an optimal care plan in order to provide some services to be dispatched to patients' homes while factoring in certain constraints (patient's time window, caregiver's lunch break, caregiver's qualification). The remainder of this paper is structured as follows. In section 2, we describe some concepts related to our problem. In section 3, we present some related work. In section 4, we present our proposed solution with AIS. Finally, section 5 is dedicated to the conclusion.

## 1. Overview

### 1.1. Solution methodology

In the literature, many optimization algorithms have been proposed to solve the HHC Routing and Scheduling problem. These algorithms include exact and approximate algorithms. Exact methods are used to find the optimal solution for a combinatorial optimization problem. This obtained solution is optimal for every instance of the problem. Among these methods, we cite Branch and Bound (B&B), Constraint Programming, Branch and Price and Dynamic Programming. However, these algorithms are not efficient in solving larger-scale combinatorial and highly non-linear optimization problems [3]. Hence, meta-heuristic algorithms have shown satisfactory capabilities to handle high dimensional optimization problems. A metaheuristic is a heuristic or a higher-level procedure to find a sufficiently good solution to an optimization problem. This solution method includes Simulated Annealing (SA), Tabu Search (TS) and evolutionary algorithm which contains Genetic Algorithms (GA) and Artificial Immune System Algorithm (AIS). Aickelin et al. [10] presents a comparison between Genetic Algorithm (GA) and AIS. The authors highlight that AIS offers powerful and robust information processing capabilities for solving complex problems thanks to the ability property of distinguishing between the good cells and potentially harmful ones (antigens). Unlike genetic algorithm which is slow in terms of computational time than the other methods. Also, choosing an implementation of encoding and fitness function is difficult in GA. AIS is a computational intelligence paradigm inspired by the biological immune system [4]. The main goal of the natural immune system is to protect the human body from the attack of foreign (harmful) organisms. These foreign organisms are called antigens [5]. Artificial Immune System (AIS) for optimization have been implemented in different ways. For instance, immune algorithms developed by Bersini and varela [6], and Toma et al [7] are based on the immune network theory while other researchers such as Cui et al [8], and Coello Coello and Cortes [9] developed AIS based on the concepts of clonal selection principle. The basic procedure of the AIS follows 9 steps: (1) Identify the antigen. (2) Generate the initial. (3) Calculate the affinity values. (4) Select the antibodies starting with the lowest affinity. (5) Update the memory cell. (6) Clone the best antibodies. (7) Mutate the antibodies with some predefined ratio. (8) Calculate the new affinity values of each antibody. (9) Repeat steps 3 through 8 while the minimum error criterion is not met.

### 1.2. The multi-agent approach

Multi-Agent Systems (MAS) have gained tremendous attention in different disciplines. The MAS concept depends on agent property. An agent could be a software or a human. It is characterized by autonomy which means being able to make decisions without any external intervention. It is also proactive as behavior is goal-directed, and reactive as it is able to respond to changes on their environment. Additionally, it may able to learn from past occurrences. Finally, agent is social considering that it interacts, including negotiation [11]. However, a Multi-Agent Systems (MAS) area collection of collaborative agents in order to perform different tasks. This latter offers several features such as: the

parallel processing (many agents realize the same task to reduce the individual work) and the management and the coordination between the agents. In fact, applying centralized approaches to solve both problems: assigning patients to caregivers and planning the caregivers' routes present some limits. For instance, the lack of communication and coordination between the stakeholders where the decisions are made with no feedback from real-time situations. Therefore, using Multi-Agent Systems (MAS) for modeling and solving real-world problems ensures good communication and coordination between the different actors involved.

## 2. Literature Review

In the literature, The HHC routing and scheduling problem is characterized with three main aspects which are: objectives, constraints and solution methodology. In this context, this problem has been solved as a single-objective optimization and as a multi-objective optimization. The most common objective is the travel time cost minimization. Other objectives have been studied that are related to the service quality, caregivers' preferences, and overtime. As an example, Rasmussen et al [12] who seek to minimize the sum of the travel cost and the penalty for unvisited clients. As well, Tohidifard et al [14] aim to minimize the distance and time of the traveling tour, the number of vehicles and the transportation cost while maximize the patients' satisfaction.

However, in this work, we consider the problem as a multi-objective optimization problem while minimizing the traveling cost, minimizing the violation of time window preferences, and maximizing patient and caregiver satisfaction. Thus, to achieve these different objectives, multiple constraints must be considered.

In the major studies, the most common constraints used are time window, caregiver qualification and working time regulations. Such as [14] and [12] have used time window and caregiver qualification constraints in their approaches. But there are other constraints that are less frequent such as lunch breaks, synchronization visit (where a patient requires the simultaneous presence of two or more caregivers for his care) and real-time scheduling (when there are unexpected events faces in the route).

In the reviewed papers, the authors used certain methodologies to solve this problem. These methodologies are classified into three categories: exact methods, heuristics and metaheuristics. Due to the fact that the search space increases with the problem size in the optimization problem and computational time, exact methods are not able to provide an approximate solution. Also, the classical approximate optimization methods like greedy algorithms require making several assumptions [3]. As a result, using the evolutionary algorithm as solution methodology for solving the routing and scheduling problem. Additionally, many experiments result in different fields have shown that the artificial immune system algorithm (AIS) is a powerful evolutionary algorithm than the other algorithms in solving the different problem, especially in the optimization problem. It can achieve the optimal solution in a reasonable time. The comparative studies done by Youssef et al [18] and Ulker [19] have confirmed the effectiveness and the efficiency of this algorithm to solve combinatorial problems.

Furthermore, many other studies in literature used a multi agent system in home health care scheduling problem. Such as [13] who provide a new way of solving a large caregiver routing problem using the caregiver's ability to dynamically design his own route. The aim of their work is to solve the routing problem in a dynamic context using a Multi-Agent System. Also, Lamine et al [15] have designed an interactive ICT platform to support care planning and coordination between actors in order to ensure the continuity of care.

In this paper, we present a dynamic approach with multi-objective for the resolution of this problem. Artificial Immune Algorithm is applied in order to generate the optimal route of each caregiver. The difference between our contribution and the other proposed approach is not only route planning but also at the level of the assignment of the caregivers with consideration of multiple constraints. Some of these constraints are related to caregivers and others related to patients. However, the various constraints that are taken in account in our study are: (i) Time Window (TW), (ii) Working Time (WT), (iii) Preference (PR), (iv) Lunch Break (BR), (v) Synchronization (SY), (vi) Geo-location (GE), (vii) Real Time Scheduling (RT).

### 3. Proposed Solution

#### 3.1. Conceptual model

In order to help the scheduler, make a good decision during the scheduling process in a dynamic context and to ensure good communication between the different actors, we use MAS in our approach. Indeed, the first step when using the MAS approach is to determine the degree of reasoning of each agent. The multi-agent system is composed of two architectures of agents: cognitive and reactive agents [11]. Figure 1 and Table 1 presents the type of each actor in our system.

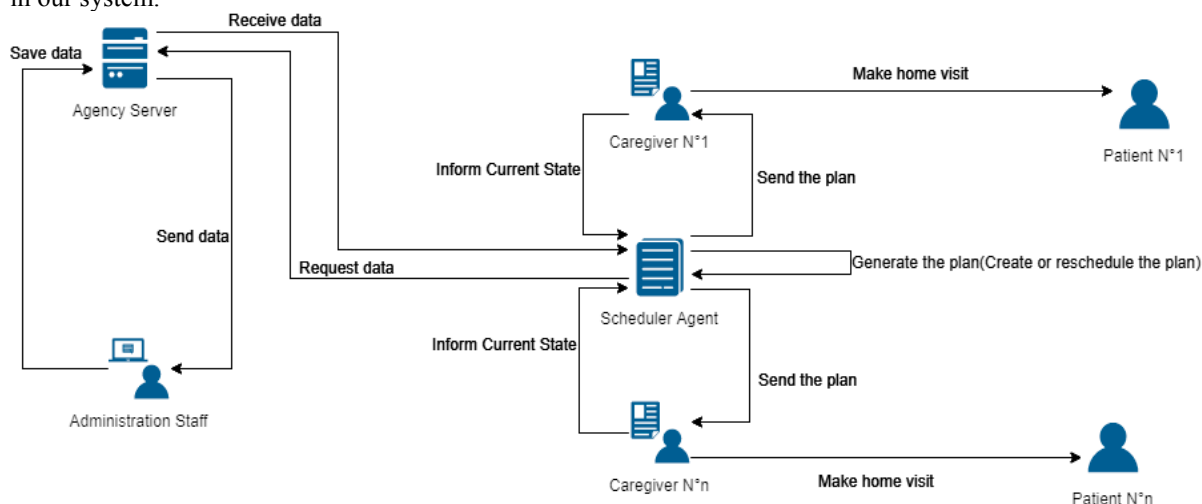


Fig. 1. Dynamic behavior of the schedule agent

Table 1. Identification of actors

Actors	Type of agent	Description
Administration Staff (Admin)	Reactive Agent	Passive Behavior: Its task is just monitoring care workers in theirs work and register the patients' information for each request.
The scheduler	Cognitive Agent	Active Behavior: The scheduler adopts dynamically the planned route with the change of situations. Also, he assigns and decides autonomously the caregivers according to their qualifications.
Care Staff (Caregiver)	Cognitive Agent	Active Behavior: He visits patient according to the planned route provided by the schedule and calculate time of treatment, traveling time and waiting time of patient. He sends and receives patients' information of their current status.
Patient	Reactive Agent	Passive Behavior: They receive their own treatment and inform their availability.

The scheduling process presents the core of our approach. A daily planning route will be generated using an evolutionary algorithm and the assignment care staff to patients respecting the multiple constraints. After the routing plan is well done and the care staff is well assigned then the caregiver makes home visitation that are mentioned in the plan. But in the case where there are unexpected events or the absence of one of the care staff, the routing plan need to be rescheduled with the new information and re-assigned to the caregivers according to the health status of patient. In this step, some constraints need to be re-checked such as caregivers' qualification, caregivers' working time, etc. Figure 1 present the framework of our solution based on the MAS.

### 3.2. HHC scheduling and routing problem using AIS

Our proposed solution is based on the powerful variant of the AIS algorithms called the Clonal Selection Algorithm (CSA) or CLONALG algorithm proposed by Castro and Von Zuben [16] to generate an optimal daily routing plan. The CSA is a population-based heuristic algorithm, inspired by the concept of clonal selection theory. The principle of this algorithm is to establish the idea that only those cells capable of recognizing an antigen will proliferate while other cells are not selected. To apply the clonal selection algorithm to our problem, we need mapping between these latter [17]. Table 2 presents mapping of immune system based on HHC scheduling problem.

Table 2. Mapping of immune system based on HHC scheduling problem.

Immune System	HHC scheduling problem
Antigen (Ag)	Initial route path
Antibody (Ab)	Feasible or optimal route
Population	Number of antibodies
Gene	A patient's home that will be visited

- Step1: Initialization of antigens: The CSA algorithm starts with initializes the antigen. In our context, an antigen represents the initial route path between the HHC agency and the patients' home that will be visited. This antigen is generated according to the minimum route distance and expected time between patients' home. The traveled distance and the excepted are calculated respectively using distance matrix and time matrix. Also, the size of a memory list must be defined in this step.
- Step2: Initialization of the antibody: In this step, the algorithm generates a P-number of antibodies by taking into account the multiple constraints of our problem. Such as time window constraint, qualification constraint, preference constraint, etc. Each antibody has different travel route sequences indicating their calculated distance and their time excepted. These road distances depend on the sequence of the traveled path in each candidate solution.
- Step3: Affinity evaluation: This step allows for calculating the affinity of each candidate solutions. The function corresponds to the value of the objective function of our problem. Otherwise, the evaluation of affinity checks each planned route according to the parameters in the objective function (traveling cost, penalty function, and satisfaction).
- Step4: Selection of antibodies: According to the affinity measure, the antibodies with the lowest affinity will be selected. Otherwise, If the affinity value of the antibody is less than the affinity value of the antigen then this antibody will be selected. Else, if it is larger than the affinity value represented by antigen, it will be removed.
- Step5: Clone the antibodies: The cloning operation consists in making copies of the antibodies. The cloned antibodies represent the best antibodies that have been selected previously. The number of clones depends on the clone factor that must be fixed in this step.
- Step 9: Mutation: The mutation operation of the immune system is an important step as it enhances the local search mechanism and helps to reach the optimal solution faster. The mutation is generated according to the hypermutation factor which means the affinity of antibodies increases from generation to the other. In other words, a random change is introduced into the genes of the cloned antibodies which will lead to an increase in their affinity. In our context, the mutation process corresponds to changing the sequence of the route to increase the value of the objective function. After mutate, we will have the best routes that will be replaced in the memory list with the worst routes in the initial solution.
- Stopping criteria: The clonal selection process will be repeated until the final conditions are reached. These stopping criteria could be either the desired optimal route has been found or the set number of generations is achieved. As a result, the CLONALG algorithm returns the best solution founded.

The CLONALG algorithm is capable of providing increased accuracy with each iteration processed. Thanks to its memorization capability that saves the experience obtained from the primary solution and uses adaptation to develop the next one. The solution of the optimization process is being improved until reaching the best possible results.

#### 4. Conclusion

In this paper, we have proposed a multi-agent model to the HHC scheduling and routing problem as an extension to the VRPTW. The objective is to minimize the total distance cost and minimize the violation of time window while maximizing patient satisfaction. To tackle with those constraints, we have adopted the AIS algorithm to generate the optimal route. In addition, our contribution is to consider the dynamic events related to the unavailability of the medical staff or the unexpected events such as (absence of the caregiver or car accident). This latter contributes to an interruption in patients' services and so the schedule must be changed in this time. In the future work, we aim for experiment the proposed model.

#### References

- [1] Yalçındag, S., Matta, A., & Sahin, E. (2011). "Human resource scheduling and routing problem in home health care context: a literature review". *Opisto Research Applied to Health Services (ORAHs)*, Cardiff, United Kingdom.
- [2] En-nahli, L., Afifi, S., Allaoui, H., & Nouaouri, I. (2016). "Local search analysis for a vehicle routing problem with synchronization and time windows constraints in home health care services". *International Federation of Automatic Control (IFAC)-PapersOnLine*, **49(12)**: 1210-1215.
- [3] Beheshti, Z., & Shamsuddin, S. M. H. (2013). "A review of population-based meta-heuristic algorithms". *Int. J. Adv. Soft Comput. Appl*, **5(1)**, 1-35.
- [4] Tan, K. C., Goh, C. K., Mamun, A. A., & Ei, E. Z. (2008). "An evolutionary artificial immune system for multi-objective optimization". *European Journal of Operational Research*, **187(2)**: 371-392.
- [5] Bakhouya, M., & Gaber, J. (2007). "An immune inspired-based optimization algorithm: Application to the traveling salesman problem". *Advanced Modeling and Optimization*, **9(1)**: 105-116.
- [6] Bersini, H., Varela, F.J. (1991). "The immune recruitment mechanism : A selective evolutionary strategy". In: Belew, R.K., Booker, L.B. (Eds.), *Proceedings of Fourth International Conference on Genetic Algorithms*, pp. 520–526.
- [7] Toma, N., Endo, S., Yamada, K., Miyagi, H. (2000). "Evolutionary optimization algorithm using MHC and immune network". In: *Proceedings of the 26th IEEE Annual Conference on Industrial Electronics Society*, pp. 2849–2854.
- [8] Cui, X., Li, M., Fang, T. (2001). "Study of population diversity of multiobjective evolutionary algorithm based on immune and entropy principles". In: *Proceedings of the 2001 Congress on Evolutionary Computation*, vol. 2, pp. 1316–1321.
- [9] Coello, C. A. C., & Cortés, N. C. (2005). "Solving multiobjective optimization problems using an artificial immune system". *Genetic Programming and Evolvable Machines*, **6(2)**, 163-190.
- [10] Aickelin, Uwe and Dasgupta, D (2005). "Artificial Immune Systems Tutorial" (Chapter 7). In: "Introductory Tutorials in Optimisation, Decision Support and Search Methodology" (eds. E. Burke and G. Kendall). Kluwer.
- [11] Wooldridge, M. (2009). "An introduction to multiagent systems, chapter preface". John Wiley & Sons.
- [12] Rasmussen, M. S., Justesen, T., Dohn, A., & Larsen, J. (2012). "The home care crew scheduling problem: Preference-based visit clustering and temporal dependencies". *European Journal of Operational Research*, **219(3)**: 598-610.
- [13] Marcon, E., Chaabane, S., Sallez, Y., Bonte, T., & Trentesaux, D. (2017). "A multi-agent system based on reactive decision rules for solving the caregiver routing problem in home health care". *Simulation Modelling Practice and Theory*, **74**, 134-151.
- [14] Tohidifard, M., Tavakkoli-Moghaddam, R., Navazi, F., & Partovi, M. (2018). "A Multi-Depot Home Care Routing Problem with Time Windows and Fuzzy Demands Solving by Particle Swarm Optimization and Genetic Algorithm". *International Federation of Automatic Control (IFAC)-PapersOnLine*, **51(11)**, 358-363.
- [15] Lamine, E., Bastide, R., Bouet, M., Gaborit, P., Gourc, D., Marmier, F., ... & Toumani, F. (2018). "Plas'O'Soins: An Interactive ICT Platform to Support Care Planning and Coordination within Home-Based Care". *IRBM*.
- [16] De Castro, L. N., & Von Zuben, F. J. (2000). "The clonal selection algorithm with engineering applications". In *Proceedings of GECCO* (Vol. 2000, pp. 36-39).
- [17] Muthreja, I., & Kaur, D. (2018). "A Comparative Analysis of Immune System Inspired Algorithms for Traveling Salesman Problem". In *Proceedings on the International Conference on Artificial Intelligence (ICAI)* (pp. 164-170).
- [18] Hatata, A. Y., Osman, M. G., & Aladl, M. M. (2017). "A review of the clonal selection algorithm as an optimization method". *Leonardo Journal of Sciences*, **16(30)**, 1-14.
- [19] Ulker, E. D., & Ulker, S. (2012). "Comparison study for clonal selection algorithm and genetic algorithm". *arXiv preprint arXiv:1209.2717*.