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Multi-agent System Architecture for Distributed Home Health Care Information Systems

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Abstract. In recent years, the aging population has increased. The intervention of Home Health Care (HHC) has been an asset, however, needs technological innovation for the high level of complexity and requirements. Innovation in the HHC system is crucial since management still occurs manually using classical methods, usually centralized and static. The mapping of real HHC problems, enables an application model of a distributed intelligent system, considering the operational planning needs, promoting a digital and sustainable ecosystem. This work aims to specify a flexible architecture for routing and scheduling tasks in distributed HHC. It considers multi-agent systems technology to guarantee the fast response to condition changes in existing planning, merged with optimization algorithms that allow achieving optimal solutions. Collaboratively, the information digitalization for real-time monitoring will coordinate a socialized solution using different tools and techniques, ensuring robustness and responsiveness in a domain with emerging needs.

Keywords: Home Health Care; Multi-agent system; Optimization.

1 Introduction

Over the last decade, Home Health Care (HHC) services have significantly increased [9]. In Portugal, for example, many elderly people live alone, isolated, specifically in interior regions. Faced with this scenario, HHC has been a response to the needs of treating, caring, and supporting dependent people, seeking to promote healthy aging and the best possible quality of life in them [6]. Traditional research in elderly care separates HHC from other home care services. Normally, home care offers non-clinical help, while HHC provides professional medical assistance. The position of this work focuses more on HHC, however it allows the collaboration of different care, in the sense that both involve skilled knowledge and the planning of visits routing.

The increasing worldwide needs efficient and effective HHC system, considering the increase in the elderly population, higher exigency, pressure from governments and stakeholders, the development of novel effective approaches for HHC decisions is imperative, such as modernization for more dynamic and optimized solutions. Despite these challenges, applied Artificial Intelligence (AI) holds tremendous promise for

transforming the provision of HHC as critical services [14]. In this context, health or social units must perform the respective allocation of the resources, manage the scheduling, and optimize the routes in decision-making processes. However, the planning, strategic and operational management, occur manually and without computational support and especially without monitoring [9]. In this sense, public or private health care providers, generates non-optimized planning, probable waste of financial and human resources, and emergencies that are not covered. From informal to formal HHC, there is a delivery network with several actors [9]. A set of problems will be considered to address three dimensions. The first one deals with the decisions through the planning horizon. The second one disseminates the functions through decisions: routing, and staff management. Finally, the third dimension describes the operation of digitalization. Thus, the use of a system based on information and communications technology (ICT) and ageing research [5], for knowledge-based decisions to improve service quality, becomes urgent.

The main research question arose from “how to provide faster and more dynamic solutions in distributed intelligent systems (when needed) without losing optimum (whenever possible) applied in HHC services?”, it is hard and difficult to deal with distributed systems using only centralized methods, such as the classical optimization methods since they have a high response time and do not provide dynamic and learning behavior considering the environment changes. Therefore, multi-agent systems (MAS) offer an alternative way to design and control systems, differing from the conventional approaches due to their inherent intelligent capabilities to cooperate and adapt to unexpected events. However, the use of only MAS, in turn, may not complement the search for optimized solutions provided by optimization models. The research prediction is that, merging the better of these two worlds, will allow a service coordination architecture for innovative solutions ensuring responsiveness and providing intelligent support in autonomous decision-making.

The main motivation of the PhD work is to build an innovative scheduling and routing system, with the application of distributed AI and optimization algorithms, using technology-supported services to generate “optimal” or near optimal solutions, and digitalize, deploy, and monitor the HHC information. The challenge of combining MAS with optimization algorithms will be supported on modern information technology systems, to solve complex procedures, by leveraging an architecture that benefits the interoperability and flexibility of the HHC decision-making. The system decentralization of different decision-makers will allow to maintain high levels of optimized solutions and, reduce the operating costs with fast responses. The assignment decision can be made using a negotiation scheme or optimization methods, trying to converge to the global objective. The idea is to reconstruct decision-making in operational planning, implementing intelligent algorithms, and promoting a better service quality, robust and sustainable. The architecture specification, fully distributed, aims to manage optimized and automated route planning, collaboratively based on swarm concept, to exhibit simple behaviours, and to compromise a socialized solution from different sources, tools, and techniques.

The paper is organized as follows: Section 2 overviews the contribution to applied AI systems, and Section 3 describes the related literature. Section 4 presents the research contribution and innovation, while Section 5 presents the discussion and critical view. Finally, Section 6 rounds up the conclusions.

2 Relationship to Applied Artificial Intelligence Systems

Nowadays, it is increasingly urgent to promote smart information and innovate technologically for intelligent systems applied, reconstructing, and modernizing basic health concepts using AI, such as primary health care at home [10].

The traditional HHC system in an all-round way, is still not intelligent, neither computerized and contains several limitations in resource management, unbalanced routes/schedules and even in unexpected events. In this sense, considering the growing need of the elderly people to receive their needs, public or private providers need to specify and implement computational, intelligent and decision support measures, capable of supporting an increasingly accurate distributed service. This service is crucial in the interior regions of Portugal and even in the context of the pandemic COVID 19, allowing due to the ease of care and follow-up of patients. Thus, within the scope of this doctoral work, the design of a prototype with evolutionary algorithms with the ability to optimize the entire operational management of the HHC service appears, merged with MAS, equipped with automated planning and autonomous scheduling [15]. The application of AI systems, carried out using MAS, are included in the area of distributed AI systems [8]. MAS offers a promising and innovative way to model, design, and manage the implementation of distributed systems and essentially distribute the intelligence by different nodes, allowing to divide a complex problem into several simple problems (“divide to win”). MAS paradigm is composed of a society of intelligent, autonomous, and cooperative entities (agents), which interact and coordinate their activities, based on the local knowledge and skills, to achieve their goals and capable of independent or group decision-making [16]. The collaboration of these technologies will be supported by a digitalized tool for management and control, making HHC service more efficient. New research points to the development of collaborative business ecosystems for integrated elderly care systems, to offer a more personalized service and promote intelligent concepts based on collaborative networks [3]. Smart HHC is not just a simple technological advancement, but also an all-round, multi-level change, embodied in the following: decentralized changes in the HHC model and changes in knowledge-based systems to emulate human cognition in the HHC tasks for decision-making and business analysis [10].

This work, aims to explore the concept of distributed HHC, focusing on an intelligent infrastructure to perceive, transmit and process information using cloud computing. Distributed HHC can promote interaction in the entities, facilitating the rational allocation of resources, routes, and health professionals. An impact on smart HHC planning is expected, representing a qualitative and quantitative improvement in the resource’s optimization, a reduction in the costs involved and, a reduction in the patients' waiting time. The intelligent real-time support could be crucial in the early detection of events of aggravation or fast response in existing planning by MAS, elimination of non-urgent urgencies in hospitals. The impact of scheduling, monitoring, and decision support tools, characterized by exponential digitalization, will lead to competition, training, and regional strengthening of HHC ecosystems.

3 Related Literature

HHC visions are facing unprecedented pressure because of changing demographics, administrative requirements, resource constraints, workforce shortages, growing needs of the population, and increased demand for HHC innovation.

Operational research today applies algorithms and mathematical models to classic HHC problems, usually in a centralized model that considers only the static problem settings. This optimization problem is complex, where specific requirements must be considered. Exact methods, hybrid methods, or metaheuristics provide “optimal” solutions, mainly in the HHC operations planning or routes timing [2], [9]. Normally, studies in HHC routing and scheduling focus mainly on the traveling issue (VRPs), however, this project will address multiple objectives such as costs, minimize the number of professionals, constraints violations, and continuity of care. Thus, these conventional methods, do not seem sufficient with the urgency of modernizing the HHC logistic, considering dynamic settings and the real-time events that may occur [4]. Considering the traveling issue and the multiple objectives, this project intends to introduce real-life needs to seek efficiency in planning resources, workload balance, experience, and potential online reactions. An additional complexity, only with operational research, will consume a lot of time and have a high effort. Thus, combining intelligent agents (even with worse solutions) with optimization algorithms will enhance cooperation, and responsiveness, allowing task effort distribution that would hardly have an “admissible” solution with the strategies separately. This includes the reactive adjustment of individual schedules for adaptively deal with a dynamic environment while balancing whenever possible, the optimized solutions. Thus, the interaction of different interconnected and even decision-capable smart algorithms, cloud computing, and digital concepts can provide powerful intelligent solutions to challenges not yet addressed to HHC operation [7], [17]. For that reason, AI, and software engineering, highlighted the efficacy and potential of intelligent health applications [12], [15]. This area includes the concept of agents. Hence, since an agent can be for instance a part of an automatic workflow or an individual representative of a real-world person, seems promising to apply MAS, as a sub-discipline of distributed AI [16]. These concepts can support automatic coordination, message communication, and interactions among real-world agents. Several approaches make use of MAS to support operational HHC in terms of allocation and scheduling, dealing with uncertainty cases [1], [11], [13]. In addition to theoretical contributions, the research has some limitations, such as the dynamic information not previously known are generated randomly. Generally, it does not provide outcomes for dynamic procedures in the long-term plan for multiple planning stages.

In general, centralized optimization methods have been widely studied over the years, which despite stability, cost savings, and good solutions, take time and do not support the reactive scheduling in the service runtime. However, restructuring is urgent, where oscillating with the decentralized model is needed, making the HHC problem more critical, scalable, and tolerant to emergencies. In turn, knowing that a single intelligent decentralized system may have more security risks and does not guarantee optimized performance. Thus, the research hypothesis in merging different innovative and technological assets, such as AI, in a distributed computing system, will be challenging, especially to generate robust/flexible settings.

4 Contribution and Innovation

This project aims to contribute to the innovation and modernization of a digital ecosystem for distributed HHC. The idea is to respond to the lack of dynamic and optimized solutions in a single system, able to support the emerging needs of HHC. Smart architecture with an adaptive scheduling approach, and distributed computing, is designed and presented in Fig. 1. It intends to integrate a well-structured system, using ICT concepts to specify in an interface, monitoring, and HHC decision-making.

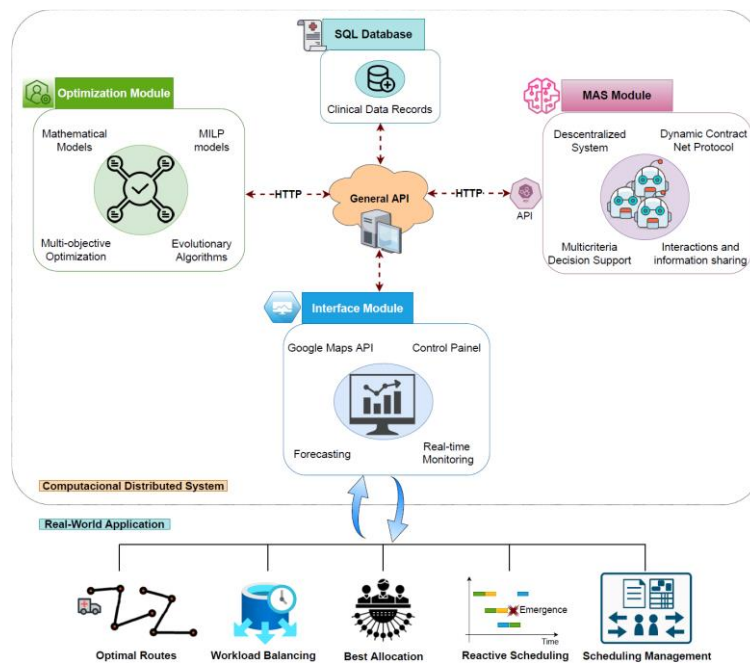


Fig. 1. Specification of the conceptual system architecture.

The wireframes modules are structured with intelligence and optimization skills for the best use of resources of HHC providers. Briefly, the computational distributed system specifies a digitalized infrastructure, which according to a cloud design, can enable reduced costs, scalability, and flexibility between components. With the general application programming interface and, the access to a database with medical records (health units' partnership), the system can acquire, store, and retrieve the data set to manage. The components will contain a RESTful server for displaying micro-services. The optimization module will be able to communicate with the service layer, collaborating in optimized scheduling combinations. This module will feature advanced technologies, such as mathematical models, evolutionary algorithms, integer linear programming, and multi-objective optimization for conflicting goals, when the problem allows to be solved stochastically or deterministically. In turn, the MAS module will be equipped with a smart platform, which will also communicate with the service layer, to support automated planning using distributed AI (Fig. 2).

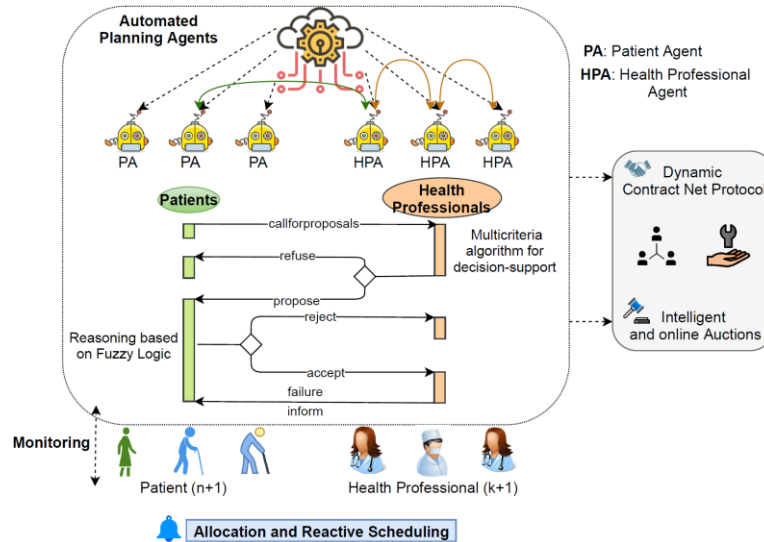


Fig. 2. Distributed AI based on MAS Module.

Interactions and information sharing between agents will enable distributed scheduling and decentralized problem-solving, making it possible to find a new solution through the system itself, efficiently, especially for fast responses in surgical emergencies. The MAS provides a fast evolving, which promotes coordinated effort, multi-criteria strategies using trading protocols among autonomous agents, and adapts their behaviour dynamically using reasoning. Any patient data manipulation will be the responsibility of the health entity, so the system will have no privacy issues.

The interface module provides users with a connection to the platforms using a user-friendly interface, which allows real-time monitoring of the solution state. The Google Maps service will serve as setup engine (maps, routes, and locations). By proposing the interconnection of all these modules, and consider the current gaps, which focus on centralizing the solution or not consider dynamic environments, the system enhances the versatility, essential to digitalize the HHC process.

In conclusion, the proposed disruptive infrastructure to support decision-making for HHC real-world application, promoting operational competitiveness but also strategic planning to ensure efficiency to achieve better routes combination, better resources allocation, workload balancing and consequently scheduling optimization.

5 Discussion and Critical View

HHC information systems, are generally based on operational management of scheduling, routing, and resources allocation. Usually, these health services are complex procedures due to their modelling complexity and are generally performed manually. Some simulations already carried out in real context, using the optimized module, based on deterministic and/or stochastic methods, have benefited in obtaining

optimized solutions and significantly improving the profitability of planning. The results of resource allocation and scheduling in a health unit managed to reduce (approximately 30%) the maximum time spent in route to existing plans [2].

Nowadays HHC services are facing an increasing demand, where the digitalization of primary health care and the consequent monitoring is imposed. However, the HHC environment requires a functional balance between static and pre-planned service, as well as alternative responses to dynamic environments, resulting in uncertainties that require real-time actions. Empower service autonomy in the event of an emergency, require a fast and optimized distributed system, to make the HHC more flexible and reduce the patient waiting times. HHC services need AI mechanisms capable of solving large real-world situations in a reasonable time and providing good solutions in a dynamic environment with resource-poor settings. Some preliminary results, with the use of agent-based models in HHC, assisted a distributed architecture in obtaining autonomous and coordinated solutions. Tests with unexpected events in online planning provided a faster and more accurate reaction to the emergency (new patient or new service) by intelligent agents, and a significant improvement in their usefulness [1]. In turn, the combination of these approaches can come to guarantee, task effort distribution and better solutions/planning in real-world HHC management.

6 Conclusions and Further Work

This paper points out and discusses the application of distributed HHC architecture highlighting the benefits of combining it with intelligent procedures, such as MAS, optimization methods, and the process of data digitalization. The development of robust expert systems for HHC modernization is urgently necessary. Sometimes the imprecise information, without coordination, negotiation, or any optimized solution, could be addressed and overcome using AI. Distributed HHC, in a decentralized manner, can be answered by technology-supported services of different smart procedures and components. However, it is necessary to introduce the control layer in the solution, encapsulating an intelligent system that consists of merging agents with optimization methods, powered by a digital application for online monitoring, providing ample opportunities to use AI to improve public health outcomes.

Nowadays, the lack of computational availability in the real-time operational management of HHC services is still evident, namely in the current emergency in combating the pandemic COVID'19. Smart HHC support is urgently needed, freeing health units and hospitals. Thus, if an HHC problem can be solved in a stochastic or deterministic way, the algorithms will provide optimized solutions, however, it is important to enabling the system to respond to condition changes in the planning. The architecture design, specifically the MAS module, allows intelligent coordination to increase efficiency and dealing with the dynamic environments based on AI. The information digitalization will provide transparency, forecasting, reaction, and real-time routes. All modules combined may be relevant to a potentially promising approach to eliminate gaps in technologies used centrally and separately.

In conclusion, the proposed distributed system can explore multidisciplinary technologies with extreme applicability in HHC, a domain with emerging needs.

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