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 an ecosystem of digital and sustainable technologies. This work aims to specify a versatile and flexible architecture for allocation, 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 digitization for real-time monitoring will coordinate a socialized solution using different tools and techniques, ensuring robustness and dynamic responsiveness in a domain with emerging needs.

Keywords: Distributed Home Health Care · Multi-agent system · Optimization.

1 Introduction

Over the last decade, Home Health Care (HHC) services have significantly increased [7]. The aging of the population worldwide has been increasing. In Portugal, for example, many elderly people live alone, isolated, specifically in regions in the interior. Faced with this scenario, HHC services have been a response to the needs of treating, caring and supporting isolated and dependent people, seeking to promote healthy aging and the best possible quality of life in them [4].

The increasing world-wide need for efficient and effective HHC system, the increase in the elderly population, higher exigency, and the increasing pressure from governments and other stakeholders in various societies, the development of novel effective approaches for home care decisions is imperative, such as modernization for more dynamic and optimized responses to services. Despite this 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 have to perform the respective allocation of the resources, manage the scheduling and optimize the routes in decision-making processes. However, the management of planning, strategic management and operational management, occur manually and without organising and prioritising the activities, without computational support and especially without monitoring [7]. In this sense, the routing, allocation and scheduling in these public or private health care providers, generates non-optimized planning, probable waste of financial and human resources and emergencies that are not covered. Thus, the use of an expert system, for a knowledge-based decisions to improve service quality, mainly in a optimized, decentralized and distributed way, 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 behaviour considering the environment changes. Therefore, multi-agent systems (MAS) offers 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 optimal 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 optimal solutions ensuring responsiveness and providing the intelligent support in autonomous decision-making for minimal external intervention.

The main motivation of the PhD work is to build an innovative system, with the application of distributed AI, evolutionary algorithms and strategies to digitize, deploy and monitor the HHC process. The challenge of combining MAS with optimization algorithms will be based on the implementation of novel concepts and solutions to solve complex challenges, by leveraging an architecture that benefits of the interoperability and flexibility of the HHC decision-making. The system decentralization of different decision-makers, will allow to maintain high levels of optimal solutions and, to reduce the operation costs with fast responses. The assignment decision can be made using a bidding/negotiation scheme or optimization methods, trying to converge to the global objective. The main idea is to reconstruct decision-making in the HHC operational planning, implementing intelligent algorithms and promoting technological advancement for a better service quality, more robust and sustainable. The architecture specification, fully distributed, aims to manage optimized and automated route planning, in a collaborative way based on swarm concept, to exhibit simple behaviors and to compromise a socialized solution from different sources, tools and techniques.

The rest of the paper is organized as follows: Section 2 overviews the contribution to applied AI systems in HHC, and Section 3 describes the related literature to the topic. Section 4 presents the research contribution and the technical innovation, while the Section 5 presents the discussion and critical view. Finally, Section 6 rounds up the paper with 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 [11].

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, taking into account 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. In particular, 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. For that reason, it is important to evolve in the application of distributed systems, powered by AI applications for minimal human intervention. 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 [6]. 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 digitized tool for management and control, making HHC service more efficient and personalized. 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 [8].

This work, aims to explore the concept of distributed HHC, focusing on an intelligent infrastructure to perceive, transmit and process information using cloud computing. It can coordinate social systems and integrate them to perform the dynamic and refined management of HHC services. 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 resources 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 urgency's in hospitals. The impact of scheduling, monitoring and decision support tools, characterized by exponential digitization, 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. Advances in the development of smart hospital-grade technologies allow HHC providers to perform medical services that were previously available only in hospitals [9].

Operational research today, applies algorithms and mathematical models to classic HHC problems, usually in a centralized mode that consider only the problem settings. This optimization problem are complex, where specific requirements have to be considered, such as matching nurses' skill and patients, regulations or workload balance measurements. Exact methods, hybrid methods or metaheuristics provided optimal solutions, mainly in the HHC operations planning or routes timing [7, 2]. Most works are limited to daily operations and consider only static and deterministic contexts. However these methods, do not seem sufficient with the urgency of modernizing the HHC logistic, considering dynamic settings and the real-time events that may occur [3]. 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. [5, 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 apply MAS, as sub-discipline of distributed AI [16]. These concepts can support automatic coordination, messages communication and interactions among real-world agents in their activities through a network without minimal human intervention. Several approaches make use of MAS to support operational HHC planning in terms of allocation and scheduling, dealing with uncertainty cases [1, 10, 13]. In addition to theoretical contributions, the research has some limitations, because for example, the dynamic information not previously known are generated randomly. Generally, not include or provide outcomes on a prototype level for dynamic procedures in long-term plan or online communication for multiple planning stages.

In general, centralized optimization methods have been widely studied over the years, however it does not allow a replication of a real problem of HHC, which despite stability, cost savings and optimal solutions takes time and does 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 the merging different innovative and technological assets, such as optimization and AI, in a distributed computing system, will be challenging. The HHC informa-

tion system for real-time decision-making and coordinated scheduling solutions, will generate robust settings and flexibility in service quality.

4 Contribution and Innovation

This project aims to develop an innovative and modernized prototype, based on communication systems, optimization algorithms, intelligent planning and monitoring, to respond to the lack of computational solutions regarding the response in the provision of HHC services. A smart architecture with an adaptive scheduling approach, using autonomous and distributed computing combined with learning experience, is designed and presented in Figure 1. It is intended to integrate a well-structured system for distributed HHC, using areas of innovation to specify in a dashboard control, real-time monitoring and decision-making.

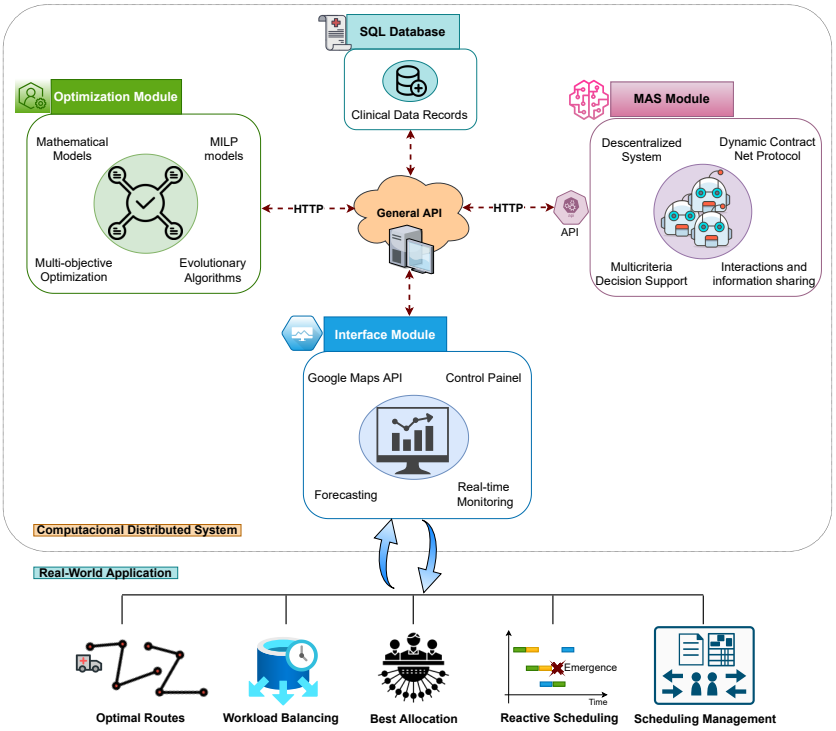

Fig. 1. Specification of the conceptual system architecture

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 digitized infrastructure, which according to a cloud architecture, can enable reduced costs, scalability and flexibility between

components. The projection of a general Application Programming Interface (API) and, the use of a database with electronic medical records, the system can acquire, storage and retrieve the dynamic data set to manage. The components will contain a RESTful server for displaying micro-services, in order to process complex procedures. The optimization module will be able to communicate with the service layer, collaborating in optimize solutions for complex allocation and scheduling combinations. This module will feature advanced technologies such as mathematical and cognitive models, evolutionary algorithms, integer linear programming for the search for optimal solutions and multi-objective optimization for conflicting objectives. In turn, the MAS module will be equipped with a smart platform, which will also communicate with the service layer, to support automated planning needs using distributed AI (Figure 2).

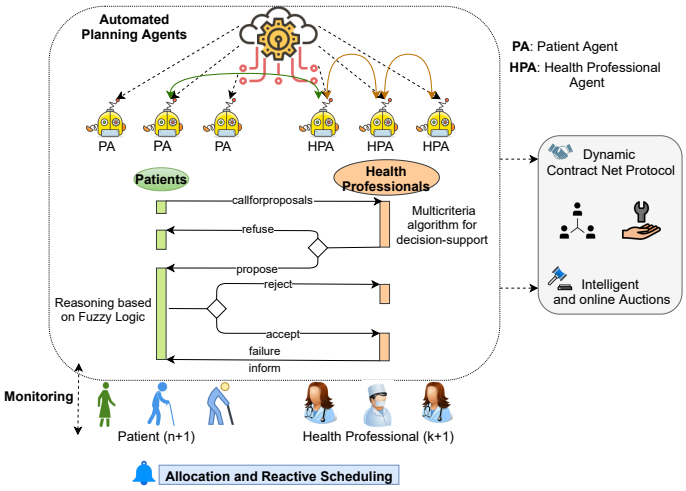

Fig. 2. Distributed AI based on MAS Module.

Interactions and information sharing between the agents will enable distributed scheduling and decentralized problem-solving, making it possible to find a new solution through the system itself, efficiently, with minimal human intervention. The MAS provide a fast-evolving, which promotes coordinated effort, multi-criteria strategies using trading protocols among autonomous agents, and adapt their behavior dynamically using reasoning based on fuzzy logic.

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 intelligent management component, are complemented by the quality of service, exchange data model, communication and context-aware modules. The Google Maps service will serve as setup engine (locations, distances and times).

In conclusion, the proposed disruptive infrastructure to support decision-making for HHC real-world application, promoting operational competitiveness

but also the strategic and automated planning to guarantee the efficiency in to achieve optimal routes combination, better allocation of resources, workload balancing and consequently scheduling optimization and management.

5 Discussion and critical view

HHC information systems, are generally based on operational management of scheduling, routing and resources allocation. Usually, this health service are complex procedures due to their mathematical modelling complexity, and are generally performed manually. Some simulations already carried out, in real context, using deterministic and/or stochastic methods, have benefited in obtaining optimized solutions and significantly improving the profitability of planning. Some 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].

On the other hand, HHC managers face complex and challenging optimization problems at different decision-levels. Nowadays HHC services are facing an increasing demand, where the digitization of primary health care is imposed and the consequent communication and monitoring of them. 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 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, benefited from a distributed architecture in obtaining autonomous and coordinated solutions. Tests with unexpected events on online planning, providing fastest and most accurate reaction to emergence's by intelligent agents, and an significant improvement in its usefulness [1]. In turn, the combination of these approaches, with a relational database as engine and the cloud computing to digitize information, can come to guarantee, task effort distribution, optimal solutions and automated 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 and the process of data digitalization. The development of robust expert systems for HHC modernization, staff scheduling and route design is urgently necessary. Sometimes the imprecise information, without coordination, negotiation or any optimized solution, could be addressed and overcome using AI. Distributed HHC, in an decentralized manner, can be answered by a service coordination architecture of the different smart procedures and components. However, it is necessary to introduce the control layer in

the solution, encapsulating an intelligent service that is to merge of 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 the fight against the pandemic COVID'19, it is becoming urgent smart HHC support service, freeing health units and hospitals. The architecture design, specifically the MAS module, will guarantee coordination and learning mechanisms to increase efficiency and the dealing with the dynamic environments to foster innovation. The information control will guarantee digitalization, transparency, forecasting, emergency reaction, and real-time route tracking.

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

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