A HOME HEALTHCARE MULTI-AGENT SYSTEM IN A MULTI-OBJECTIVE ENVIRONMENT

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ABSTRACT

Decision making in home care service is complex due to the need to satisfice multi-objective goals such as maximizing customer service quality, minimizing service cost, and maximizing employee satisfaction. With the increasing world-wide need for efficient and effective home healthcare, the increasing elderly population, and the increasing pressure from governments and other stakeholders in various societies, the development of effective novel approaches for home care decisions is imperative. In this paper, we present a multi-agent architecture that facilitates decision making characterised with multiple objectives. The approach integrates the capabilities of a multi-agent system and Web services so as to facilitate effective decisions for home healthcare services. The aim is to provide a multi-agent system based on genetic algorithm, where decisions are based on intelligent agents that provide intelligent alternative decisions in a multiple-objective environment.

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1 INTRODUCTION

The provision of health care and assistance to patients in their own homes often occurs in an uncertain environment [1]. Healthcare worker schedules in general and homecare worker schedules in particular, are constructed under uncertain, imprecise, and often conflicting goals and restrictions. Some critical examples of the conflicting management goals include the minimization of schedule cost [1] [2], the maximization of healthcare service quality, and the maximization of healthcare worker satisfaction [2]. Satisfying all these goals simultaneously is almost impossible due to their conflicting behaviour. Common restrictions encountered while constructing homecare worker schedules include the need to satisfy all the health care requirements of the patients (clients), the need to provide service to every patient within a given time window at a specific location, and the limitation on the maximum working hours that can be assigned to each worker per day. These restrictions fall into two main categories, that is, demand constraints and time constraints.

While demand constraints seek to satisfy all the healthcare requirements by clients, time constraints are concerned with time window restrictions, total work hours per day per worker, and other specific work time restrictions as stipulated by specific organizations and legislations. In the presence of all these constraints, the decision maker needs a robust decision support tool so that schedule cost, healthcare service quality, and worker schedule quality goals are met. As these goals involve humanistic perceptions and judgments from three players, i.e., the management, the clients, and the healthcare workers, the development of a more judicious approach to home healthcare scheduling is imperative. As such, the concept of satisficing is appropriate.

Satisficing is a flexible and adaptable alternative to optimization for multiple objective problems, where the decision maker gives up the idea of obtaining the “best” solution and seeks a solution that is “good enough” to exceed the preset lower bounds. The “satisficer” believes that, in practice, there are too many uncertainties and conflicts in values for true optimization, such that it is more reasonable to do “well enough”. The provision of home healthcare services takes place in a particularly mobile, dynamic, and imprecise environment. The healthcare system evolves constantly over time due to one or more of the following:

1. Handling of heterogeneous information;
2. Complexity of home healthcare tasks;
3. Dynamic preferences and goals of care givers, management and patients; and,
4. Imprecision of goals and preferences.

The real issue in a homecare system is that of efficient and effective coordination of players in the system. Multi-agent systems have been recognized as one of the technologies that would meet decision making needs in an agile and fast-changing environment [3] [4]. Monostori et al [5] [6] define an agent as a software object that mimics the role of a competent personal assistant to perform a specific task on behalf of the user, intelligently or not, independently of with little guidance. The authors also state that an agent is a computational system that is situated in a dynamic environment and is capable of exhibiting autonomous and intelligent behaviour.

The purpose of this work is to propose a framework for developing multi-agent systems for home healthcare systems in a multi-objective environment. As such, the objectives of this research are as follows:

1. Identify common operational problems associated with home health care services in a multi-objective environment;
2. Propose a homecare multi-agent system framework, highlighting agent functionalities, and the overall system services; and,
3. Apply the framework to homecare task allocation in a dynamic multi-objective environment.

The rest of paper is organized as follows. The next section presents a general description of the problem. Section 3 provides the proposed framework for developing a homecare multi-agent system. Section 4 presents an application of the framework to homecare task allocation in a dynamic multi-objective environment. Conclusions and further work prospects are provided in Section 5.

2 PROBLEM DESCRIPTION

Home healthcare service providers are faced with dynamically changing staff schedules due to evolving homecare systems. Staff preferences and patient preferences change over time. In addition, management targets are often adjusted according to internal and external changes. Oftentimes, preferences and management goals are expressed without measurable precision, but rather, in linguistic expressions such as “about 8 hours”, “preferably 30 hours per week”, and “preferably morning shifts” and other forms. Moreover, the interaction of the three players, the management, staff, and patients, is complex and difficult to model using closed form methods. Managers need intelligent interactive decision support tools in such complex, dynamic and multi-objective homecare environments. Decisions need to be made as regards to scheduling of tasks for nursing staff and assignment of homecare tasks that are to be performed at preferred time windows specified by the patients. The use of intelligent agents for decision making is the most viable option.

2.1 Nature of Homecare Services

The homecare environment is concerned with constructing work schedules and assigning tasks to care givers over the course of day. Care workers visit patients are their homes at specific time windows, defined by earliest start time and latest start time. In the process, the staff, patients, and management communicate through mobile and other network channels to update information and to revise staff schedules as needed. Meanwhile, a number of objectives have to be considered simultaneously when updating the staff schedules and task assignments.

2.2 Complicating Characteristics

Due to the presence of multiple conflicting objectives in homecare decisions, multiple goals are considered when developing suitable solution to homecare staff scheduling and task assignment. Three goals are considered simultaneously: (i) minimizing the schedule cost, (ii) maximizing client satisfaction, and (iii) maximizing worker satisfaction. This essentially involves finding a judicious trade-off between the goals, considering preferences and choices of the decision maker. In a typical homecare environment, the decision maker needs to consider a number of objectives, including the following:

1. *Schedule cost*. This is a management objective concerned with minimizing the cost associated with the trips followed by healthcare givers. The cost of each trip is estimated in terms of the total distance from the care giver’s point of origin to the first client, the distances between successive clients, and from the last client back to the care giver’s point of origin.
2. *Patient satisfaction*. This objective concerns the maximization of client satisfaction or service quality which can be expressed as a function of the violations of time windows preferred by the clients. A penalty pseudo-cost is often imposed when a care giver reaches a patient’s home too early (earliness) or too late (lateness) in comparison to the preferred *time window of the patient*.
3. *Worker satisfaction*. In practice, it is essential to consider healthcare worker satisfaction, which entails meeting the worker preferences to the highest degree possible. Each worker indicates specific preferences in terms of individual working hours, work starting time, work finishing time, among others. The most common

specification is the total individual working hours. The overall worker satisfaction should be maximized.

In practice, the decision maker seeks to consider a trade-off between client satisfaction, worker satisfaction and cost minimization. This can be achieved by developing a multi-agent system.

3 PROPOSED MULTI-AGENT SYSTEM FRAMEWORK

In this section, we briefly describe the overall system structure, its goals, and the individual agent functionalities.

3.1 Overall System Structure and Goals

The suggested system framework incorporates intelligent agents, internet services, wireless networks, and mobile devices. The framework consists of a number of functional agents that are supervised by a supervisor agent, and managed by a manager agent through available communication channels. The system consists of Manager Agent, Supervisor Agent, Resource Agent, Scheduler Agent, Nurse Agent, and Patient Agent. The overall goal of the multi-agent system is to provide intelligent and robust decisions in a fast evolving homecare environment. Quick and robust decisions are especially needed in regards to homecare staff scheduling and task allocation where task loading is dynamic over the course of day, staff capability and availability change over time due to unforeseen circumstances, and patients' requests are updated over the course of day.

Figure 2 shows the proposed framework for developing a home healthcare multi-agent system. The descriptions of the functionalities of the agents follow.

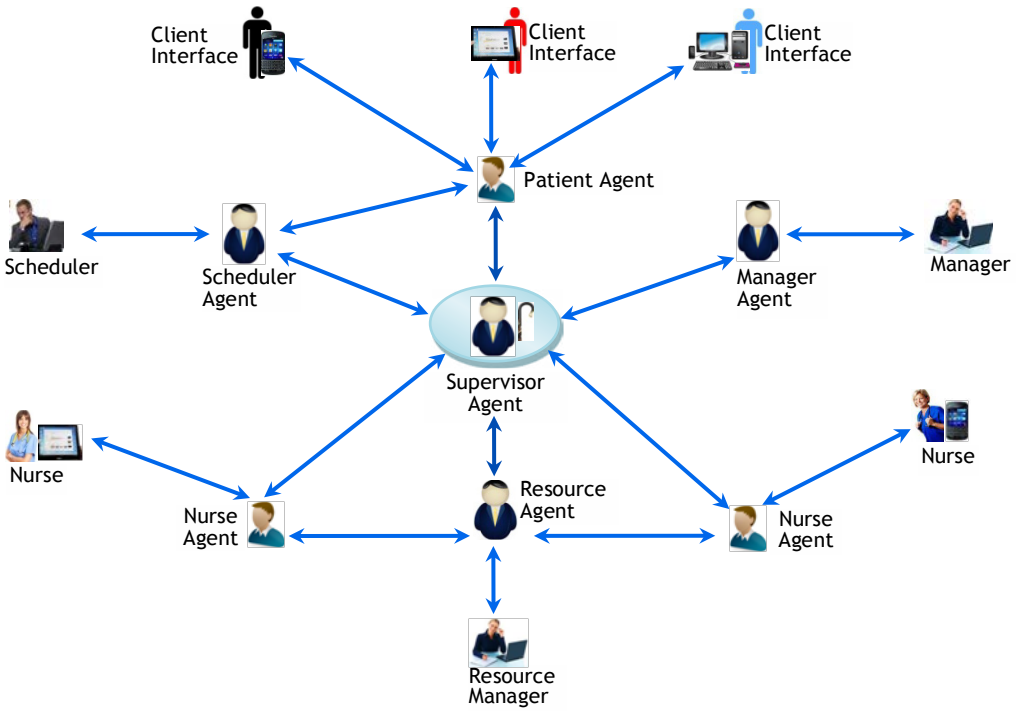

Figure 2: A Framework for a Homecare Multi-agent System

3.2 Agents and Functionalities

The agent platform forms the heart of the multi-agent system. These agents communicate and collaborate together through reliable communication channels to achieve a common

goal. Each agent should have specific functionalities, capabilities and characteristics. This enhances system flexibility to add in new agents, as necessary. The major agents and their functionalities are described:

3.2.1 Manager Agent

The manager agent has the overall responsibility of managing resolving conflicts between functional agents, as communicated by the supervisor agent. It holds and keeps track of the quality of service, the nurse preferences, and the management requirements. This information is necessary for task scheduling and assignment decisions. In this respect, it sends requests for information updates from the supervisor agents. Overall, the manager agent is responsible for,

1. setting and updating the overall management goals;
2. regularizing patient and staff preferences; and,
3. finalizing staff planning and scheduling decisions originally prepared by the supervisor agent.

3.2.2 Supervisor Agent

The supervisor agent ensures that all the agents function correctly in the system. The agent periodically sends diagnostic messages to verify the status of all the agents. In the case that an agent malfunctions, another instance of the agent should be created. The supervisor agent is also responsible for conflict resolutions among other agents, as directed by the manager agent. In summary, the supervisor agent is responsible for;

4. correct functioning of other agents in the system;
5. conflict resolution between agents;
6. status updates from agents in the system; and,
7. updating information on management goals, staff preferences, and patient preferences.

3.2.3 Resource Agent

The resource agent keeps track of the information on capabilities and availabilities of staff resources in the system; compares the capabilities of staff with the workload, as advised by the supervisor agent and the nurse agents. It informs the supervisor agent on the times the nurse staff are available according to their current schedules. If there are any tasks that can be completed by the available staff, the information is relayed to the scheduler agent through the supervisor agent. Therefore, the resource agent is responsible for,

8. maintaining updates on staff availabilities and capabilities;
9. keeping track of task requirements and task loading; and,
10. comparing current loading and resource availabilities, and updates the supervisor agent.

The resource agent closely interacts with the nurse agents, obtaining resource information updates periodically.

3.2.4 Nurse Agent

The nurse agent schedules the nurse's working day and manages profiles, tasks, available time, and the resources. The agent must generate the plan considering the nurse's preferences such that all that all the patients assigned to the nurse receive care according to their time preferences. In addition the schedule must ensure that the nurse's working hours do not exceed the present maximum hours. Thus, the every nurse agent generates personalized plans based on the nurse's profile and working habits, as well as patient preferences. In summary, the nurse agent is responsible for,

11. managing nurse's profile, tasks, availability, and resources;
12. keeping track of the nurse preferences and working habits;
13. generating primary schedule plan, considering nurse preference, patient preferences and management goals.

3.2.5 Patient Agent

The patient agent manages patients' personal data and behaviour, that is, monitoring location, daily tasks, and reporting anomalies, if any. The patient agent is the most sensitive agent and it must frequently update information regarding the beliefs, preferences, and expectations of patients. Requests from the patients are recorded and considered. Precisely, the patient agent is responsible for,

14. updating information on patients' behaviour and healthcare preferences;
15. updating task requirements; and,
16. reporting patient anomalies.

Thus, the patient agent frequently updates the supervisor agent as well as the scheduler agent concerning the patients' requested tasks so as to maintain or improve the quality of service.

3.2.6 Scheduler Agent

The scheduler agent integrates management target, resource, and task information from the manager agent, the resource agent, and patient agent, respectively. The aim is to generate the ultimate schedule, subject to management goals, staff preferences, patients' preferences, and other constraints. Thus, in the presence of imprecise or uncertain goals and preferences, the scheduler agent generates an overall satisficing schedule that seeks to suffice and satisfy the overall expectations of the three players in the actual system: the management, the staff, and the patients. In short, the scheduler agent,

17. integrates the evolving target, resource and task information from other agents;
18. generates a satisficing solution for the ultimate staff schedules;
19. updates the scheduler's choices and preferences.

Therefore, the scheduler provides a satisficing solution, considering management targets, nurse preferences, and patient preferences that often evolve with time. This enables the healthcare system to provide improved quality of service.

4 APPLICATION IN A DYNAMIC MULTI-OBJECTIVE ENVIRONMENT

It is noted in this study that a dynamic multi-objective homecare environment is characterised by (i) goals, expectations, and preferences that evolve over time, (ii) multiple conflicting objectives, and (iii) imprecise or uncertain information. In the presence of fuzzy and dynamic data, coupled with conflicting objectives, the most appropriate decision is the one that seeks to satisfice the players in the system. Therefore, we propose a satisficing procedure that judiciously selects from a generated solution space at a given point in time, and then updates the solution space in accordance with the evolving information.

Figure 2 shows the proposed satisficing heuristic for interactive homecare staff scheduling decisions. Formally, the heuristic begins by searching from the solution space S_j, an untested solution $X_i \subseteq S_j$, and testing whether or not it is satisficing. If X_i is not satisficing, the search process continues, otherwise the solution is selected and implemented. After the implementation of the schedule, the perceptions of the three players – employee, client, management – will change over time, such that the decision maker needs to acquire and assess new information on their satisfaction or preferences and goals. If the new preferences reach the pre-specified thresholds, then the solution space S_j should be updated accordingly. The decision maker updates his preferences according to the new information obtained. The search for a satisficing solution starts again with the update information. The heuristic

makes the approach more applicable and adaptable to the real life human decision process. However, the information pertaining to constraints and preferences is usually imprecise or uncertain.

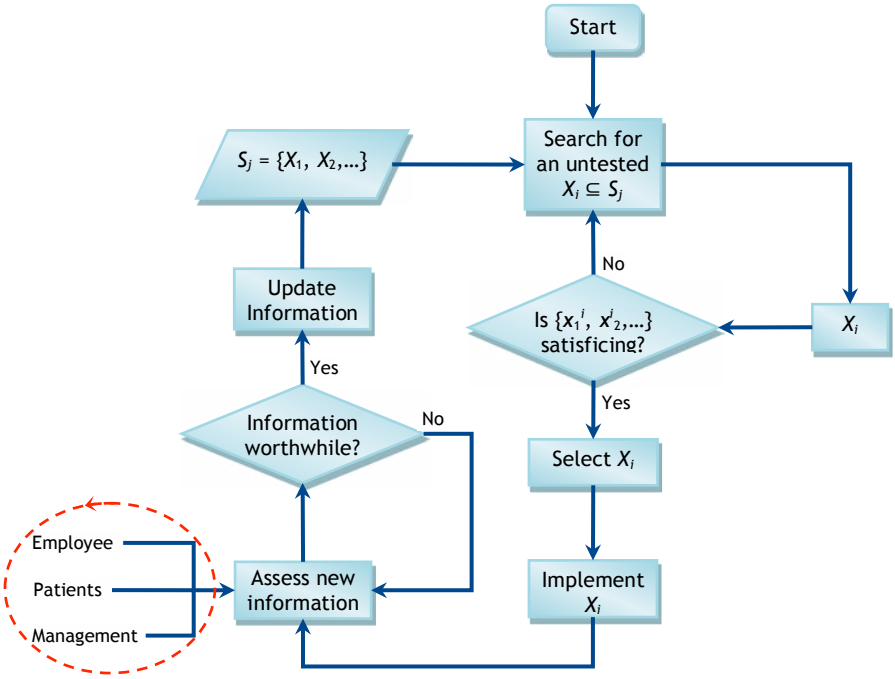

Figure 2: A satisficing approach to homecare decision making

5 CONCLUSION

Due to the ever-growing need to provide satisfactory care and support to patients at their homes and the widespread drive to offer such care services, novel and effective solutions to homecare decisions are essential. Developing robust decision making systems for homecare staff scheduling and task assignment is urgently necessary. This paper proposed a framework for developing multi-agent systems for homecare staff scheduling and task assignment decisions when the management goals, the staff preferences, and the patients' preferences are dynamic and conflicting. Considering that the information so provided is often imprecise in practice, the paper proposes a satisficing algorithm based on a dynamic solution space generated at a specific time subject to evolving preferences of the staff, the patients and the management. The proposed framework consists of a number of collaborating agents that communicate and are coordinated through efficient communication channels so as to achieve a satisficing solution at any point in time. It is anticipated that the framework forms a platform for robust decision making in homecare environments where information is imprecise and dynamic.

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