Agent-Based Decision Support for Allocating Caregiving Resources in a Dementia Scenario

Tobias Widmer(✉) and Marc Premm

Information Systems 2, University of Hohenheim, Stuttgart, Germany
{tobias.widmer,marc.premm}@uni-hohenheim.de

Abstract. Due to the increasing number of Dementia patients, the overall costs for caregiving has grown by 32 % between 2002 and 2008. The efficient use of smart decision support systems for managing ambulant care and mobile nursing services that provide professional care for Dementia patients is an important challenge to reduce cost and increase service quality. The optimal allocation of caregiving resources from different mobile nursing service firms to a growing number of Dementia patients, however, is a difficult problem in the healthcare domain. We approach this problem from a multiagent systems perspective by designing and implementing a distributed decision support system that utilizes an auction-based protocol for allocating caregiving resources subject to Dementia-specific service attributes. We demonstrate the usefulness of the proposed protocol by an early stage prototype implementation presenting the system's proof-of-concept.

Keywords: Decision support · Multiagent systems · Auctions

1 Introduction

The increasing number of Dementia patients has caused the overall costs for caregiving to grow by 32 % between 2002 and 2008. The World Alzheimer Report [1] unveils that in year 2010, a total of US$ 239 Billion were spent for caregiving services in Dementia. More than 80 % of all caregivers for Dementia patients state that they frequently experience high levels of stress and almost half report that they suffer from depression [2].

Agent-based software solutions offer a potential base for supporting both Dementia patients and professional caregivers in a wide range of applications. For example, the optimization of the visiting schedules and the provisioning of medical assistance for Dementia patients in geriatric residences have been realized by designing decision support systems by means of multiagent systems. These agents facilitate the caregivers' and physicians' work by providing updated information about patients and emergencies, as well as historical data [3]. In addition, caregiving resources can be represented by means of nursing care service models to design language extensions in high-level decision support systems [4].

The optimal allocation of caregiving resources among a growing number of Dementia patients is a difficult problem in the healthcare sector. Patients with differing disease stages require caregiving services from professional caregivers at different competency levels. More advanced stages of the Dementia disease, for example,

J.P. Müller et al. (Eds.): MATES 2015, LNAI 9433, pp. 233–248, 2015.
DOI: 10.1007/978-3-319-27343-3_13

demands family members to bear the full caregiving burden– often at the cost of their own health condition. On the other hand, caregiving professionals employed by different mobile nursing service firms are subject to highly varying working environments and scheduling conflicts. In addition, changing personnel of professional caregiving network institutions require access to sensitive patient health data which often leads to nonprofessional handling of health-related information subject to strict privacy. Hence, multiple caregivers from different mobile nursing services offer their services to a range of Dementia patients at varying disease stages, subject to heterogeneous service attributes.

We address this problem by designing an agent-based decision support system that implements an auction-based communication protocol for efficient caregiving resource allocation subject to a set of Dementia-specific service attributes. Resource allocation is a well-established field in multiagent systems research [5]. Hence, we propose a software system in which each individual actor is represented by an intelligent software agent that acts on behalf of its user (patient respectively caregiver). The emerging multiagent system captures two distinct features. First, it respects privacy-aware information sharing. Second, the allocation process is based on a double-sided auction which achieves a socially optimal allocation of caregiving resources across multiple patients and professional caregivers from different mobile nursing service firms. A generic overview of the described setting is presented in Fig. 1.

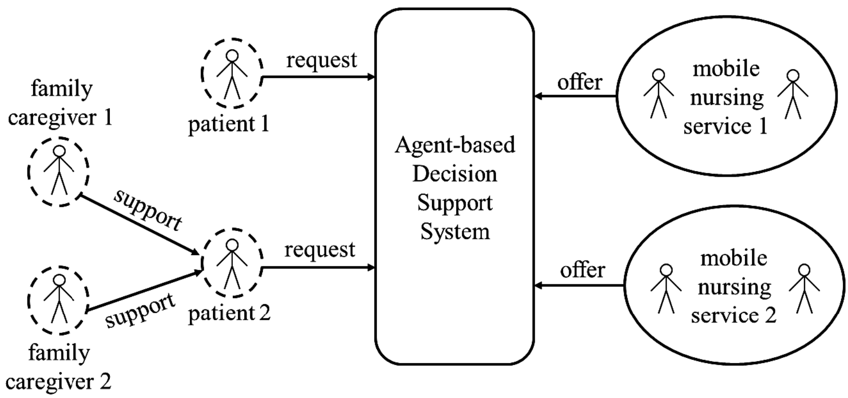


Fig. 1. Agent-based decision support system for allocating caregiving resources.

This research is conducted in accordance to the design science paradigm [6]. The objectives are to: (1) develop and implement an auction-based protocol for allocating Dementia caregiving resources in multiagent systems (method artifact) and (2) evaluate this artifact in a Dementia scenario with multiple patients and caregivers (scenario-based evaluation). The contribution of this research is the design and the initial prototype implementation of an agent-based decision support system for supporting the caregiving allocation among Dementia patients and their caregivers.

The remainder of this paper is structured as follows: In Sect. 2, we review the extant literature related to our research. In Sect. 3, we present the multi-attribute double auction protocol for allocating caregiving resources. In Sect. 4, we report the scenario-based evaluation of the protocol within the initial prototype implementation. Section 5 concludes the paper and gives an outlook of future work.

2 Literature Review

We discuss extant literature on decision support in eHealth and auction-based resource allocation approaches and examine the allocation of caregiving resources from a multiagent system perspective.

2.1 Decision Support in eHealth

The support of patients suffering from Dementia with the help of electronic devices has been analyzed and developed since the emergence of modern IT. There is a lot of work in literature that tries to support the family caregiver or directly the patient itself with computer supported guidance. In one of the first approaches, Brennan et al. developed the electronic support ComputerLink and showed in field experiment that the use of computer decision support for home caregivers could reduce isolation and enhance decision making skills [7, 8]. However, the individual intensity of system usage significantly varied between different end-users. Also, the static implementation has been replaced by the use of adaptive and intelligent systems in the healthcare section [23]. The multiagent systems paradigm suits well for designing improved decision support systems that are able to represent the interest of each individual actor. Schuele et al. present a method that enables end users represented by software agents to cooperate in the decision making process still ensuring data security and privacy for the participants [9]. A similar approach has been presented by Corchado et al. with the stronger focus on the monitoring aspect. The "Alzheimer Multi-Agent System" enables nurses to optimize and dynamically adapt the working time and guarantees that each patient assigned to a nurse receives the right care [3]. However, multi-attribute patient-nurse allocation with multiple participants is not considered. With an optimizing approach from Operations Research, Lanzarone and Matta [10] study the problem of assigning the right caregiver to each patient by an analytical approach to provide decision support of healthcare management with a focus on hospitals. Aktas et al. presented a similar approach [11]. From the perspective of one professional caregiving provider all information relevant for the problem optimization is available. However, this precondition is not available in scenarios with multiple parties that have conflicting interests like on a market for caregiving resources.

While the previously discussed approaches support only the work of the family or the professional caregiver, the correlation between both also has to be considered for an optimal system performance. For instance, at more severe stages of the disease family members have to be replaced by professional caregivers because the caregiving burden exceeds the family caregiver's capacity. This requires an efficient resource allocation that includes the interest of all parties involved. Couch et al. present a model that involves time and money for the allocation of caregiving resources [12]. The authors examined different household types with family caregivers and their response on the circumstances of the dementia patient. The study shows that the response is strongly influenced by economic considerations and states that future demand for professional caregivers that may help family caregivers will increase. Bargaining approaches for family caregivers' resources in intergenerational household formations have been examined by Pezzin and Schone [13]. The theoretical framework includes one single elderly parent's well-being as well as the daughter's time used to serve in caregiving and in labor market participation.

Bearing in mind the monetary aspects of Dementia worldwide, one may not lose sight of the disease itself. In any case, high-priority tasks such as assistance at meals must be performed and cannot be shifted or even ignored by any allocation process. One method that copes with the issue of prioritizing tasks in home caring scenarios is presented by Hirdes et al. The method for assigning priority levels (MAPLe) is used to categorize the need for caregiving activities of a patient [14]. The priorities are set on a discrete scale from "low" to "very high" and were evaluated in numerous countries. MAPLe furnishes an algorithm to set the appropriate priorities and can be connected with an agent-based approach to ensure data security and privacy issues. Together with a resource allocation approach that involves additional factors like time, money, or caregiving skills, the overall efficiency of the caregiving system is significantly improved. Since one major problem of the task aligning family and professional caregivers is the absence of a central instance that holds all necessary information, the method needed has to deal with the distributed nature of this problem.

2.2 Auction-Based Approaches in Resource Allocation

There are few approaches available that incorporate the previously stated requirements. One prevalent possibility that is commonly used in resource allocation problems is the design of an auction. Auctions support the distributed nature of the problem with various groups and participants following different goals and, thus, inherent different utility functions. New mechanisms even support the coincident usage of multiple attributes [15] and, hence, include multiple attributes such as time, money, priority and caregiving skills.

In multiagent systems research, auctions have become a popular means to efficiently allocate resources among software agents [5]. Auction-based approaches promise a significant increase in efficiency when allocating resources in agent-based systems. Such agent-based decision support systems allow for increasing the efficiency in the context of allocating caregiving resources to patients. Therefore, what is still missing is an auction-based approach that uses multiagent technology to cope with the efficient allocation of caregiving resources of multiple caregiver or caregiving facilities to numerous patients. For this setup, double auctions have been proven to outperform other mechanisms and are also well-suited for the use with a multiagent system representing real world actors [16].

Paulussen et al. take a game-theoretic perspective to analyze an intra-unit scheduling problem in hospitals [20–22]. In their work, patients and hospital resources (e.g., physicians, medical devices) are represented by self-interested software agents who coordinate with each other to resolve each individual's goal conflicts. Multiple competing market participants on both sides of the market, however, are not considered in their work.

3 Multi-attribute Double Auction Protocol

This section introduces the protocol used by the multiagent system for allocating caregiving resources among participating agents. We start by laying out the overall software architecture of the decision support system, followed by an analysis of the Dementia-specific requirements to the allocation of caregiving resources. Then, we present the formal model of the underlying double auction and describe the high-level communication protocol of the multiagent system.

3.1 Software Architecture

The overall software architecture of the multiagent system implementation is presented in Fig. 2. Dementia patients and caregiving professionals interact via individualized portals accessible through an Internet browser or a mobile application. External interfaces allow for communication and interaction with the actual multiagent subsystem which constitutes the core of the prototype implementation. Within the multiagent subsystem, each actor (i.e., patients and caregivers) is represented as a software agent in the proposed approach. These agents are able to perform autonomous actions in order to pursue its individual objectives [17].

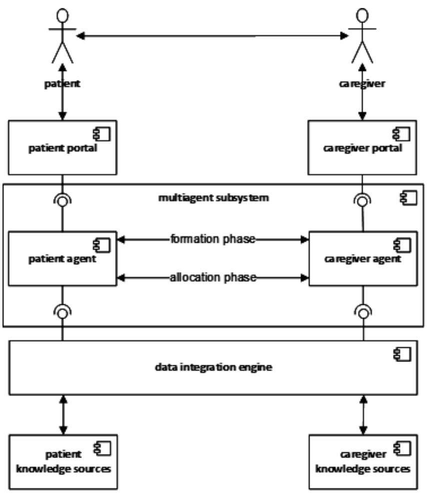


Fig. 2. Software architecture of the multiagent system implementation.

The multiagent subsystem enables individual agents to communicate and negotiate with each other through an agent communication language. A standard language for agent communication is the Contract Net protocol which is a high-level protocol for achieving efficient cooperation through task sharing in networks of communicating problem solvers [17].

The proposed communication and interaction scheme consists of two distinct phases. In the first phase, the formation phase, patient agents and caregiving agents exchange data that is necessary for the allocation process. Due to the high sensibility of health-related patient data, the formation phase is characterized by distributed, privacy-aware knowledge sharing among the agents. Schuele et al. have identified software design considerations that enable shared decision making in patient-health professional relationships within the scope of a decision support system in eHealth [9]. This concept is applied to the current proposal to enable privacy-aware patient-caregiver interaction.

In the second phase, the allocation phase, the agents use the data exchanged in the first phase to perform the actual caregiving resource allocation. The protocol implementation internalizes an auction-based allocation approach for the optimal distribution of caregiving resources among the agents. Optimality in this mechanism design approach refers to maximizing the utilitarian social welfare, which is a common performance measure in multiagent resource allocation [5]. Due to the double-sided nature of the problem (patients and caregivers), the concept of a double auction [18] is applied to guarantee the best possible outcome of the resource allocation. In a double auction, both sides of the market submit bids to an auctioneer which then dictates the optimal allocation of caregiving resources and determines the appropriate market-clearing price.

The multiagent subsystem exposes interfaces to the data integration engine. The data integration engine is a semantic-based knowledge management system that integrates heterogeneous knowledge sources and provides access to these sources through semantic reasoning processes. For example, this component is capable of representing knowledge contained in a personal health record of a patient. Similarly, a professional caregiver's availability calendar can be accessed via the data integration engine.

In the following, we focus on the domain-specific requirements of the allocation phase within the multiagent subsystem implementation.

3.2 Dementia-Specific Requirements

Caregiving resources and services require specific attributes that must be considered to meet the needs in the Dementia scenario. These requirements are listed in the following.

Caregiving Service and Required Time. The care for Dementia patients can be divided into individual services. Each service requires a specified time to be completed by the caregiving professional. Table 1 gives an overview of selected services with the average time required for completion of the task.

Table 1. Caregiving services (tasks) and required time for patient care.

Task	Required Time
Complete personal hygiene	20-25 min
Partially personal hygiene	8-10 min
Shave	5-10 min
Dental hygiene	5 min
Full bath/shower	20-30 min
Urination and defecation	5 min
Assistance at meals	15-20 min
Cooking of meals	20 min
Room cleaning	30 min
Shopping service	60 min
Mobility service	30-45 min
Relief service	20 min
Activation (Walking, ...)	60-90 min
Activation (Mental training, ...)	30-45 min
Wound care	10 min
Medication assistance	5 min

Service Quality. A patient must be able to specify a particular service quality when requesting for a caregiving service. Examples of quality attributes include the competency level of caregiving professional as well as the popularity level of caregiving professional that is implemented by a rating system. In the following, we focus on the competency level of caregiving professionals.

Patient Day Care. The daily routine of a Dementia patient is divided into five time slots in which caring tasks should be completed. Each time slot has a duration of two hours for a task to be completed. Tasks can be shorter than two hours, but cannot exceed it. Figure 3 illustrates the individual time slots of the daily routine of a Dementia patient (left hand side) and an example setting for possible caregiving services during these time slots (right hand side).

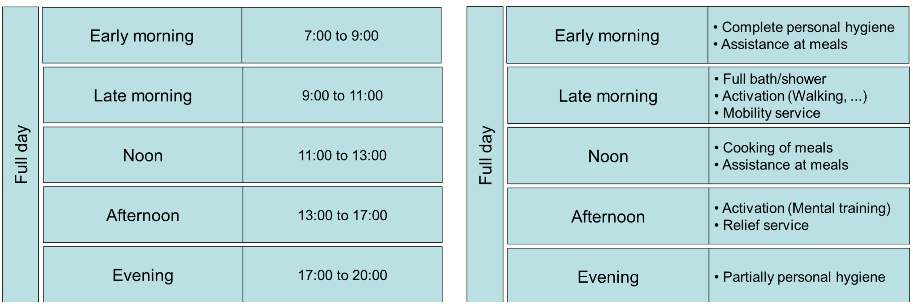


Fig. 3. Time slots of a patient day routine (left hand side) and an example setting for possible caregiving services during these time slots (right hand side).

Caregiving Availability. Different professional caregivers from mobile nursing services are typically available at different times for different durations. Within the five time slots described above, caregivers may specify several durations in which they are available. An example of a caregiver's availability is illustrated in Fig. 4.

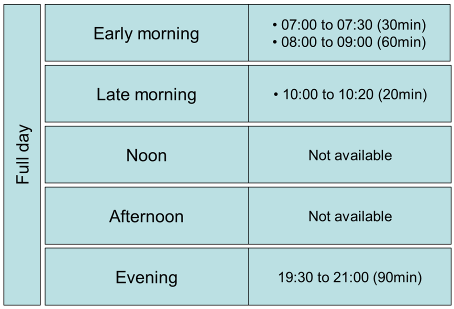


Fig. 4. Time slots of a caregiver's availability requirements during a full day.

Priority Services. A service which is requested by a patient receives a priority attribute. For example, the services "assistance at meals" and "complete personal hygiene" receive a high priority, while "activation (walking etc.)" obtains a lower priority. In this way the services can be provided depending on the priority.

Valuation of Patients and Cost of Caregivers. When specifying its demand, the patient agent expresses its valuation for the requested service. Similarly, the caregiving professional agent specifies its cost to provide the requested service to a patient agent. Valuation and cost can be seen as bids in an auction and are represented by monetary units. The underlying auction mechanism is then responsible for finding the best match between patient and caregiving professional.

3.3 Auction Model

The agents' participation in the auction requires service requests and bids. Requests are submitted by patient agents and include the requirements specified in the previous section and must be considered in the underlying allocation process. Requests of patient agents and offers by caregivers are assumed to be standardized so that they can be matched together. In this work it is assumed that the number of requests and offers is large enough to ensure appropriate matches. For instance, caregiving networks such as the German organization "Pflegenetz Heilbronn" [19] manage an increasing number of patients and caregivers (e.g., individuals and caregiving institutions). Such organizations guarantee that the market on both sides is large enough.

Request. Let i denote the index of a patient. Then each patient agent's request is given by the tuple

$$R_i = (r_1, r_2, \ldots, r_k), \tag{1}$$

where each individual request r_k for $k \in \{1, \ldots, K\}$ is given by

$$r_k = (s, q, t, p, v). \tag{2}$$

In the tuple r_k, the quantity s denotes the required service including the average time required to fulfill the task, q is the requested service quality (i.e., the requested competency level), t is the time slot in which the service is needed, p is the priority of the service, and v is the valuation the patient agent assigns to the requested service. In this notation, parameter s contains the service description as well as the average time needed to complete the service (see Table 1). The valuation of a patient may correspond to a certain caregiving level assigned by the patient's health insurance. Depending on a patient's health condition, an insurance will be willing to reimburse a certain amount of money for a caregiving service. Hence, the valuation of a patient may depend on the severity of her health condition. An example request of patient agent *i = 1* may be

$$r_1 = (\text{“}\textit{dentalhygiene}\text{”}, \text{“}\textit{medium}\text{”}, \text{“}\textit{earlymorning}\text{”}, \text{“}\textit{high}\text{” “20”}), \tag{3}$$

$$r_2 = (\text{“}\textit{roomcleaning}\text{”}, \text{“}\textit{medium}\text{”}, \text{“}\textit{latemorning}\text{”}, \text{“}\textit{low}\text{”}, \text{“15”}) \tag{4}$$

$$R_1 = (r_1, r_2), \tag{5}$$

Patient agent *i = 1* therefore requests for two services in two different time slots. First, the service "dental hygiene" at service quality "medium" within the predefined time slot "early morning" at a high priority. The valuation the patient agent assigns to this multi-attribute service request in this example is given by the monetary unit "20". Second, the patient agent requests for the service "room cleaning" with similar attributes. In this way, patients have the ability to plan out a full caregiving day routine.

Offer. Let j denote the index of a caregiver agent in the system. Each caregiving agent's offer is given by the tuple

$$O_j = (o_1, o_2, \ldots, o_L), \tag{6}$$

where each individual offer o_l for $l \in \{1, \ldots, L\}$ is given by

$$o_l = (q, t, d, c) \tag{7}$$

In the tuple o_l, the quantity q denotes the service quality (i.e., the competency level), t is the time slot in which the caregiver is available for d minutes (the duration for which the caregiver is available in this particular time slot), and c is the cost accruing to the caregiver agent for completing the requested service. An example offer may be

$$o_1 = (\text{“}\mathit{medium}\text{”}, \text{“}\mathit{early\,morning}\text{”}, \text{“}15\,\mathit{minutes}\text{”}, \text{“}18\text{”}) \tag{8}$$

$$o_2 = (\text{“}\mathit{high}\text{”}, \text{“}\mathit{late\,morning}\text{”}, \text{“}10\,\mathit{minutes}\text{”}, \text{“}20\text{”}) \tag{9}$$

$$O_1 = (o_1, o_2). \tag{10}$$

Caregiving agent $j = 1$ therefore offers two distinct availability bids to provide any service (notice that a caregiver is not bound to a specific service). First, the caregiver is available within the predefined time slot “early morning” for a duration of 15 min within this time slot. The cost accruing to the caregiving agent to provide this multi-attribute service is given by the monetary unit “18”. Similar attributes are given for the second offer. Collusion formation among caregiving agents is out of scope in this work.

Auctioneer. Let the number of patient agents in the system be $I \in \mathbb{N}$ and the number of caregiving agents be $J \in \mathbb{N}$. The auctioneer agent collects all patient requests $\{R_1, R_2, \ldots, R_I\}$ and caregiver offers $\{O_1, O_2, \ldots, O_I\}$ from all agents, sorts these bids into time slot and duration categories, and determines the optimal allocation of caregiving resources to patients by considering the required attributes. For calculating the optimal allocation within one category, the auctioneer agent employs the concept of a *double auction*. This process is described in the following section in detail.

3.4 Auction Protocol

The auction protocol for allocation caregiving resources among the agents involves two phases. In the first phase, the auctioneer agent sorts all received requests and offers into appropriate categories for one whole day. Tasks of high priority are assigned immediately before the actual action begins in order to ensure that these tasks are always executed. Further, a category contains services of the same quality as well as the same time slot and duration. In the second phase, the auctioneer performs a double auction within each category and determines the optimal match between caregiver and patient for that day. The auction protocol comprises the following steps:

- All patient agents submit their requests $\{R_1, R_2, \ldots, R_I\}$ to the auctioneer agent, each of which specifies a full day routine of necessary services.
- All caregiving agents submit their offers $\{O_1, O_2, \ldots, O_I\}$ to the auctioneer agent, each of which specifies a full day routine of offered services.
- The auctioneer agent sorts all requests and offers by matching the specified attributes together. In particular, requested time slots by patients are matched to the offered time slots by caregivers for one whole caregiving day. At this point all requests and offers are sorted into distinct categories.
- For each category, the auctioneer agent performs a double auction by taking the valuations and costs into account. In particular, the double auction performs the following. Given a total of n requests with valuations $\{v_1, v_2, \ldots, v_I\}$ within a category, sort the valuations in *descending* order such that

$$v_1 \geq v_2 \geq \ldots \geq v_n \tag{11}$$

Further, given a total number of m offers with costs $\{c_1, c_2, \ldots, c_m\}$ within a category, sort these costs in *ascending* order such that

$$c_1 \leq c_2 \leq \ldots \leq c_m. \tag{12}$$

Next, the auctioneer ranks both sequences against each other and matches the highest valuation with the lowest cost, the second highest valuation with the second lowest cost, and so on, as long as the valuation is strictly greater than the cost. The remaining services that cannot be matched in the current round of the auction are postponed to the next round if their assigned priority is low. High priority tasks will always be executed and are not subject to the postponing process. Then, the auctioneer determines the market-clearing price for each category via

$$price = \frac{v_k + c_k}{2}, \tag{13}$$

where k is the largest index such that $v_k \geq c_k$. This market-clearing price is calculated once per category. For subsequent categories a new price is determined which is independent of the price of the previous category.

- The protocol is repeated until one full day for each patient's care is allocated.

Hence, this communication protocol captures three distinct features. In a first step, matching time slots and matching service durations are grouped together. In the second step, within each group a double auction is performed and caregiving resources are allocated to patients. In the final step, all remaining requests and offers are moved to the next protocol iteration to be considered in the subsequent double auction for the next day. Therefore, this iterated protocol allocates all caregiving resources for the current full day and moves the unmatched service requests and offers to the next day. In this way, no service request is ignored and high priority tasks are completed immediately.

4 Evaluation

We present a scenario-based evaluation [6] that applies the auction-based caregiving resources approach within the scope of a software prototype implementation. Apart from an initial proof-of-concept, we provide an early version of the implementation. We first describe the scenario setup and then discuss the findings.

4.1 Description

The scenario includes a set of Dementia patients who request for caregiving services from a set of caregivers. Through the respective portals, both patients and caregivers submit their bids to the auctioneer. Figure 5 illustrates an example for an auction market with two caregivers and two patients, each bidding their offers respectively requests to the auctioneer.

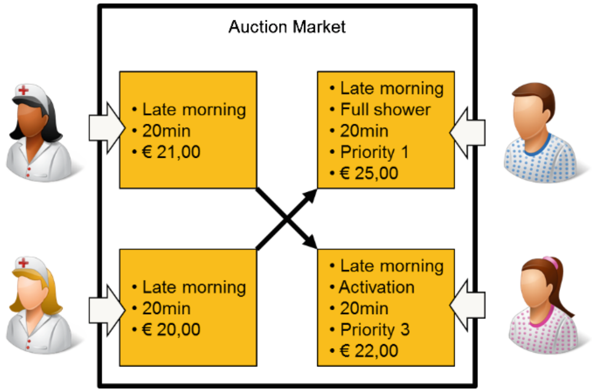
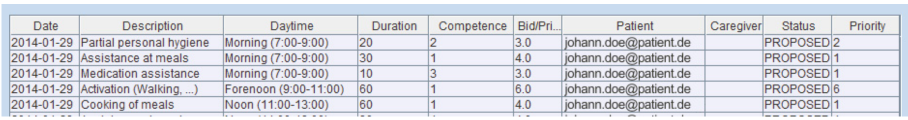


Fig. 5. An auction market with two caregivers and two patients.

As specified by the interaction protocol of the multiagent system, all bids are sorted with respect to the submitted attributes. For example, all bids for resources requested for the "late morning" shift including the appropriate duration for service completion are grouped together. Second, the concept of a double auction is applied to allocate the caregiving resources in an optimal way.

The agent-based prototype implementation exposes a set of graphical user interfaces (GUI) that can be used by the individual portals of the system. Once a patient agent submitted all bids requesting for caregiving resources for a full-day routine, these bids are visible via the GUI of the patient portal as shown in Fig. 6. Notice that the column "Caregiver" is empty in this stage as the auction has not been launched yet. Therefore, the status of the allocation is set to PROPOSED in the "Status" column of the submitted bid list. The column "Bid/Price" contains the submitted valuation of the patient agent to receive the respective service. Once the allocation protocol terminates, this column contains the calculated market-clearing price which the patient agents pays the allocated caregiver for service provisioning.



Date	Description	Daytime	Duration	Competence	Bid/Pri...	Patient	Caregiver	Status	Priority
2014-01-29	Partial personal hygiene	Morning (7:00-9:00)	20	2	3.0	johann.doe@patient.de		PROPOSED	2
2014-01-29	Assistance at meals	Morning (7:00-9:00)	30	1	4.0	johann.doe@patient.de		PROPOSED	1
2014-01-29	Medication assistance	Morning (7:00-9:00)	10	3	3.0	johann.doe@patient.de		PROPOSED	1
2014-01-29	Activation (Walking, ...)	Forenoon (9:00-11:00)	60	1	6.0	johann.doe@patient.de		PROPOSED	6
2014-01-29	Cooking of meals	Noon (11:00-13:00)	60	1	4.0	johann.doe@patient.de		PROPOSED	1

Fig. 6. GUI of patient portal displaying the submitted bids.

Similarly, a caregiver agent submits its bids for a full day specifying the availability of the caregiving professional. The bids submitted by a caregiving professional are collected and displayed via the GUI of the caregiving portal as shown in Fig. 7. Here, the column "Patient" is empty because no resource has been allocated at this point in time. Similar to above, the "Status" column is set to PROPOSED. Again, the column "Bid/Price" contains the submitted costs that accrue to the caregiving agent to provide

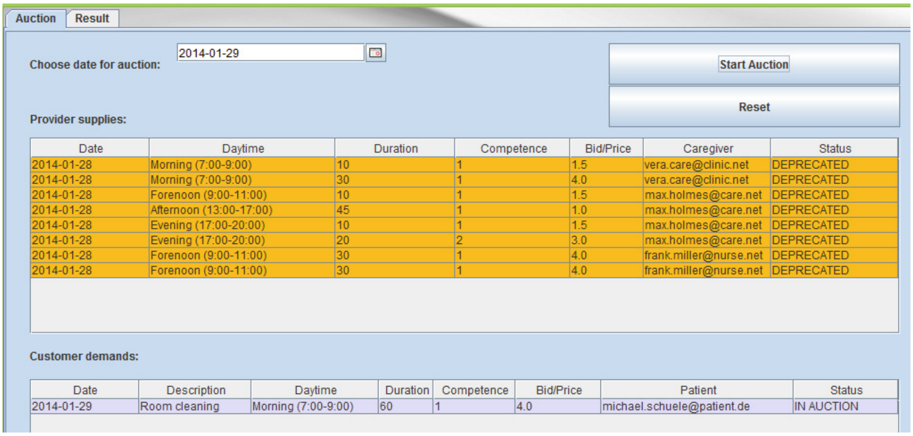
Date	Descripti...	Daytime	Duration	Competence	Bid/Price	Caregiver	Patient	Status
2014-01-29		Morning (7:00-9:00)	10	1	1.5	max.holmes@care.net		PROPOSED
2014-01-29		Morning (7:00-9:00)	10	1	1.5	max.holmes@care.net		PROPOSED
2014-01-29		Morning (7:00-9:00)	10	1	1.5	max.holmes@care.net		PROPOSED
2014-01-29		Morning (7:00-9:00)	10	1	1.5	max.holmes@care.net		PROPOSED
2014-01-29		Morning (7:00-9:00)	10	1	1.5	max.holmes@care.net		PROPOSED
2014-01-29		Morning (7:00-9:00)	30	1	4.0	max.holmes@care.net		PROPOSED

Fig. 7. GUI of caregiving portal displaying the submitted bids.

a service. Upon termination of the auction, this column contains the calculated market-clearing price which the caregiving agents receives from the patient receiving the service.

Once all bids are submitted by all patients and caregivers, the auctioneer agent collects all these bids and starts the auction. The GUI of the auctioneer is presented in Fig. 8. The upper part of the GUI shows a list of caregiving offers that could not be matched to any patient request on that particular day. Reasons for unmatched requests and offers include too high costs of caregivers or low valuations of patients.

The lower part of the GUI is the result page of successful matches. It displays a list of patient requests that has been moved to the next day. Since "room cleaning" has a rather low priority, it is moved to the next day's allocation process where it will be auctioned off automatically.


Auction Result

Choose date for auction: 2014-01-29

Start Auction

Reset

Provider supplies:

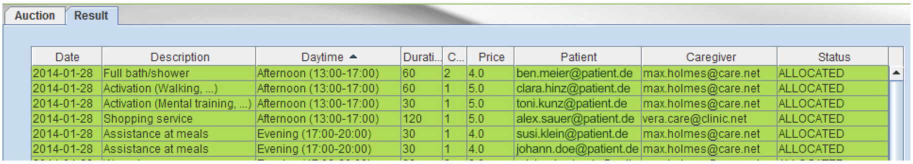
Date	Daytime	Duration	Competence	Bid/Price	Caregiver	Status
2014-01-28	Morning (7:00-9:00)	10	1	1.5	vera.care@clinic.net	DEPRECATED
2014-01-28	Morning (7:00-9:00)	30	1	4.0	vera.care@clinic.net	DEPRECATED
2014-01-28	Forenoon (9:00-11:00)	10	1	1.5	max.holmes@care.net	DEPRECATED
2014-01-28	Afternoon (13:00-17:00)	45	1	1.0	max.holmes@care.net	DEPRECATED
2014-01-28	Evening (17:00-20:00)	10	1	1.5	max.holmes@care.net	DEPRECATED
2014-01-28	Evening (17:00-20:00)	20	2	3.0	max.holmes@care.net	DEPRECATED
2014-01-28	Forenoon (9:00-11:00)	30	1	4.0	frank.miller@nurse.net	DEPRECATED
2014-01-28	Forenoon (9:00-11:00)	30	1	4.0	frank.miller@nurse.net	DEPRECATED

Customer demands:

Date	Description	Daytime	Duration	Competence	Bid/Price	Patient	Status
2014-01-29	Room cleaning	Morning (7:00-9:00)	60	1	4.0	michael.schuele@patient.de	IN AUCTION

Fig. 8. GUI of auctioneer portal displaying the failed matches (above) and the patient requests moved to the next day (below).

Figure 9 shows the GUI of the auctioneer portal containing a list of all successful allocations for the current day. In particular, it shows the market-clearing price that was calculated by the double auction ("Price" column).



Auction | Result

Date	Description	Daytime	Durati...	C...	Price	Patient	Caregiver	Status
2014-01-28	Full bath/shower	Afternoon (13:00-17:00)	60	2	4.0	ben.meier@patient.de	max.holmes@care.net	ALLOCATED
2014-01-28	Activation (Walking, ...)	Afternoon (13:00-17:00)	60	1	5.0	clara.hinz@patient.de	max.holmes@care.net	ALLOCATED
2014-01-28	Activation (Mental training, ...)	Afternoon (13:00-17:00)	30	1	5.0	toni.kunz@patient.de	max.holmes@care.net	ALLOCATED
2014-01-28	Shopping service	Afternoon (13:00-17:00)	120	1	5.0	alex.sauer@patient.de	vera.care@clinic.net	ALLOCATED
2014-01-28	Assistance at meals	Evening (17:00-20:00)	30	1	4.0	susi.klein@patient.de	max.holmes@care.net	ALLOCATED
2014-01-28	Assistance at meals	Evening (17:00-20:00)	30	1	4.0	johann.doe@patient.de	max.holmes@care.net	ALLOCATED

Fig. 9. GUI of auctioneer portal displaying the results of the successful resource allocation.

4.2 Discussion

With the proposed approach we provide an agent-based prototype implementation that enables caregiving resource allocation in a shared patient-caregiver context considering multiple Dementia-specific service attributes. The usability of the system is a very important issue in order to not fail because of low technology acceptance of the users. The multiagent system paradigm enables users to delegate their individual objectives to an autonomous software agent while preserving privacy-related requirements with regards to sensitive patient health data.

We aim to achieve the following benefits for the different participants. Caregivers of Dementia patients are often family members of that patient undergoing severe caregiving burdens depending on the stage of the disease. Hence, our approach provides an IT-based decision support system providing individual support for handling the patient's care. Family caregivers can specify the individualized needs of the Dementia patient via an easy-to-use portal and thus obtain customized support from professional caregivers working for mobile nursing services. Due to the high competition involving many patients and caregivers, the auction-based allocation process guarantees an affordable market price for the caregiving service. Therefore, the proposed software system can finally reduce the caregivers' burdens and improve their quality of life. At the same time, costs can be managed more efficiently allowing for a more flexible caregiving service model.

Professional caregivers have the opportunity to plan their caregiving day routine in a more efficient way. Mobile nursing services can submit service offers that cover all times of the day and consider the specific competency levels of their employees. The underlying auction-based allocation process allows for a more flexible payment scheme that can be applied to the employees of the nursing service. At the same time, the daily time management of professional caregiving personnel can be improved by allowing for a flexible bidding language incorporating multiple service attributes. Hence, the full time and service schedule of multiple competing mobile services is determined by a double auction process that guarantees optimal caregiving allocations as well as market usual prices.

The allocation outcome achieved by a double auction has a number of desirable economic properties [18] which are listed briefly in the following. First, the resulting allocation maximizes the social welfare. Second, all agents are sure to be better off in terms of utility after they participated in the auction. Third, no third party must subsidize the auctioneer, i.e., the auction is able to finance itself. At last, for a growing number of agents, the allocation process is incentive compatible for all participating agents.

5 Conclusion

This work presents an agent-based decision support system for modelling caregiving resource allocation in a Dementia scenario and proposes a communication protocol that implements a double auction considering multiple attributes specific to the Dementia use case. Patients and professional caregivers are represented as software agents that autonomously negotiate service provisioning based on a set of different Dementia-related service attributes. We evaluate this protocol in a scenario-based evaluation in which multiple patients and caregivers submit bids to the auctioneer agent. Within the scope of the evaluation, we present an initial prototype implementation of the proposed multiagent system that exposes a set of graphical user interfaces for each actor. The current protocol implementation is limited to two specific agent types, namely patient agents and caregiving agents. Furthermore, collusion formation among caregiving agents is not considered in this work. The formation of cartels or bidding rings among the agents potentially entails severe efficiency losses in terms of the auction's economic properties [24]. However, the protocol developed by [25] as a special case of general collusion in double auctions maintains a set of these crucial properties even if bidders can submit false-name bids. In our future work, we plan to extend the current decision support system to include further types of agents such as physician agents and facility agents, each of which having their domain-specific service attributes.

Acknowledgement. This work has been supported by the eHealthMonitor project (http://www.ehealthmonitor.eu) and has been partly funded by the European Commission under contract FP7-287509.

References

1. Alzheimer's Disease International: The World Alzheimer Report 2010. www.alz.co.uk (2010). Accessed 21 August 2014
2. Etters, L., Goodall, D., Harrison, B.E.: Caregiver burden among dementia patient caregivers: A review of the literature. J. Am. Acad. Nurse Pract. **20**, 423–428 (2008)
3. Corachado, J.M., Bajo, J., de Paz, Y., Tapia, D.I.: Intelligent environment for monitoring Alzheimer patients, agent technology for health care. Decis. Support Syst. **44**(2), 382–396 (2008)
4. Hess, M., Meis, J.: Entwurf ausgewählter Spracherweiterungen zur Ressourcenmodellierung in Pflegedienstleistungsmodellen. In: Wirtschaftsinformatik Proceedings 2011, paper 109 (2011)
5. Chevaleyre, Y., Dunne, P.E., Endriss, U., Lang, J., Lemaitre, M., Maudet, N., Padget, J., Phelps, S., Rodriguez-Aguilar, J.A., Sousa, P.: Issues in multiagent resource allocation. Informatica **30**, 3–31 (2006)
6. Hevner, A.R., March, S.T., Park, J., Ram, S.: Design Science in Information Systems Research. MIS Q. **28**(1), 75–105 (2004)
7. Brennan, P.F., Moore, S.M., Smyth, K.A.: Computerlink: electronic support for the home caregiver. Adv. Nurs. Sci. **13**(4), 14–27 (1991)
8. Brennan, P.F., Moore, S.M., Smyth, K.A.: The effects of a special computer network on caregivers of persons with alzheimer's disease. Nurs. Res. **44**(3), 166–172 (1995)

9. Schuele, M., Widmer, T., Premm, M., Criegee-Rieck, M., Wickramasinghe, N.: Improving knowledge provision for shared decision making in patient-physician relationships– a multiagent organizational approach. In: Proceedings of the 47th Annual Hawaii International Conference on System Science (HICCS), pp. 646–655 (2014)
10. Lanzarone, E., Matta, A.: Robust nurse-to-patient assignment in home care services to minimize overtimes under continuity of care. Oper. Res. Health Care **3**, 48–58 (2014)
11. Aktas, E., Ülengin, F., Sahin, S.Ö.: A decision support system to improve the efficiency of resource allocation in healthcare management. Socio-Econ. Plann. Sci. **41**, 130–146 (2007)
12. Couch, K.A., Daly, M.C., Wolf, D.A.: Time? money? both? the allocation of resources to older parents. Demography **36**(2), 219–232 (1999)
13. Pezzin, L.E., Schone, B.S.: Intergenerational household formation, female labor supply and informal caregiving– a bargaining approach. J. Hum. Resour. **34**(3), 475–503 (1995)
14. Hirdes, J.P., Poss, J.W., Curtin-Telegdi, N.: The method for assigning priority levels (MAPLe): a new decision-support system for allocating home care resources. BMC Med. 6 (9) (2008)
15. Bichler, M.: An experimental analysis of multi-attribute auctions. Decis. Support Syst. **29**, 249–268 (2000)
16. Das, R., Hanson, J.E., Kephart, J.O., Tesauro, G.: Agent-human interactions in the continuous double auction. In: Proceedings of the International Joint Conferences on Artificial Intelligence (IJCAI), pp. 1169–1176 (2004)
17. Wooldridge, M.: An Introduction to MultiAgent Systems, 2nd edn. Wiley, Chichester (2009)
18. Wilson, R.: Incentive efficiency of double auctions. Econometrica **53**, 1101–1115 (1985)
19. Pflegenetz Heilbronn e.V. http://www.pflegenetz-heilbronn.de. Accessed 26 June 2015
20. Paulussen, T.O., Zöller, A., Rothlauf, F., Heinzl, A., Braubach, L., Pokahr, A., et al.: Agent-based patient scheduling in hospitals. In: Kirn, S., Herzog, O., Lockemann, P., Spaniol, O. (eds.) Multiagent Engineering - Theory and Applications in Enterprises, pp. 255–275. Springer, Berlin (2006)
21. Paulussen, T., Jennings, N.R., Decker, K.S., Heinzl, A.: Distributed patient scheduling in hospitals. In: Proceedings of the Eighteenth International Joint Conference on Artificial Intelligence (IJCAI 2003). Morgan Kaufmann (2003)
22. Paulussen, T., Pokahr, A., Braubach, L., Zöller, A., Lamersdorf, W., Heinzl, A.: Dynamic patient scheduling in hospitals. In: Mulitkonferenz Wirtschaftsinformatik, Agent Technology in Business Applications, Essen (2004)
23. Tan, J., Wen, H.J., Awad, N.: Health care and services delivery systems as complex adaptive systems. Commun. ACM **48**(5), 36–44 (2005)
24. McAfee, R.P., McMillan, J.: Bidding rings. Am. Econ. Rev. **82**(3), 579–599 (1992)
25. Yokoo, M., Sakurai, Y., Matsubara, S.: Robust double auction protocol against false-name bids. Decis. Support Syst. **39**(2), 214–252 (2005)