An Efficient Multi-agent Patient Scheduling Using Market Based Coordination Mechanism

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Abstract— ***An increase in specialization and technology, especially in the health care department has invariably resulted in a need for efficient management of the resources and more timely treatment for the patients. Agents are deployed to solve the patient scheduling problem in the hospitals because they work well in a distributed, decentralized and dynamic environment. Each patient and resource in the hospital is represented by an agent. A combinatorial auction is a specialized form of market based coordination mechanism used to coordinate the allocation of timeslots of the resource***

Keyword: Combinatorial Auction, Multi-Agents, Patient Scheduling

I. INTRODUCTION

The wake of the new millennium has experienced major leaps in technology and innovation. One such innovation in the field of computer science is the use of agents as another paradigm to represent more accurately real world entities. In the present day of hospitals, the scheduling scenario is very much patient-centered focusing on reducing the waiting time of patients thereby providing higher quality of service [1]. The combination of several resources required by the patients increase the complexity of the problem. Traditionally, several dispatching rules such as First Come First Serve (FCFS) are employed to schedule patients with manual rescheduling. However, using these rules has certain drawbacks such as lack of decentralization and result of an optimal schedule.

Due to the inherently dynamic and distributed nature of hospitals and also the ineffectiveness of several electronic scheduling mechanisms, recent research has taken a new dimension on the possibility of deploying software agents to solve the scheduling problem [2]. Agents are a natural choice because they are known to represent a distributed environment well and they are also capable of continuously adjusting to different schedules in response to a dynamic environment. Agents also have the ability to represent specific constraints and preferences which plays a major role in many hospital scheduling problems [3].

II. THE PATIENT SCHEDULING PROBLEM

In many modern hospitals, the hospitals are divided into many departments. Some departments cater for the general needs of the hospital and other departments are highly specialized. Each department maintains a degree of independence and authority. Patients can be generally categorized as inpatients and outpatients.

Upon arrival of a patient in a hospital an initial treatment plan like in Fig. 1 consisting of a set of tasks is given which form the initial diagnosis. Based on the results of the initial diagnosis, the treatment plan is refined and a new set of tasks is listed for a patient. This is an iterative process and is repeated until no further care is needed for the patient. The patients have different levels of priority based on their health condition.

Treatment Plan
Name: John Doe
Category: Inpatient

No.	Task	Duration	Resource Required
1.	Blood Test	3 min	Blood Test Machine
2.	Scan of Heart	5 min	CT Scan
3.	Visit Cardiologist	15 min	Dr. James Wesley

Fig. 1 Example of Treatment Plan for patient

Each task in the treatment plan requires a particular resource for a given duration. The different tasks have partial precedence constraints and each task can only be performed individually. The resources in the hospital include specialists, doctors and also machines such as MRI Scan. We assume the operators for the machines are also available. Each resource has some workload constraints in that each resource can only handle one patient at a time.

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A. Literature Survey of Agent Based Scheduling in the Medical Domain

An *Agent based Approach* allows representation of each object as responsible autonomous entities with own goals which models the inherently distributed environment of hospitals. In the medical domain, auction protocols have been used to solve operating room scheduling [4], and negotiation has been used in rescheduling medical appointments, and planning of patient tests. Coordination mechanisms proposed for the patient scheduling problems include GPGP [3] and utility function negotiations [4], [5], [6], [7] for bidding protocols. Agent-based scheduling in the medical domain is a relatively recent field and some systems that have been developed are MedPage[8] with a FIPA-based implementation, the MAPEX(Multi Agent Pareto improvement exchanging algorithm) [2] which reschedules appointments with a 'nobody-worse' Pareto improvement, and 'Agent.Hospital' [9] which is an open framework for multi-agent systems.

III. AUCTION BASED COORDINATION MECHANISM USING MULTI-AGENTS

In the patient scheduling scenario, the Patient Agent (PA) requests for a set of timeslots from different Resource Agent (RA) based on the treatment plan. This approach is patient oriented with the Patient Agent (PA) requesting for timeslots. Due to high demand, the RA may be unavailable for the timeslot requested by the PA. The PA may opt for an alternate resource or wait for the resource to become free. In the case of the latter, the PA waits for the RA to trigger auction once it becomes available. The problem is solved in a distributed manner.

A. Framework for Agent Based Patient Scheduling Using Auctions

The framework given in Fig. 2 has three main agents, the Resource Agent (RA), the Patient Agent (PA) and the Common Agent (CA). Each of these agents represents a physical entity. The PA and RA participate in a combinatorial auction where patient agents bid for multiple timeslots from various resources. The objective of the auction is to minimize the overall weighted waiting time for all patients. Agent coordination is achieved via communication between agents via message passing. The result is an optimized schedule for each patient and resource.

Common Agent (CA): This agent is responsible for the registration of the patient agents and prescription of the initial treatment plan. CA may be a general physician or the receptionist in the hospital. CA also assigns priority to a patient based on their health condition. Emergency cases are given highest priority.

Patient Agent (PA): A patient agent represents both inpatients and outpatients. Each patient has a specific treatment plan outlining a set of tasks to be performed. These tasks have partial precedence constraints. Each task requires a particular resource for a specified period of time. The patient agent has preferences for the resource required or desired timings for appointments. The patient's health condition may improve or deteriorate upon which the priority level of the patient changes. PA will create a local schedule for the patient that minimizes the patient's waiting time. PA bid for requested timeslots by sending PROPOSE messages to the resource agents. If a REFUSE message is received, the PA might continue to wait for the resource to become available.

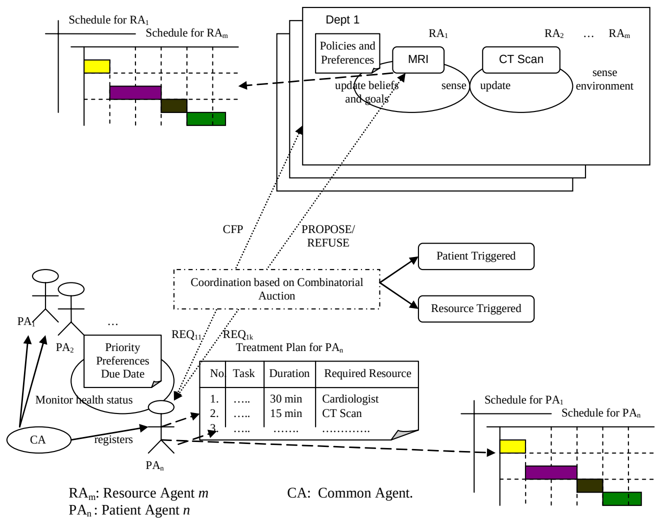

Fig. 2 Framework for Auction based Patient Scheduling using Multi-agents

Resource Agent (RA): The resource agent represents the various machines in the hospital and also specialists and doctors. The resource is subject to the departmental policies of the presiding department. Specialists or doctors may also have availability timings and their preferences. The resource agent constantly updates beliefs and goals based on the preferences and current environmental conditions.

B. Auction based Scheduling Mechanism

The scheduling mechanism is auction based and each resource and each patient is represented by an agent. Each resource agent is also an auctioneer and each patient agent is a bidder. Patient agent requests for a combination of timeslots from resource agents leading to a combinatorial auction [10]. The fully distributed algorithm is adapted from [11], [12].

Step 1: Registration of Patient

Upon the patient's arrival, the patient is registered by the CA. The initial set of tasks and any precedence constrained are also recorded. Each task requires a particular resource for a given time period. The patient availability time, given by the set of timeslots requested, are also recorded.

Step 2: Construction of Bids by Patient Agents
After the patient registration is complete, a local schedule is created with the objective of minimizing the weighted waiting time for the individual patient. The patient agents then look up the prices of the required timeslots in various resources, and construct bids. The bids are sent to resource agent using the PROPOSE message.
Step 3: Resource Agent updates its price for the Patient agents who submitted bids
The resource agent accepts the bids and first creates an infeasible schedule. Resource agent constructs feasible schedule for the patient agents that submitted bids. The feasible schedule is a schedule that does not violate the resource constraints such that each timeslot can only be allocated to one patient. The price is calculated based on the sum of the weighted waiting time of all the patients from the feasible schedule. The price of resource *m* for timeslot *t* is given by λ_{mt}.

The price adjustment, P_D is calculated by subtracting the current price, λ_{mt} of all the timeslots from the total weighted waiting time of all the patients the infeasible schedule $V(P_{\lambda_i})$

$$P_D = \sum_{i=1}^{N_c} V(P_{\lambda_i}) - \sum_{t=t_c}^{t_c+L} \lambda_{mt} \qquad (1)$$

where N_c refers to the total number of patients, t_c refers to the current decision time and L refers to the total length of the time horizon.
Also the task of a patient cannot be pre-empted and the feasible schedule should also take into consideration the preferences and policies of the resource agent and also the patient agent. If there are contending patient agents for a particular timeslot, the price for that timeslot is higher.
Step 4: Check Stopping Criterion
The stopping criterion is when the auction converges to an optimal schedule or if a maximum number of iterations has been reached.
Step 5: Increment the iteration counter
Step 6: Evaluate the bids
If stopping criterion is met, the bids are evaluated and the patient agent scheduled at the earliest timeslot of the feasible schedule is the winner of the timeslot. The ACCEPT_PROPOSAL message is sent to the winner and a REJECT_PROPOSAL is sent to all the other bidders.

Resource-oriented – If resource is not available and patient needs the resource.
Step 6: Send explicit request to resource
The patient agent sends an explicit request using the REQUEST message on reception of a REJECT_PROPOSAL message from the resource. This is to indicate the need for the resource at any time the resource becomes available.
Step 7: Resource Agent triggers auction when timeslot becomes available.

When the resource agent becomes available, it looks up the list of pending patient agents, and invites bids for the timeslot

$$\sum_{i=1}^{n} w_i \times \max(0, C_i - d_i) \qquad (2)$$

from the patient agents.

IV. RESULTS AND DISCUSSIONS

The auction-based multi-agent framework is simulated in the JADE multi-agent platform. The multi-agent framework for the patient scheduling problem is simulated using the JADE multi-agent platform. The experiment is conducted with 3 resources and varying number of patients. An assumption is made that patient requires these three resources in different orders for varying durations. Patients have varying priority levels with emergency cases having highest priority with weight 6, outpatients with weight 4 and Inpatients with weight 2. Experimental inputs are generated for 3 patients, 10 patients, 15 patients and 20 patients.
In the previous work, a purely resource triggered auction was developed [13]. The chief drawback of this approach is that the number of messages passed was very high and hence led to an inefficient framework. In a purely resource triggered auction, patient agents reply to a CFP from a resource agent by either sending a PROPOSE or a REFUSE message. In the patient triggered auction, patient agent send REQUEST messages to only the required resource and once the REQUEST has been met, the resource agent does not send CFP to the patient agents. This greatly reduces the amount of message passing and leads to a more effective coordination mechanism (Fig. 3).

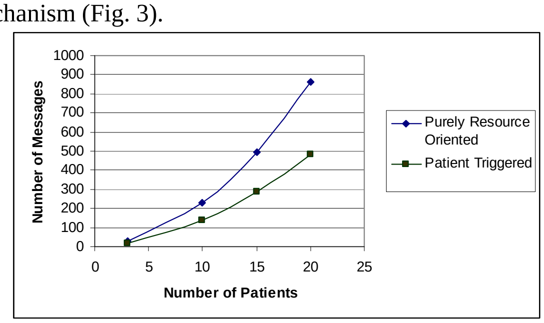

Fig. 3 Comparison of the number of message passed for purely Resource oriented vs. Patient Triggered Coordination Mechanism.

A. Performance Evaluation

The performance of the multi-agent system is evaluated against the performance of traditional scheduling algorithms such as (First Come First Serve) FCFS, (Earliest Due Date first) EDD, (Longest Processing time first) LPT, (Shortest Processing time first) SPT, (Weighted Shortest Processing Time first) WSPT and (Minimal Slack first) MS. There are

several performance metrics for the scheduling problem. The objective of patient scheduling problem is to minimize the patient waiting time and improve the resource utilization in the hospitals. The *Total weighted Waiting Time* as a metric to evaluate the performance calculated as follows,
where w_i is the weight associated with the patient based on priority level, C_i is the completion time of the tasks of the patient and d_i is the due date of the patient. A minimized value indicates better performance.

B. Simulation and Result Analysis

The framework is simulated in JADE and a schedule that meets the constraints is produced for each individual patient and resource agent.
As can be seen from the Fig. 4, the prices for timeslots that have many contending patient agents are higher (Refer to Formula 1 for price Calculation). The price of timeslots not allocated is nil. The price of timeslots occupied by higher priority patients is higher than those occupied by patients with a lower priority.

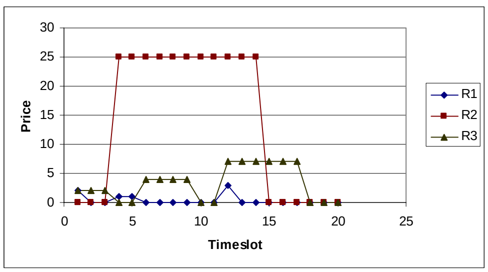

Fig. 4 The price fluctuation of various timeslots for resources R1, R2 and R3 obtained from simulation of 3 patients for 20 timeslots.

As can be seen in Fig. 5 the total weighted waiting time of SPT and LPT has the highest weighted waiting time of 2900 and 2802 respectively. The performance of FCFS, EDD and WSPT are similar with weighted waiting time in the interval of 2400 to 2500 with only a 100 unit difference.

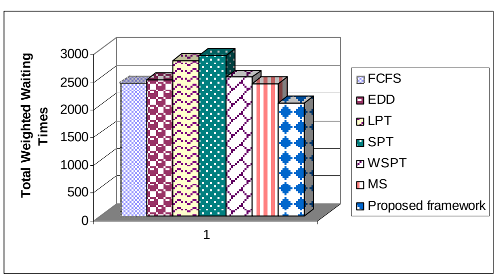

Fig. 5 Comparison of Weighted waiting time of proposed framework with traditional dispatching rules for 20 patients on 3 resources. (refer Section 4.2)

Even the best performing traditional dispatching rule, MS has a 15% difference as compared to the proposed framework. The proposed framework has the least weighted waiting time value of 2034 units.

V. CONCLUSIONS

The patient scheduling domain is a highly dynamic domain and an effective solution will improve the quality of life of the society. A schedule that minimizes the patient waiting time may even aid in saving the person's life. The auction based framework is designed to work in the distributed, dynamic and decentralized environment in the patient scheduling domain. This framework solves hospital scheduling problems that involve patients requiring a set of resources in a given order with resource availability and patient preference constraints.

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