A Multiagent Based System for Resource Allocation and Scheduling of Distributed Projects

Sunil Adhau and M. L. Mittal

Abstract—**In this paper, a multi agent based decentralized decision making approach is presented for allocating resources and scheduling of distributed multiple projects. The resource allocation and scheduling is performed cooperatively and collectively by a group of autonomous project agents, resource agents and a mediator agent. We propose a price mechanism that allows project agents to bid for the needed resources. A new contract net protocol (CNP) concept is used for negotiations and coordination among the agents. This approach is successfully applied on an example problem.**

Index Terms— **CNP; bidding; multiagent; multi project; scheduling.**

I. Introduction

Multi-project scheduling is a process of the scheduling of two or more simultaneously running projects which demand the same scarce resources. These problems are referred to as the resource-constrained multi-project scheduling problems (RCMPSP). RCMPSP can be solved by exact procedures, metaheuristics, or simple priority rules. For real-world problems, however, exact procedures are impractical due to computational intractability and thus heuristic procedures are used.

In most of the research on multi-project scheduling problems, planning and control of projects is often considered centralized and managed by a single manager. This in practice is very limiting assumption. In decentralized multi-project scheduling problem the decision making process is decentralized with as many local and autonomous decision makers (project managers) as the projects. Confessor [1] refers to this problem as the decentralized resource constrained multi-project scheduling problem (DRCMPSP). This kind of environment is commonly found in automobile industry where supplier carries out several engineering projects with different automobile manufacturers or original equipment’s manufacturers (OEM’s).

In the last decade, agent based systems for project scheduling has received a great attention from the academic. An agent may be defined as an entity that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives [2]. An agent is considered intelligent when it has the following capabilities: reactivity, proactiveness, and social ability [3].

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A multi agent system (MAS) is a distributed artificial intelligence system composed of a number of autonomous agents capable of communicating and collaborating with each other to achieve common goals [3].

This paper is concerned with developing a multi agent based scheduling approach in which multiple distributed projects share a set of global resources. All the projects have to be planned simultaneously by a group of local decision makers (project managers, resource agent and mediator agent). A project agent PA_i is responsible for a project i consisting of a set of activities. Activities in the projects need certain resources for their completion which are provided by the resource agents. A resource agent RA_g is responsible for a resource type g; that receives the resource requests from project agents and negotiates with the project agent for the allocation of the resources. The objective of the problem is to obtain a quality schedule of all the projects while respecting the resource availability and precedence constraints.

The remainder of this paper is organized as: Section II summarizes some related work on multi agent based project scheduling problems. Section III formally describes the distributed multi-project scheduling problem. Section IV presents the multi agent based model. Section V introduces the proposed system and describes implementation mechanism. Section VI illustrates the proposed work on simple problem. Finally, the paper presents conclusions.

II. Literature Review

Different methodologies and techniques have been proposed in the literature for agent-based project scheduling. Knotts et al. [4] develop eight agent-based algorithms for solving the multimode, resource-constrained project scheduling problem. Yan et al. [5] present a MAS as a technique to resource allocation problem in a distributed environment. For solving decentralized multi-project scheduling problems, only a few methods are available in literature. Lee et al. [6] is probably the first who presented a dynamic economy model and a novel market based mechanism for dynamic resource allocation in a multi-project environment. Later on, Confessore et al. [1] developed a MAS model for scheduling of multiple projects. Authors assume that single unit of a shared resource is available in each period of planning horizon. Both systems are based on modern electronic auctions for resource allocation and simple heuristics for scheduling activities. A coordination mechanism using argumentation-based negotiation is introduced by Lau et al. [7],[8]. They propose a MAS consisting of a set of schedule agents and a set of contractor or resource agents with different local objective functions. Homberger [9] suggested a MAS for the DRCMPSP with several global resources. Each single project is planned by one responsible schedule agent. An iterative coordination mechanism based on centrally imposed solutions is used. Adhau and Mittal [10] presented a new approach to solve the decentralized resource constrained dynamic multi-project scheduling problem using a cooperative MAS.

The brief review of the related literature shows that there are only a few studies concerning multi-project environment, using multi-agent technology in particular. The current paper considers these problems and proposes a multi agent based solution approach for scheduling of distributed multiple projects.

III. Problem Description and Objectives

A DRCMPSP can be described as follows.

- There is a set of M projects running simultaneously at geographically different locations utilizing local (always available to the concerned project) and global (shared among the projects) resources for their completion. The resources are available in limited quantity on per period basis. The projects are to be scheduled decentrally and autonomously.
- Each Project $i \in \{1, \ldots, M\}$ consists of n_i non-preemptable activities a_{ij} with a set $j \in \{1,\ldots,n_i\}$;
- Two fictitious activities a_{i0} and a_{in+1} each of duration zero are added to each project i for representing the 'start' and the 'end' of the project;
- E_i is a set of precedence relations in project i. Pair (a_{ij}, a_{ik}) means : $a_{ij} \prec a_{ik}$;
- Each project i has an earliest release time t_{ri} , from which activity a_{i0} can be started;
- Each activity a_{ij} has a non-preemptive processing duration p_{ij} ;
- For each project i, a set of local renewable resources k ($k = 1, \ldots, K$) are provided in an amount R_{kti} in each period t ($t = 1, \ldots, T$). Each activity a_{ij} requires an amount r_{ij}^{k} of resource type k [11];
- For each project i, a set of global renewable resources g ($g = 1, \ldots, G$) which is shared among the projects is available in quantity R_{gt} in each period t ($t= 1, \ldots, T$). An activity j of project i may require an amount r_{ij}^{g} ; of resource type g;

The performance of proposed method is evaluated for the Mean Project Delay (MPD) [1]; [12]; [13].MPD is defined as below,

$$Mean\ project\ delay = \frac{1}{M}\sum_{i=1}^{M}(C_i - D_i) \qquad (1)$$

where,
C_i = Completion time of project i,
D_i = Desired due date of project i, as determined by initial scheduling with local resources.

IV. Agent- Based Modeling for Multi-Project Scheduling

In this study, we model a distributed multi-project scheduling problem as a multi agent system. An agent PA_i is used to model the scheduling processes of a project i. It is implemented as a program that is located at the individual project and aims at building initial feasible local schedule based on its capacity constraints. PA_i also negotiates for global resources and determines the schedule of the activities with respect to resource availability of the global resources. Each project agent has its own scheduling objective and acts independently to each other.

Objective of project agent PA_i is to complete the project within a given due date and at minimum total cost (TC_i). Total cost is the sum of the cost of performing, earliness and tardiness costs of the activities of the project. The earliness cost EC_{ij} incurs when an activity j of project i is completed earlier to its due date d_i (desired due date of activity a_{ij} as determined by initial scheduling with local resources). The tardiness cost T_{ij} incurs when an activity j of project i is completed later to its due date. The earliness cost penalizes idle time between consecutive activities [7]. The schedule S_i of project i is referred to as the vector of start time ($s_{i1}, \ldots, s_{in}$). Let A_t represent the set of activities in progress during the time interval (t-1, t). Mathematical formulation of cost function for each project agent is as follows,

$$Min\ \ TC_i = \sum_{j=1}^{n}[O_{ij} + E_{ij} + T_{ij} \qquad i = \ \ldots \ M \qquad (2)$$

where,
O_{ij} = Operating cost of activity a_{ij},
E_{ij} = Earliness cost of activity a_{ij},
T_{ij} = Tardiness cost of activity a_{ij}
Subject to,

$$s_{ij} + p_{ij} \le s_{ik} \qquad \forall \boldsymbol{i} \in M\ ,\forall\ a_{ij}\ \ a_{ik}\ \in E_i \qquad (3)$$

$$\sum_{A_t} r_{ij}^{g} \le R_{gt} \qquad \forall \in [1,..,T], \quad \forall\, g \in [1,..,G] \qquad (4)$$

The objective function (2) is to minimize the total operating cost of the solution schedule. The set of constraints (3) ensure the precedence constraints between activities of each project. Constraint (4) represents the capacity constraint with respect to different global resources of resource agent in each period.

Each global resources g has a corresponding resource agent RA_g who owns all available quantity of resources g during different time periods. The properties of resources and the utilization status are recorded in the memory of RA_g. The mediator agent (*MA)* will be responsible for identification of resource conflicts and allocate global resources to projects using bid selection algorithm. Mediator agent updates the capacities of the available global resources allotted to current projects. It also stores the schedules of all projects into the database.

V. Co-ordination mechanism

Contract net protocol (CNP) is used in this paper for distributed planning and scheduling. Contracts are a powerful co-ordination mechanism in distributed systems. CNP specifies a bidding approach that enables resource allocation among multiple agents [14]. Based on the cost functions derived in section IV, this paper proposes a new contract-net based negotiation mechanism for allocating global resources to the projects. The negotiation process is coordinated by a mediator agent. We apply economy-based bidding mechanism which coordinates resource allocation among the project agents competing for specific amount of global resources. Fig. 1, depicts the communication scenario between project agent *PA* and resource agent *RA* concerning a slot reservation of global resources. The CNP negotiation process and the activities performed by different types of the agents are discussed as follows.

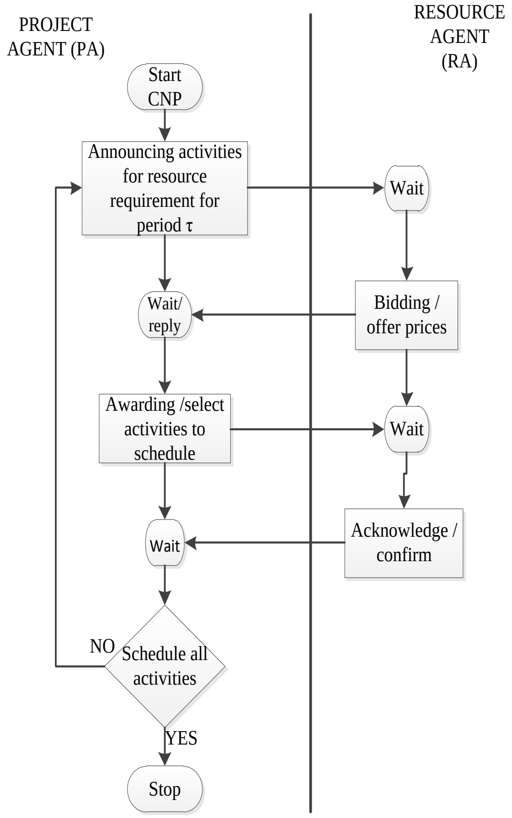

Fig. 1. CNP negotiation protocol.

A. Project Agent

In each scheduling period *t* the execution of protocol begins with project agents. PA_i starts to schedule activity a_{ij} when all its preceding activities of a_{ij} have been scheduled. Each project agent do following;

1.1. Project agent PA_i announces resource requirement to the corresponding resource agent RA_g with the bid message = {Project ID, Activity ID, p_{ij}, r_{ij}^{g} , time window}

1.2. PA_i receives list of offers containing resource price P_{rg} for requested global resources *g* as per step 2.3 and virtually reschedule the project.

1.3. Calculate bid prices for all the resources for time slot *t* using following expression;

$$B_{pik} = P_{rg} \times p_{ij} + \max\left(VC_i - D_i\right) \tag{5}$$

where, VC_i = Completion time of virtually scheduled project *i*,

1.4. Communicate bid = {B_{pik}, r_{ij}^{g} ,time window} to mediator agent for evaluation..

1.5. PA_i receives the cheapest slot for scheduling activity a_{ij} as per step 3.1 to 3.3 of *MA*.

1.6. Send award message to RA_g and schedules a_{ij} on this selected slot .

1.7. Repeat steps 1.1 to 1.6 for each activity of project *i* in turn, setting $t = t + 1$.

B. Resource Agent

Resource agent RA_g receives bid messages up to some expiration time from project agent PA_i as per step 1.1 and prepare list of offers using its own pricing model given below (steps 2.1 and 2.2) for reservation of time slot on the resource requirements.

2.1. Calculate aggregate demand D_{gt} of global resources in each period *t* by the following formula:

$$D_{gt} = \sum_{j=1}^{n}\sum_{i=1}^{M} r_{ij}^{g} \tag{6}$$

where, $0 \le r_{ij}^{g} \le R_{gt}$.

2.2. Calculate P_{rg} on the basis of D_{gt} and constant availability of R_{gt} shared by all projects as below:

$$P_{rg} = p_r \times \sum_{j=1}^{n}\sum_{i=1}^{M} r_{ij}^{g} \tag{7}$$

where, p_r= initial/reserve price of global resource per unit time.

2.3. RA_g announces resource price P_{rg} to project agent PA_i through mediator agent.

2.4. Receives award message as per step 1.6. Checks the available capacity of recourses. In period *t*, reserve resource for project and send a commitment message to the corresponding project.

C. Mediator Agent

The mediator agent apply the bid selection algorithm to choose the best bid as below,

3.1. Receives bids from all PA's as per step 1.4.

3.2. WHILE($t \le T$)

Make sequence of bids in ascending order of bid price.

Evaluate and select bid submitting highest bid price for each resource.

3.3. Communicate selected bid to PA_i and RA_g**.**

3.4. Update the capacities until all activities with global resource requirement are finished. Update time period $t = t + 1$.

VI. An Illustration

This section presents a simple example to demonstrate how the proposed mechanism collaboratively allocate resources and schedule the distributed multiple projects. We consider a simple multi-project problem with three projects for clear demonstration of the interactions among agents. Fig. 2 represent the activity-on-node networks of three different independent (single) projects $i = 1, 2$, and 3. The constituent activities for these project, their processing duration p_{ij} and requirements for local r_{ij}^{k} and global resources r_{ij}^{g} are given in Table 1. The total availability of local (equal for all the projects) and global resources is 3 units respectively. The decisional process goes as given below in two phases.

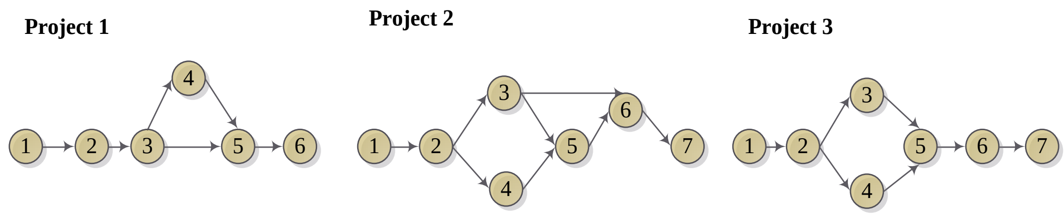

Fig. 2. Project network of project 1, 2 and 3

TABLE I: DATA OF PROJECT 1, 2 AND 3

ID	p_{ij}	r^k_{ij}	r^g_{ij}	ID	p_{ij}	r^k_{ij}	r^g_{ij}	ID	p_{ij}	r^k_{ij}	r^g_{ij}
1-1	0	0	0	2-1	0	0	0	3-1	0	0	0
1-2	2	1	0	2-2	1	3	0	3-2	3	1	0
1-3	1	2	2	2-3	1	2	0	3-3	1	2	0
1-4	2	2	0	2-4	2	2	2	3-4	2	1	0
1-5	2	3	2	2-5	1	2	0	3-5	1	1	0
				2-6	2	3	0	3-6	2	3	2
1-6	0	0	0	2-7	0	0	0	3-7	0	0	0

A. Phase I: Initialization

The project agents perform the local scheduling using a static project scheduling algorithm with minimum latest finish time (min LFT) priority rules and serial schedule generation scheme [15]. At this phase we ignore the global resource requirements and thus all the activities can be scheduled in projects by utilizing local resources only. Fig. 3 shows the Gantt chart for the schedules for projects 1, 2, and 3.

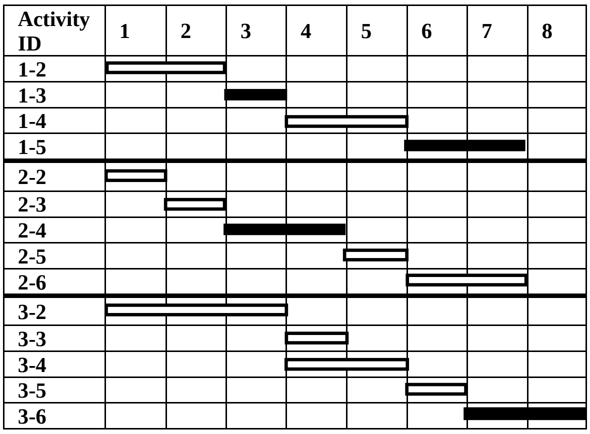

Fig. 3. Gantt chart for schedule with local resources.

The x- axis of the chart is subdivided into equal units of periods (days in our case). The y-axis, on the other hand, lists the project activities. The dummy activities in each network are not shown in the chart.

B. Phase II: Allocation of global resources

As can be seen in Fig. 3 there are resource conflicts for global resources during periods 3-4 (activity 1-3 requires 2 units and activity 2-4 requires 2 adding to 4) and period 6-8 (activity 1-5 requires 2 units and activity 3-6 requires 2 units). The resource conflicts for global resources are to be solved via the CNP negotiation process of the agents as described in section V. Each project agent sends request for resource requirement in bid massage (RFB) to resource agent $RA_{g.}$. Initial/ reserve price of global resource per unit time is assumed, p_r =2. The resource prices is calculated as per the equation (7) and communicated to project agent. In bidding round the bid price are determined by project agent PA_1, PA_2 as 10 and 17 respectively. The mediator evaluates the bids and selects the activity 2-4 with higher bid price (17) as per the bid selection algorithm. The procedure is repeated for the next time slot for allocation of the global resources to all activities. The start time of all activities which required the global resources from all projects are fixed and the remaining scheduled activities are rescheduled locally at each *PA*. With this interactive agent negotiation scheme, implemented on example projects, the resources are distributed successfully, and overall schedule of all projects emerges. The optimum sequence of activities for global resource allocation is emerges as 2-4; 1-3; 3-6; 1-5 considering maximum bid price criteria for bid selection. Fig. 4 shows the final multi project schedule of our sample problem.

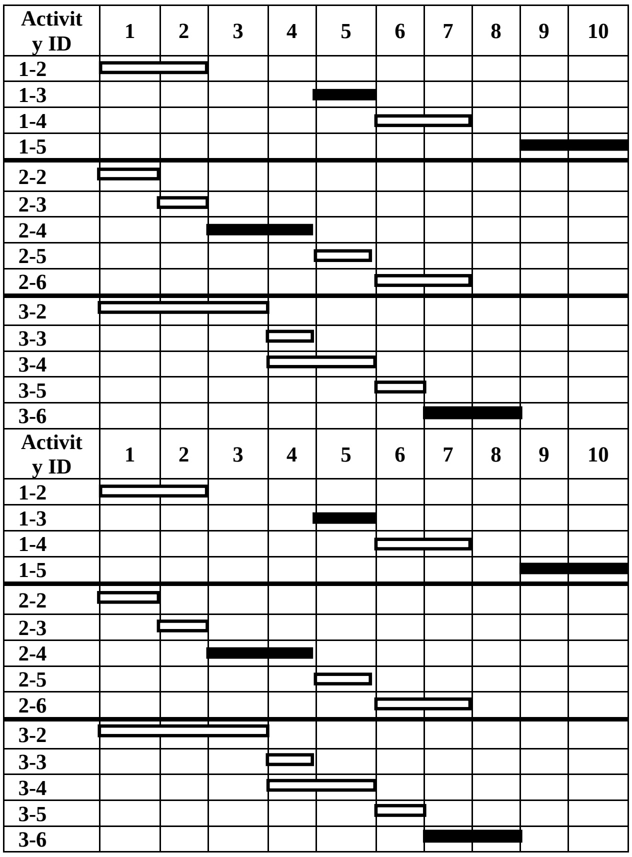

Fig. 4. Final Multi-project Schedule.

It is noted that project 1 shifted right with three days delay. While project 2 and project 3 do not impact on its due date for shared resource requirement. Result shows that the optimal multi-project schedule has minimum mean project delay = 0.66. The procedure can be validated considering multiple local as well as global shared resources.

VII. CONCLUSION

In this paper we have considered distributed multi-project scheduling problem where each project utilizing limited amount of its own local and global (shared among the projects) resources for their completion. A multi agent based decentralized decision making approach is presented for scheduling of multiple projects. An agent based model is developed. The objective of the model is to minimize the makespan. We apply economy-based bidding and price mechanism in which multiple project agents compete for specific amount of resources supplied by resource agents. The bidding process is coordinated by mediator agent. We proposed a new negotiation mechanism on contract net protocol for allocating global resources. This approach is successfully applied and simulated on an example problem to validate the proposed method.

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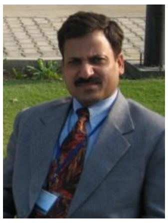

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