Multi-Agent Systems for Resource Allocation

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Abstract: The resource allocation in complex systems needs developing systems as multi-agent systems and the negotiation is a usual way to acquire the resources in the needed amounts and at appropriate times. The strategies and tactics depend upon the developed system. The paper analyzes the results in resource allocation and gives an example for distributed computer architecture.

Keywords: resource allocation, multi-agent systems

1 Introduction

Distributed Artificial Intelligence (DAI) designs agents that interact effectively. One of the basic ability of the agents cooperation is the negotiation and based on it, they reach mutually beneficial agreements. The agent actions and also the negotiation are time consuming, so, the designers of MASs must be faced with this important difficulty.

Research in MASs is concerned with coordination intelligent behavior of a collection of autonomous intelligent agents. There is a possibility for real competition among the agents. MASs deals with interactions among self-motivated, rational and autonomous agents. There are systems where the agents may share a common goal although even in such situations the agents are self-motivated and act only according to their interests. Also each agent can have its own utility function and its rational behavior involves maximizing expected utility. The agents use a set of shared resources and every agent intend to use the resources in order to attain its goals in an own efficient and eventually optimized manner.

The purpose of present paper is to analyze and examine the problem of resource allocation and task distribution among the autonomous agents. There are domains where agents due to limited resources must share a common resource and also in other domains where the resources are unlimited the agents may still mutually benefit from sharing a common resource since resources may be expensive or from distributing a set of common tasks. In the resource-sharing problem there is a competition for a valuable resource, each agent seeking a larger share of the resource. In the task distribution problem where the agents have a common goal, several tasks need to be executed to fulfill the goal. Each agent would like the common goal to be achieved with the least effort on its part this case has a competitive element: each agent wants to perform a smaller part of the task.

2 Resource Allocation

2.1 The Resource Allocation Problem

There are some possible situations for defining an appropriate model and these must matter on the knowledge dispose, one versus the other, the agents that interact one to other.

A set of agents shares a (common) resource. The resource is constituted of an integer amount of unities. The agreement is sought that all the agents will be able to use the resource. An agreement is a schedule that divides the usage of the resource among the agents. Sharing a common resource requires a coordination mechanism that will manage the usage of the resource.

It is obviously to outline that in real systems there are more than one resource that is used in a time instant by an agent. Also it must be fixed that between the agents exist different and conflicting goals. From these considerations the mechanisms used for resource allocation should be stable and symmetric.

One of the major features is that there is some cost associated with the times that elapses between the time that the resource is needed by an agent and the time the agent actually gains access to the resource. Also, another cost appears form the fact that an agent can obtain a less amount that than it required.

2.2 The Task Distribution Problem

Let a set of autonomous agents that has as a common goal to satisfy. In order to satisfy the goal an agent has to reach some agreement with the other agents. Each of the agents wants to minimize its costs i.e., prefers to do as little as possible. There is a conflict of interests. So the tasks that should be performed by the agents will be chosen after they will try to optimize in some sense their actions.

As conclusion, the resource allocation problem and task distribution problem basically can be solved with the same tools.

3 Criteria for Evaluation of Negotiation Protocols

In multi-agent systems are used negotiation mechanisms (protocols) that allow to the agents to solve the conflicts and to reach a cooperative agreement. Because of complex nature of MAS, the negotiation protocols should satisfy the following features:

- *Distributed.* The decision making process that achieves the negotiation should be distributed. There should be no a central entity that manages the negotiation process;
- *efficient and stable.* The outcome of the negotiations should be efficient. The agreements done during the negotiation should satisfy all the participants to the negotiation protocols in order to each of them being able to obtain sone efficient results after a negotiation. There should be some equilibrium point to the negotiation protocol. Usually this protocol is viewed as a game. The equilibrium should not violate the condition, i.e., the negotiation should be give a Pareto-optimal agreement;
- *symmetric.* The agents should not be treated differently. In a given specific situation, the replacement of an agent with another that is identical with respect to some attributes will not change the outcome of the negotiation. Obviously, the agent utility and its role are relevant attributes and other attributes are not relevant;
- *instantaneous.* Conflicts and agreements should be solved without delay;
- *accessible*. An agent that needs the resource in a finite time interval it must have access to the resource (there is no starvation);
- *simple.* The negotiation protocol should be short and consume a reasonable amount of resources (such as computation time and communication).

4 Negotiation Strategies

Usually a generic theory of strategy in negotiation was done in the context of particular interaction protocols or class of protocols. Were identified some factors that may influence the creation of a strategy for a rational agent.

Based on [11], the negotiation is a form of interaction in which a group of agents, which desire to cooperate but with potentially conflicting interests, seek to reach a mutually acceptable division of a scarce resource or resources. Every agent enters in a negotiation interaction with some particular goals in mind. There are some alternatives that can appear. An agent may try to achieve the largest possible share of the resource, or it may try to achieve the maximum possible share for itself and some subset of the agents engaged in the negotiation, or it may try to achieve an equitable share for all participants. Such an individual agent goals may conflict with the goals of other agents in the sense that not all goals can be achieved simultaneously.

A negotiation strategy can be defined as a rule or algorithm, which provides that, can do an agent when it enters in a particular negotiation interaction. The factors that can guide the design and selection of strategies for agents engaged in negotiation interactions depend on the strategy used in a particular case.

A strategy specifies what an agent should utter and when in a negotiation interaction. A tactics govern a small number of utterances in an interaction and it is obviously to make difference between the strategy and tactic, because some tactics implement certain strategy.

The resource allocation problem was treated theoretical and conceptual in [3] were the negotiation in multi-agent systems under time constraints, was in detail analyzed. In [8] the strategy and also the tactics were stated. Were given the factors that may influence the design of strategies for an agent engaged in a negotiation interaction with other agents. These factors are:

- *goals* The objectives or goals of the agent that the agent wishes to achieve from a negotiation interaction over the resources are in many cases complexes. These objectives can be or not explicit;
- *domain* Strategies may differ according to the nature of resources under negotiation (some are task oriented another state-oriented domains);
- *protocol* The nature of the interaction protocol. The information used in the protocol strategy is a particular one that must be given in an appropriate way and also just in time;
- *capabilities* Some agents in many multi-agent systems can have different capabilities concerning the interaction protocol;
- *values* Some actions of the agent may be permitted or not by the protocol and the capabilities of the agent. Here must be maintain a coherent profile of the agent in accordance with the protocol in that it is involved;
- *resources* The time and resource available to the agent including the computational resources and also the expert advice (where the case is) must be take into the account;
- *alternatives* The nature of any alternatives for resolution available to the agent should be permitted for the agents that interact in the negotiation.

Having purposeful agents, then they have some goals that lead the agents when enter in a negotiation interaction. Depending on the system, the agents can be implied simultaneously in more than one negotiation interaction eventually with different goals. In the strategy design a major influence will be the interaction capabilities of the agent negotiator. The agent engaged in a negotiation interaction must be able to make utterances that are legal according to the rules of the protocol. Depending upon the specific protocol the capabilities can be:

- *making proposed deals*;
- *accepting proposed deals*;
- *rejecting proposed deals*;
- *presenting information proactively to a counterparty*;
- *seeking information from a counterparty*;
- *providing information reactively to a counterparty*;
- *seeking to exert pressure on a counterparty*;
- *retracting commitments*;
- *withdrawal form an interaction negotiation*.

Some constraints that can be imposed on the potential capabilities are:

- *interaction protocol*;
- *values*: agent specificities can influence potential capabilities of it;
- *resource constraints*: concerning the computing resources (time memory processing particularities).

An agent enters in a particular negotiation interaction with another agents over a specific state of resources in a specified instant of time in order to achieve its negotiation goals. The specific action(s) are grouped in the tactics adopted. The strategy particularities are detailed in the tactics that are used by the agents. The details depend upon the systems specificities.

5 Models for Resource Allocation

To automate the negotiation process many interaction and decision mechanisms were studied and proposed.

The behavior in multi-agent systems was stated in [2] adapted to contract negotiation. The deals and the contracts were defined. Also were estimated their complexities. The Pareto optimality is the basis for defining criteria for contract negotiation.

In game theoretic analysis [10] the optimal strategy is determined based on the interaction as a game between identical players and seeking its equilibrium. The strategy so determined is optimal for a participant given the same rules, the assumed payoffs and the goals of the participants.

Due to some real constraints as resource limitations when it is not possible to reach optimal outcome were developed heuristics. Heuristics produce approximate and eventually suboptimal solutions. Some interesting model was developed in [6], [7].

Market mechanisms and auctions [4] [5] can be an effective method to control resources especially electronic resources for the same reasons that markets have effectively regulated the trade of traditional goods. Currency-based models allow for common valuation of heterogeneous resources giving system managers or agents the ability to establish priority or specify preferences. Markets are appropriate for decentralized and as a consequence distributed systems because independent allocations can occur simultaneously in a distributed network without a central authority. Prices can serve as low-dimensional feedback for control. The auctions are preferable instead of pricing mechanisms because of the transparency of the allocation rule removes any information advantage of knowing how a price rule is derived.

6 Application

6.1 The Message Scheduling

Let a real-time Ethernet network system model. It allows prioritization on Ethernet networks. The IEEE 802.1p standard establishes eight levels of message priorities. Network adapters and switches route traffic on the network segment based on the priority level of the messages. Usually the routers use some particular scheduling algorithms. As is shown in Figure 1 the router maintains a message queue per processor and store incoming messages that are destined for that processor on its message queue.

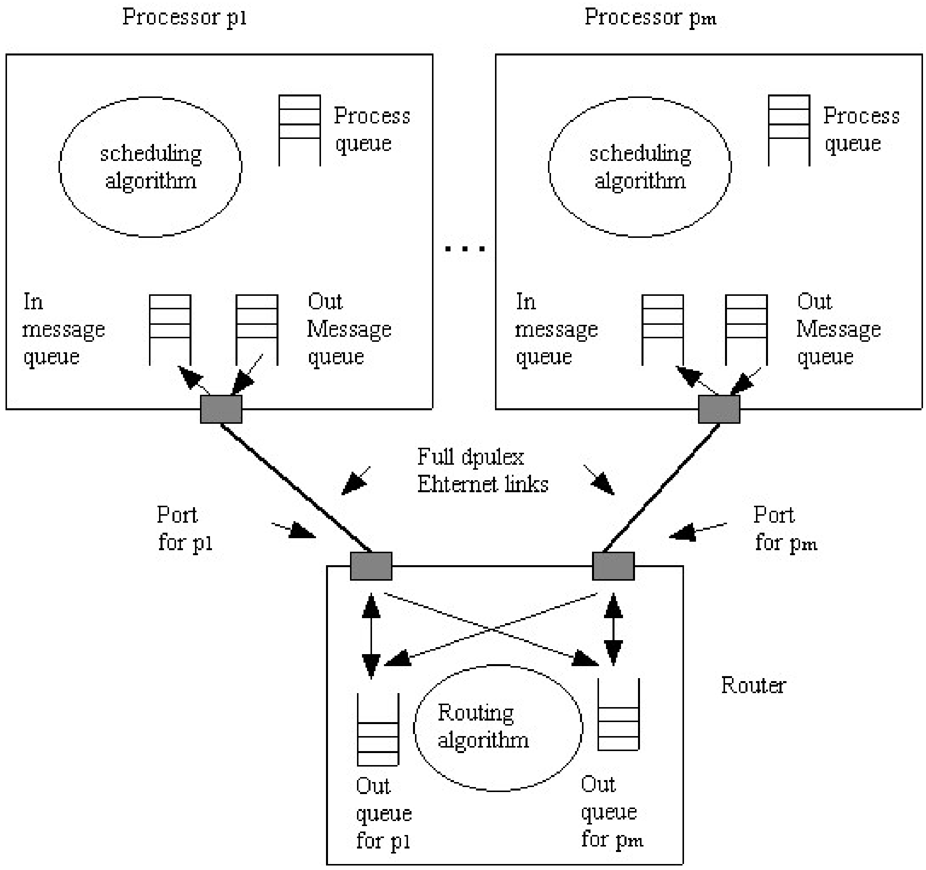

Figure1
The Ethernet network system

In some complex models [9] the messages are associated to tasks that use it. The task cannot be executed without the necessary messages. In such models the task has its own deadline and as a consequence the messages must arrive in time in order that the task its deadline, so the messages are also their times of arrival. A particular model will be shortly sketched. In the proposed algorithm estimates message communication delays based on a workload function that is anticipated on average. In the following the task T_i is divided into subtasks $t_{i_k}, k = 1,2,\dots,m$ such that between the t_{i_k} and $t_{i_{k+1}}$ some message $me_{i,k}$ arrive (we suppose that this message will be used by the subtask $t_{i_{k+1}}$ during its execution for the simplicity of presentation, because usually there are more than one message used by a subtask). Then the deadline for a message $me_{i,k}$ is for an average data size d_{avg} is given by

$$dl(me_{i,k}) = ecd(me_{i,k}, d_{avg}) + (dl(T_i) - \sum_{s=i}^{m} ecd(me_{s,k}, d_{avg}) -$$
$$\sum_{s=i+1}^{m} ex(t_s, d_{avg}) * ecd(me_{i,k}, d_{avg}) +$$
$$(\sum_{s=i}^{m} ecd(me_{s,k}, d_{avg}) + \sum_{s=i+1}^{m} ex(t_s, d_{avg})))$$

where: $ecd(me_{i,k_j}, d_{avg)}$ is the estimated communication delay for the message me_{i,k_j} and $ex(t_{i,k}, d_{avg})$ is the estimated execution of the t_{i_k} for a data size d_{avg}.

6.2 Proposed Model

Now we must state when a message arrives at its destination. Every message has an estimated arrival deadline that in our vision (given above) pessimistic. The factors that influence the delay incurred for a message to pass from its sender to its destination are the followings:

- *the contention that the messages at the outgoing queue at the sender*;
- *the incoming and outgoing queues at the router*;
- *the incoming queue at the destination.*

The strategies and politics used in treating the service at these queues.

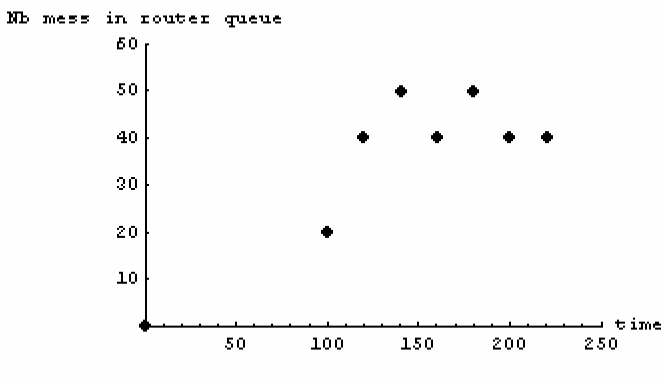

Figure 2
Number of messages in router queue

The model proposition for such system is the following. The tasks are executed on the previous architecture. Every task sends and receives messages that comply with the previous assumptions. Every processor and also the router have an agent that manages the communication, as it will be given in the following.

The agent A_i that is dedicated to a processor has for every task uses subtasks; their duration for execution and the time instants when their appropriate messages must arrive such as was presented above. Based on these the agent requires and negotiates with the agent that governs the router for the times when messages must arrive to the processor. Also the agent will manage the messages that will be sent by the processor for other processors. The agent that manages the processor cooperate with the processor agents in order to deliver required messages in a way that optimize the whole system i.e., minimize the delays for messages. In the following the model will be detailed.

Let the current process $p_i, i = 1,2,\ldots,n$ and the appropriate agent A_i and A the router agent. It has two queues one for incoming messages and another for messages that must be sent. Concerning the messages of the current processor we have the following cases:

- messages form own input queue - these messages are picked as soon as these are required;
- messages from out queue dedicated to other processors are required by these based on the time instant when the messages will be used. As consequence the queue is with priorities that are stated below.

Also, the messages for every processor p_i are placed in the appropriate queue q_i. From such queue a message is sent to the processor based on the priorities that are stated below.

Let q_i the out queue for a processor p_i from the router. Let the messages $me_{i,k}, k = 1,2,\ldots,r$ that are in a time instant in the queue. For such message let $rt_{i,k}$ the time at that the message is required to the receiver processor. The next message that will have the maximum priority and that will be sent is that what has the minimum time instant for arrival $\min_k (rt_{i,k}, k = 1,2,\ldots,r$ and the index of the min in the 1,2,…r is l. This mechanism defines the priority for message delivering in out queues of the processors and in the queues of the router.

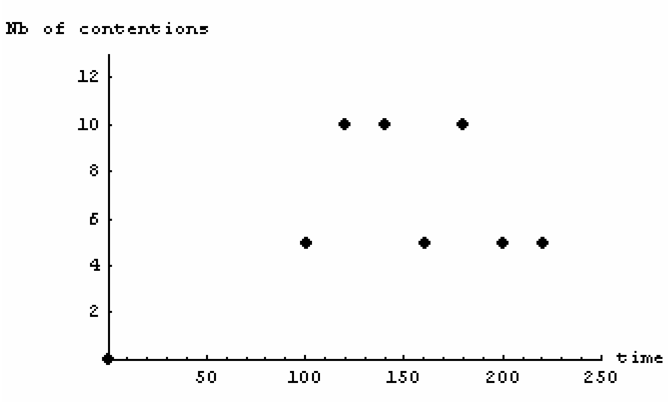

Figure 3
Contentions number in queue

The agent A and $A_i, i = 1,2,\ldots,n$ negotiate in the case of contention generated by the priorities that define the next message to be sent in a time instant. The contention has as object:

- the same time instant for more than one message that are the same priority (the priority is the $rt_{i,k}$) . It can be solved taking into the account the shortest message length;
- the required message is not found in any queue: the queue q_i of the router or in the out queue of the sender processor p_j . In this case the agent request can not be delivered and its appropriate task is suspended (waiting for an external event).

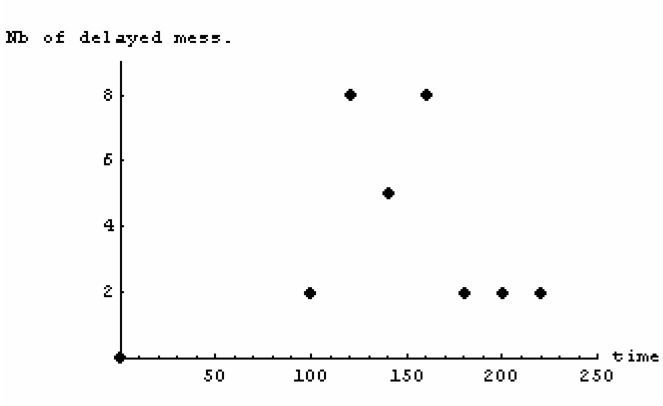

Figure 4
Number of delayed messages

As experiment were used 4 processors and for the router was implemented an algorithm for the above model for priorities. In our example illustrated by the Figures 2-4, about all messages were found in some of the queues processors or router, so any only two tasks were suspended.

7 Conclusions and Future Works

Resource allocation as a general problem is a very difficult problem. Depending on the modeled system it can be emphasized. The negotiation protocols must be conceived based on the above criteria and also the strategies and tactics used must be developed in accordance with the protocols.

As future work we intend to define some utility function and use it in optimizing in some sense the resource allocation.

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