Agent-based approach for Network allocation problems

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***Abstract*—Numerous applications can be formulated as a resource allocation problem, which require a distributed solving method especially when dynamic environments are considered. According to such methods, a solution does not only consist in an optimal allocation, but needs a sequence of transactions leading from a given initial allocation to an optimal one. Up to now, studies have been based on ideal contexts. Indeed, agents are omniscient and/or have complete communication abilities. Most of the time, these assumptions are not plausible. We propose in this paper a multi-agent system in which agents elaborate themselves optimal allocations by means of local negotiations. This self-organized system is based on a more realistic context, where provided solutions can be viewed as emergent phenomena. Agents have a limited perception of their environment and restricted communication abilities. We show that the individual rationality, does not allow the achievement of socially optimal allocations, and we propose a more suitable criterion: the sociability. Our method provides a sequence of transactions leading to an optimal allocation, according to any communication networks.**

***Keywords*-Multi-Agent system, Allocation problem, Network, Negotiation**

I. Introduction

Resource allocation problems arouse a great interest in the computer science community. Allocation problems can be encountered through countless applications in real life. They are often evaluated from a global point of view thanks to notions of the social choice theory [1]. Each notion evaluates a resource allocation by considering the individual welfare of all agents in a different way. Allocation problems have been studied a lot, from a theoretical point of view [10], [6], from a centralized point of view [11] and from a distributed one [2], [7], [9]. Centralized techniques are not efficient when the aim is to maximize a complex welfare notion (without nice mathematical property) or when the environment is dynamic. Most of studies on distributed solving methods focus on the characterization of solutions, but not on the mechanism required to achieve these solutions. Indeed, these studies focus on the existence of transaction paths, on their length or on the properties satisfied by a solution according to the solving method's parameters. Moreover, most of these studies do not consider a realistic context: the *contact network* is often neglected. Indeed, all agents can always negotiate. According to this assumption, agents have complete communication abilities. It is not satisfied in many applications, like in applications either based on peer-to-peer networks or on social networks. A peer (or a member) is not aware of the whole system and can only communicate with its neighbors (or friends). Restricted networks have been considered in other contexts [4], [3]. Solutions provided by solving methods that do not consider restricted communication abilities, may not be achievable in practice. Moreover, studies are often based on population of omniscient agents: they always knows everything about everybody. Such an hypothesis is not satisfied in many cases, where privacy or dynamism is required.

II. Issues on agent negotiations

We focus on distributed mechanisms to solve reallocation problems. A distributed solving process starts from an initial allocation, which evolves, step by step, thanks to local negotiation between agents, until the achievement of optimal allocations. Such problems can be defined as follows:

Definition 1 (Reallocation problem)**.** A reallocation problem is a tuple $\langle \mathcal{P}, \mathcal{R}, \mathcal{T} \rangle$, where $\mathcal{P} = \{a_1, \ldots, a_n\}$ is a finite population of n agents, $\mathcal{R} = \{r_1, \ldots, r_m\}$ is a finite set of m resources, and $\mathcal{T}$ corresponds to the set of transactions allowed during the negotiation process.

Related to the resource nature, we choose to consider unique and atomic resources which are not shareable. Agents cannot alter the resources they own, they are only able to trade them. Let $\mathcal{A}$ be the set of all possible allocations.

We propose to consider several parameters, on which is based the definition of agent. An agent is defined with a **bundle** describing the owned resources, the **preferences** used to evaluate the agent satisfaction, a **behavior** specifying how agents interact, an **acceptability criterion** on which the agent determines if a deal is profitable, and a **neighborhood** representing the communication abilities.

Agents express preferences over the resource set, which are used to determine their individual welfare [5]. We choose to use a cardinal quantitative representation: an additive utility function.

Definition 2 (Utility function)**.** An agent evaluates its individual welfare thanks to an additive utility function $u_{a_i} : 2^{\mathcal{R}} \to \mathbb{R}$. When agent $a_i \in \mathcal{P}$ owns a set of resources

$\rho \subseteq \mathcal{R}$, its utility is evaluated as follows:

$$u_{a_i}(\rho) = \sum_{r_a \in \rho} u_{a_i}(r_a), \quad a_i \in \mathcal{P}, \rho \subseteq \mathcal{R}.$$

Agents must be able to determine whether or not a transaction is acceptable using the decision-making criterion, which should be based only on local information. The aim of the problem is to maximize the efficiency from a global point of view. To evaluate this efficiency, notions from the social choice theory are often used [1]. Since agents have no global knowledge, allocations achieved at the end of negotiation processes can be viewed as emergent phenomena.

Different welfare notions exist focusing on various aspects of a societies. The four most used notions are the utilitarian welfare that focuses on the average satisfaction, the egalitarian welfare that focuses on fairness, the Nash welfare which is a compromise between fairness and average satisfaction, and the elitist welfare that focuses on the richest agent of a society. For each, the optimal value can be determined or estimated by means of centralized algorithms, as suggested in [8]. The optimal values, provided by these algorithms, can be used as references to determine the absolute efficiency of a negotiation process.

Other facets of negotiations must also be considered. The impact of the social graph topology can be evaluated, in order to determine the cost of considering restrictions on agent communication abilities. Such restrictions limit the number of possible transactions and then the resource traffic. It impacts inevitably the negotiations' efficiency but constitutes a more realistic environment. Topological features favoring or penalizing the efficiency of negotiation processes can thus be identified.

The topological sensitivity should also be evaluated. Indeed, considering different topologies of the same class, negotiation processes starting from the same initial allocation can achieve different allocations. The topological sensitivity can be evaluated thanks to the standard deviation among the social values achieved at the end of negotiation processes. A large deviation means that the negotiation process is very sensitive to the graph topology, and thus the quality of provided solutions significantly varies according to the initial conditions.

III. Conclusion

Many applications can be represented by an allocation problem where resources are initially distributed to the agents. The aim is to find a transaction sequence leading from the initial allocation to an optimal solution. Centralized techniques are not adapted due to the problem complexity, and former agent-based approaches were based on a ideal context. Indeed, agents were omniscient and were able to negotiate with all agents of the population. However, such assumptions are not realistic compared to real life applications.

We propose an approach based on a realistic context, where agents have limited perception of the whole system. Agents starts negotiating knowing only their resource bundle, their own preferences and a list of possible partners. They have to reorganize themselves the resource allocation using local transactions. All kinds of contact network can be used to restrict agents' communication abilities. The contact network is an important parameter to consider in order to guarantee the negotiation efficiency in real conditions. Characteristics favoring and penalizing the negotiation efficiency according to different negotiation settings and different welfare notions. We provide efficient settings for agent negotiation in a more realistic context.

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