CENTRALIZED VERSUS MARKET-BASED APPROACHES TO MOBILE TASK ALLOCATION PROBLEM: STATE-OF-THE-ART

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Abstract

Centralized approach has been adopted for finding solutions to resource allocation problems (RAPs) in many real-life applications. On the other hand, market-based approach has been proposed as an alternative to solve the problem due to recent advancement in ICT technologies. In spite of the existence of some efforts to review the pros and cons of each approach in RAPs, the studies cannot be directly applied to specific problem domains like mobile task allocation problem which is characterised with high level of uncertainty on the availability of resources (workers). This paper aims to review existing studies on task allocation problems(TAPs) focusing on those two approaches and their comparison and identify major issues that need to be resolved for comparing the two approaches in mobile task allocation problems. Mobile Task Allocation Problem (MTAP) is defined and its problematic structures are explained in relation with task allocation to mobile workers. Solutions produced by each approach to some applications and variations of MTAP are also discussed and compared. Finally, some future research directions are identified in order to compare both approaches in function of uncertainty emerging from the mobile nature of the MTAP.

I. Introduction

Centralised versus market-based approach to resource allocation and work coordination has been one of major research issues in both academia and industry due to the importance of managing available resources efficiently and effectively (Cheung and Zhou, 2001) (Chen, 2002). Particularly its importance is gaining further weight due to the high presence of the ever-increasing customer needs and competition in addition to the uncertainty factors imposed by the working environment. Existing studies on two approaches were assuming static working environment where uncertainty in working environments is minimal, or even totally neglected. However, when it comes to consider uncertainty, due to the nature of the application considered or its environment like mobile business, centralized approach has been the one chosen by default in the market though the promising techniques employed in the market-based approach and studied in the academia and even applied in some scientific domains like robotics.

This review tries to cover both approaches in the context of task allocation in general then moves on to the mobile version of task allocation problems, and tries to identify any theoretical explanation for the dominance of the centralized approach for dynamic problems concerning mobile business like courier & transport companies (Gendreau et al., 1999) and emergency services (Gendreau et al., 2001) among many other applications. According to this review, we aim to identify some key future research directions in task allocation methods for mobile working environments. Notably, to cover the lack of approaches' comparison in terms of performance and operation costs in function of uncertainty. This paper is structured as: Section 2 presents a review on the state-of-the-art of the centralized and market-based (decentralized) approaches individually as pioneers in problems of resource allocation, existing comparisons are also presented. Section 3 presents MTAP and its variations as well as the applications addressed by both approaches; Section 4 contains discussion. Finally, conclusions are drawn in Section 5.

2. Centralized and Market-based: Approaches for resource allocation problems

Although task and resource allocation have been widely studied in the literature, there are two main approaches identified to tackle the problem of optimizing the resource-demand pair, namely the 'Centralized Approach' and the 'Decentralized Approach' (also known as 'distributed Approach').

2.1. Centralized Approach:

In the centralized approach, decision making process is done at a central, well-informed point, which is usually ranked higher than the working processors (e.g. resources, workers, etc.) in a hierarchical structure (Malone and Smith, 1988). This central-point has as a goal to collect all relevant data about every entity involved in the problem, and by applying a certain tool or mechanism, an output solution is generated. Techniques in Operational Research (OR), heuristics, and Artificial Intelligence (AI) are the main tools used by the central points to obtain their results (Shen, 2002) (Dias et al., 2006). This used to be the classical approach and the one used by default in combinatorial problems in many different applications of resource allocation. Centralized mechanism has been widely used in industrial engineering for various applications like job scheduling on machine resources, (Cheung and Zhou, 2001) used a genetic algorithm to schedule sequence-dependent jobs on machines in a job shop. Similarly, in the field of semiconductor industry, Dobson and Nambimadom (2001) studied the problem of sequencing batch jobs that belong to different families to a single processor in order to minimize the mean weighted flow time. In another study (Ahmadi et al., 1992) a heuristic is used in order to schedule batch-jobs on a model consisting of 2 discrete processors in a semi-conductor factory.

In the field of project management (Bouleimen and Lecoq, 2003) and (Chen and Askin, 2009) a simulated annealing heuristic is proposed in order to address the problem of scheduling a set of resource- and precedence- constrained activities. Timetabling is also a well know application that uses centralized approaches to generate feasible timetables, for example Ogulata and Erol (2003) proposed hierarchical multiple criteria mathematical programming models in order to generate weekly schedules for operating rooms in hospitals, because of the complexity of the problem, it was decomposed into simpler hierarchical stages. A detailed survey (Ernst et al., 2004) suggests the successful implementation of centralised techniques, such as heuristics and operational research, for staff and crew scheduling. A common feature that clearly identifies most of the previous studies is the static nature of the problems discussed. The availability of all necessary information for the decision making made the used techniques successful. Necessary information for such decision making can be obtained by constant supervision of the problem global state in cases where dynamics occur, for instance: the close physical presence of resources to the central decision point or via constant communication with remote agents facing uncertainty.

Uncertainty has been studied under the centralized approach, and some techniques have been investigated in order to tackle some dynamic equivalents of known deterministic problems. (Sahinidis, 2004) provides a comprehensive review on the theory, algorithms, and methodologies development for optimization in uncertain environments.

2.2. Market-based Approach:

The second most promising and well established technique used to address the resource management issues is the decentralized approach (Tan and Harker, 1999), sometimes referred to as distributed approach. It is mainly characterized by the omission of a centralized decision-making point; it rather relies on the interaction of the agents involved in the system located at the same level or multiple levels to make up the final decision. In other words, agents interact and communicate local knowledge according to predefined - protocols to exchange local information, such as market-based protocols.

Market-based mechanisms proved to be powerful when dealing with distributed business environments (Wellman, 1993). It is using market and economic principles in order to coordinate tasks assignment among resources. Auctions like Contract-Net-Protocol (CNP) and combinatorial markets are the basic tools in order to exchange information and tasks among involved agents to assign tasks based on the local knowledge of each participant. However, solutions generated by market auctions greatly depends on the used- protocol implementation, and therefore may lead to significantly sub-optimal solutions. Market-based approach has been applied in many fields like robotics and coordination of autonomous robots (Zlot and Stentz, 2006), in the allocation of computing resources in grid computing fields (Wolski et al., 2001), bandwidth allocation in telecommunication applications (Dramitinos et al., 2004), and also it appears in some domains where the centralized approach used to be dominant like job scheduling in a shop floor (Lin and Solberg, 1992). Table 1 presents and summarize the key differences between the centralized and the market-based approaches:

	Centralized	**Market-based**
Taxonomy	Centralized, hierarchical.	Distributed, flat.
Decision making location	Central decision making point.	Work processors (workers).
Degree of required knowledge	Global.	Local.
Decision making techniques	Heuristics, AI, Integer programming, etc.	Combinatorial markets, auctions and negotiations.
Communication required	Lower	Higher
Solution quality	Optimal, near optimal.	Sub-optimal.
Approach philosophy	Global & central knowledge + powerful central decision making tool.	Local knowledge + market-based communication.

Table 1. A summary of comparison of centralized and market-based approaches.

2.3. Comparisons of Centralized and Market-based:

The existence of both approaches opened the door for some researchers to compare them in the context of some applications to determine the conditions at which a mechanism should be used rather than the other and how. Malone and Smith (1987) study was the most outstanding cost-based performance comparison study of four different organizational structures; they also mapped their comparison on both human organizations and topologies of computer systems. Tan and Harker (1999) extended Malone and Smith's (1987) study by emphasizing on the comparison of two of the suggested structures, the functional hierarchy representing the centralized approach and the decentralized market representing the distributed market-based approach. They conducted their study using mathematical equations based on queuing theory and probabilities. Their study lead to some hypothesis to support decision makers to choose which approach in function to some system variables such as mean task duration, tasks mean inter-arrival time etc. Though these studies are of great value, however they were limited to study very basic models including very limited uncertainty and no mobility, the method used is quite difficult to extend to incorporate new variables or reproduce more complex business processes, in addition to current existing technologies (GPS, GIS, GSM, etc...) which were not present at the time of these studies may change many concepts for mobile business.

Another comparison was conducted by Ygge and Akkermans (1999). They compared both approaches for the problem of allocating cool air among offices in a building. Their study explained the strength of the market-based method developed by Huberman and Clearwater (1994) and showed that a centralized standard engineering control approach could overcome the market-based one, then an extension based on strict local knowledge of agents representing offices and combinatorial market was demonstrated and proved to outperform the centralized approach. However the use of combinatorial markets is only suitable for limited number of goods to exchange (tasks) because an optimal allocation would require to compute all combinations of tasks, which is exponential in function to the number of tasks (Sandholm 2002) preventing the auction participants to efficiently calculate their bids, moreover, the studied environment was static facing no uncertainty and totally operating offline, i.e. the demand as well as the available resources were well known in advance.

	Centralized Structure	**Market-based Structure**	**Environment Uncertainty**	**Comparison Criteria**	**Study Outcome**
Malone and Smith (1987)	Product hierarchy, functional hierarchy	Decentralized market, centralized market.	Low (based on processors failures).	Production, coordination, and vulnerability costs.	Analogy between organization structures and future IS architectures.
Tan and Harker (1999)	Functional hierarchy.	Decentralized market (CNP).	Low (based on processors failures).	Same as Malone and Smith (1987).	A set of corollaries prescribing when an approach is more suitable than the other according to multiple variables.
Ygge and akkermans (1999)	Standard engineering control.	Multi-agent system with combinatorial market.	Static.	Performance measured as standard deviation of the optimal solution.	Local knowledge + market communication = Global control.
Mes et al. (2007)	Local dispatch and serial scheduling heuristics.	Hierarchical market structure with Vickery auctions.	Stochastic arrivals of orders.	Costs incurred by vehicle utilization, and service level.	Market-based approach always yields higher performance.

Table 2. A summary of general comparisons done to compare centralized with market-based approach.

From the literature surveyed, considerable work can be observed in resource allocation and coordination. Both centralized and market-based approaches proved their existence in many fields. However, to the best of our knowledge, no recent study has been made to collect works done on centralized and market-based approaches in order to compare them in the context of uncertainty under the task allocation problem and/or its variations.

3. Mobile Task Allocation Problem (MTAP)

In organizations where team management and coordination is crucial for its success and contrary to business where workers (or generally resources) are not operating in one physical place, MTAP is an important problem to consider if it comes to manage teams and members that have to operate individually on tasks geographically distributed. In such cases many parameters have to be considered in order to optimize organization's performance, such as travelling and operation costs, workers schedules and working hours, skills of workers, and last but not least, the dynamism and uncertainty of the mobile nature of such businesses must also be taken in consideration during execution.

3.1. Description:

The Mobile Task Allocation Problem (MTAP) can be defined as the problem of assigning a set of geographically-distributed tasks of multiple importance to a set of mobile workers who start their days work from different initial locations, move from locations to others in order to maximize the reward gained from successfully completing a subset of those tasks, to end their schedules at the last task's location. Each task is coupled with a certain importance and priority for execution. The importance of each task is reflected by a bonus that will be obtained by the worker(s) who successfully completes the task. Therefore, the objective of the organization is to generate a set of schedules for workers in order to maximize the net benefits that can be described as the total collected bonus points minus total incurred costs. This objective reflects the completion of the most important tasks, while taking costs in consideration by preserving them to a minimum. Costs incurred are mainly those of travelling, operational costs for specific tasks (for e.g. the need of special equipments), and those arising from environment uncertainty. Figure 1 presents a simple instance of MTAP. Figure 1demonstrates a small instance of MTAP consisting of six tasks and 3 workers. The problem described in figure 1 contains all the necessary information to solve the problem, like workers initial locations, tasks locations, duration, priority, and distance matrix. These information can be gathered when operating in static environments or during planning, however, the availability of these information and data becomes harder to get and to control when different uncertainties and exceptions happen.

	W1	W2	W3
T1	1	1.6	0.8
T2	0.4	1.3	0.9
T3	0.5	0.9	1.2
T4	0.8	0.2	1.2
T5	1.5	0.6	0.3
T6	0.6	0.6	0.5

Distances of each worker from each task.

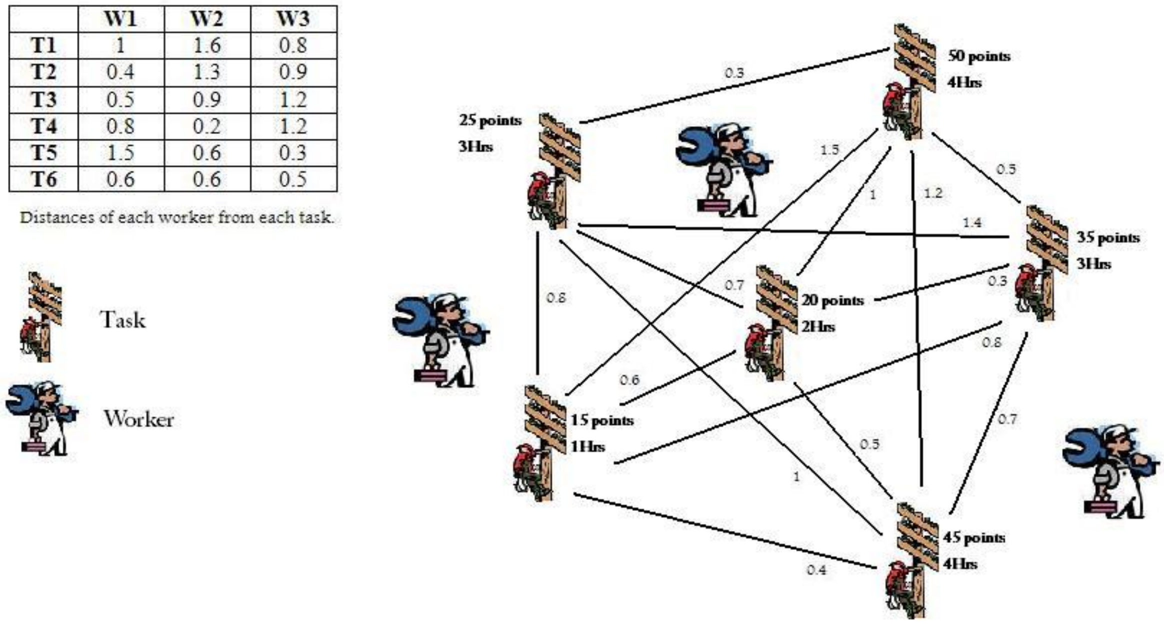

Figure 1. The Mobile Task Allocation Problem (MTAP).

The problem of task allocation is a combinatorial problem, and it has been widely investigated in the field of discrete optimization in operational research (Toth and Vigo 2002) (Gutin and Punnen 2002), artificial intelligence (Braun 1991), Heuristics (Chao et al. 1996), and management science. Many well-known problems in the OR literature can be related to the one of assigning tasks to mobile agents. The Travelling Salesman Problem (TSP) is a fundamental and in-depth studied problem which has as an objective to find the minimum-cost rout for a mobile salesman to visit the whole set of given locations exactly once, starting and ending at a home location. (Gutin and Punnen 2002) provides a comprehensive review of this problem with its variations. Multiple TSP (MTSP) has also been studied for the case of multiple agents, each agent visits a mutual-exclusive subset of locations in a way that all agents visit all locations starting from and ending at a depot location. (Bektas 2006) presents a review of the MTSP. The Vehicle Routing Problem (VRP) is a generalization of the MTSP. VRP can viewed very similar to the MTSP in terms of objectives and constraints, but some extra constraints such as vehicle capacity not allowing to serve customers more than the capacity of the servicing vehicle complicate the problem. A comprehensive review of VRP is presented in (Toth and Vigo 2002). The Team Orienteering Problem (TOP) (Chao et al. 1996) is a variation of the MTSP, and it is the most resembling well-known problem to the MTAP.

In the Team Orienteering Problem (TOP), m team members, starting from a specific point 1, has to visit n control points, each point is coupled with a bonus point S_i obtained by the team when a member visits that point. All members have to reach the end point n within a time limit T_{max}. Because the time limit doesn't allow the team members to visit all locations, members have to select a subset of points to visit in order to maximize the total collected points by the team and reach the end point by T_{max}.

	Objective Function	**Main Constraints**	**Number of Agents**
Travelling Salesman Problem (TSP)	Minimize travel costs, finding shortest path.	Visit all locations exactly once. Start and end at the initial location.	1
Multiple Travelling Salesman Problem (mTSP)	Minimize travel costs by the group of travelling agents. Minimize the sum of travelled distances.	Each agent visits a subset of locations. A location is visited only once by an agent. A visited location by an agent can't be visited by another agent. All agents' subset are mutually exclusive and their union is the set of all locations. All agents start and end at the same initial location.	m
Vehicle Routing Problem (VRP)	Minimize travel costs.	Same as mTSP. Capacity constraints. Pickup and delivery constraints are sometimes present.	m
Team Orienteering Problem (TOP)	Maximize the sum of collected points from visiting a subset of locations.	Each location is visited at most once by an agent in the team. All agents start, have to visit locations, and return to start point within time T_{max}. Travel times are considered. T_i is the time needed to visit location i.	m
Mobile Task Allocation Problem (MTAP)	Maximize the sum of collected points from visiting a subset of locations taking incurred costs in consideration.	Each location is visited at most once by an agent in the team. Agents start at different locations and end at the last visited location. Travels and visits duration don't exceed T_{max}. Travel and processing costs may differ between agents.	m

Table 3. A comparison table comparing MTAP with other relevant well-known problems.

TOP has widely been studied, under different names and variations (Vansteenwegen et al. 2009), such as the Selective Travelling Salesman Problem (STSP) (Laporte and Martello 1990), the Maximum Collection Problem (MCP) (Butt and Cavalier 1994), or the Bank Robber Problem (BRP) (Arkin et al. 1998). The Orienteering Problem, which is a special case of the TOP where $m = 1$, was proved to be NP-hard (Golden et al. 1987). Thus, because TOP is a generalization of OP, TOP is also NP-hard, and due to the importance of its applications, many algorithms and heuristics have been developed solving many types of the problem, for e.g. (Tang and Miller-Hooks 2005) proposed a TABU search algorithm for the TOP.

(Vansteenwegen et al. 2009) provides a mathematical formulation for the TOP as an integer program as follows:

$$\text{Max} \sum_{d=1}^{m}\sum_{i=2}^{n-1} S_i y_{id}, \quad (1)$$

$$\sum_{d=1}^{m}\sum_{j=2}^{n-1} x_{1jd} = \sum_{d=1}^{m}\sum_{i=2}^{n-1} x_{ind} = m, \quad (2)$$

$$\sum_{d=1}^{m} y_{kd} \le 1; \quad \forall k = 2,\dots,n-1, \quad (3)$$

$$\sum_{i=1}^{n-1} x_{ikd} = \sum_{j=2}^{n} x_{kjd} = y_{kd}; \quad \forall k = 2,\dots,n-1; \quad \forall d = 1,\dots,m, \quad (4)$$

$$\sum_{i=1}^{n-1}\left(T_i y_{id} + \sum_{j=2}^{n} t_{ij} x_{ijd}\right) \le T_{\max}; \quad \forall d = 1,\dots,m, \quad (5)$$

$$2 \le u_{id} \le n; \quad \forall i = 2,\dots,n; \quad \forall d = 1,\dots,m, \quad (6)$$

$$u_{id} - u_{jd} + 1 \le (n-1)(1 - x_{ijd}); \quad \forall i,j = 2,\dots,n; \quad \forall d = 1,\dots,m, \quad (7)$$

$$x_{ijd}, y_{id} \in \{0,1\}; \quad \forall i,j = 1,\dots,n; \quad \forall d = 1,\dots,m. \quad (8)$$

Where:

T_i is the time needed to visit point i. u_{id} is the position of point i in the schedule d, $x_{ijd} = 1$ if a visit of point i is followed by a visit to point j in the schedule d, 0 otherwise. $y_{id} = 1$ if point i is visited during schedule d, 0 otherwise.

However, an important aspect in the TOP is the absence of the costs in the objective function. It only considers maximizing total bonus points of visited locations. However, costs of travelling between these locations and other costs, for e.g. processing costs because of the use of a special tool, are not explicitly considered in the objective function, though travel times are considered in the constraints. MTAP has to consider such costs in the objective function. Costs should include travelling costs, that can be different for each agent in advanced MTAP's (agents may use different kinds of vehicles which have different running costs). Optional costs can also be introduced, such as special processing costs or different workers' wages.

Another difference is that in MTAP, mobile agents start their journeys at different locations (home places), and end at the last scheduled location. Therefore constraint (2) in the previous model is no longer necessary.

In addition to the particularity and uniqueness of MTAP, It has a wide variety of applications in business involved to operate in mobile environments, like routing teams of technicians (Tang and Miller-Hooks 2005), multi-vehicle home fuel delivery (Golden et al. 1987), and managing carriers and private fleet (Hall and Racer 1995). MTAP can also be a good testbed to compare the centralized and the market-based approaches with uncertainty as parameter from performance and costs perspectives. It is confirmed that the more dynamic a system is, the more difficult or/and costly is to generate quick feasible solutions (Larsen et al. 2002), so by increasing uncertainty in MTAP we will be able to observe how it will be managed by each approach, what is the impact on the resulted performance and at what cost.

The presence of uncertainty in the MTAP and the need for a quick reaction makes it a real-time problem. Moreover, a real-time problem can be viewed as being both dynamic and stochastic. According to (Ghiani et al. 2003) when a VRP problem is stochastic it means that some (or all) of its input data changes as time passes and cannot be fully accurate at the planning phase, for example: changes in travel times due to congestion. However, when a problem is stochastic it means that not all input data are available beforehand and further data can enter the system during execution, for example, on-line problems where new tasks emerges while schedules are being executed are considered to be stochastic. Emergency applications like fire fighting and ambulance services (Gendreau et al. 2001) are examples of on-line problems.

Instances of MTAP as well as many related problems have been solved in both, Centralized and Market-based, approaches in different fields.

3.2. Centralized Approach:

Centralized solutions for the MTAP haven’t really been present in the literature, however many solutions are found to similar problems, like for Multiple Travelling Salesman Problem (mTSP) (Bektas 2006), TOP (Chao et al. 1996) and the TOP with time windows (TOPTW) (Dohn et al. 2009), and the Partially Travelling Repairman Problem (PTRP) (Larsen et al. 2002) among others. Solutions for These problems can be adopted for the MTAP. Centralized solutions for the TOP were mainly based on heuristics and meta-heuristics after defining the problem in the shape of integer programming (Chao et al 1996) (Vansteenwegen et al. 2009).

The heuristic presented in Chao et al (1996) was an early attempt to solve the TOP, it relied on simple procedures able to produce good solutions with relatively small computation costs. Many exact algorithms have been proposed in the literature based on branch-and-bound, like Laporte and Martello (1990), but these algorithms are computationally expensive and unfeasible for dynamic situations, the reason that lead researcher to focus on approximate solutions, especially for large problem instances. Tang and Miller-Hooks (2005) proposed a TABU search heuristic to solve TOP. Recently Vansteenwegen et al. (2009) suggested a guided local search meta-heuristic which reduces computation time compared to other techniques and still produce quite good solutions.

3.3. Market-based Approach:

Market-based approach also proved its existence in combinatorial and resource allocation problems. Wellman (1993) suggested the Market-Oriented Programming (MOP). MOP is a paradigm which uses combinatorial auctions in order to find equilibrium between demand (e.g. tasks) and supply (resources) by altering market prices of the resources till equilibrium is reached and the supply corresponds to the demand. Solutions obtained by reaching the equilibrium are theoretically optimal solutions. This paradigm has been applied to the multi-commodity flow problems (Wellman 1993), and an extension of the MOP was developed to solve the task allocation problem (Wellman and Walsh 1998). However combinatorial auctions show little performance as problem size increase because the number of possible bundles is exponentially related to the items to assign, and communication needed to reach the equilibrium price can also grow significantly with problem size (Dias et al. 2006).

Direct negotiations and auctions are also present in the market-based approach literature as an alternative of the MOP. The Contract Net Protocol (CNP) (Smith 1980) is an early, and still widely used, attempt to implement market protocols between agents based on auctions. Contrary to MOP, in CNP, an agent (the initiator) requiring a certain service initiates an auction by sending call for proposals to participating agents (participants), each participants evaluates the request and replies with an offer as a bid, the initiator chooses the best offer(s), then the winner(s) is(are) committed to provide the service. In CNP the initiator and participant roles are interchangeable among agents, in other words, there are no restrictions to be an initiator. The main focus when designing a CNP-based market is: a- the bid construction by participants and b- the bids evaluation by the initiator. These two operations distribute the computations of a single large problem into many smaller ones. Each agent solves independently part of the problem according to its state by calculating its bid reflecting its utility of allocating the task. The main advantage of CNP is the need of only one round of auctions to reach the best solution, if there is any. However, the solution quality greatly depends on the way bids are generated by participants, and therefore can be significantly inferior to the optimal one.

Task allocation problem has been significantly studied in the field of robotics. The nature of the multi-robot applications, like mapping and exploration missions (Dias et al. 2006), amplified the need to coordinate teams of robots achieving common goals. In such cases coordination lead to better resource distribution and higher performance, but the constant presence of the obstacles reflected by changes in tasks, resource failures, and unpredictable uncertainty makes the task of coordination harder (Dias et al. 2006). In market-based coordination, each robot is represented as a self-interested agent in a market, able to execute tasks but has to pay for resources it uses.

3.4. Centralized vs. Market-based:

Despite the existence of both centralized and market-based approaches to solve task allocation and other related problems, comparison studies are still very scarce in the literature, notably in the context of uncertainty for the task allocation problem. A study conducted by (Mes et al. 2007) compared a market-based approach auctions against two other centralized heuristics for a full truckload problem with time windows, which is a generalization of VRP, with stochastic arrivals of new tasks. Their results showed that market-based approach always showed better performance; even when dynamism rate is low. This finding can be attributed to the hierarchical structure of the used market mechanism; which is an aspect of centralized control.

4. Discussion

Though many studies are present in the literature considering a variety of optimization problems, however, there is a lack of consistent and rigorous studies identifying the most suitable approach to a precise problem of MTAP. MTAP is a practical problem with high interest in real world team management, especially when dealing with those situations facing environmental uncertainty. This problem (and its variations) has been addressed from a centralized point of view by default, while market-based approaches are promising. Literature suggests that Centralized approach have been widely adopted for addressing most of the MTAP-resembling problems in general, however in the field of Robotics, similar kind of MTAP problems are addressed using the Market-based approach.

Communication was once a point of interest regarding costs reduction (Tan and Harker 1999), but nowadays the issue of communication costs and reliability has been solved considerably, that even modern centralized systems use mobile telecommunication with distributed sensors to check system's state. Furthermore, the presence of technologies like GPS, GIS, and mobile communication networks, may lead to innovative ways of addressing the MTAP. Basically, these tools were designed and improved in response to business demands and were employed in order to have a better quality of service and to reduce operational costs. Few years ago, combinatorial problems were addressed in static and deterministic environments not because uncertainty wasn't known at these days, but facing dynamism and/or stochasticity incurred high costs of communication with resources in order to update current system's state. Communication technologies which were arbitrary and not well established for such mobile environments are now well-present and used in nearly every contemporary team management system and for cheap costs.

Similarly, computational capabilities of modern computers and other handheld devices exceed the computational power of servers used a decade ago. Furthermore, these devices have the capability of being continuously connected to a network and exchanging information. Modern handheld devices with their computational capacity are mainly and solely used for communication in the centralized approach, however, by using distributed techniques like market-based negotiation, they can also take part in solution finding and overcome bottlenecks and point of failure problems. As for the matter of facing uncertainty, when an exception occurs, in a centralized approach, the central server has to be contacted in order to convey raw, and probably inaccurate, information related to the exception and current state, put the load on the server for generating a new solution and probably to contact other agents for plan updates notification. In such an approach all agents are limited to a passive action. On the other hand, in the market-based version for the same situation, the affected agent starts a negotiation session with other participants in order to trade changes and deal with exceptions. The computational power of the handheld devices would be used more efficiently by applying sort of light heuristics to calculate and evaluate exchanged bids and improving the global solution. In such a scenario the agents are enabled to have a more reactive action permitting them to use their own knowledge and experience while keeping the motivation high.

The advancements in computer technologies and architectures also resulted in huge computational powers for central servers. Such machines are able to solve many problems that a decade or two ago were impossible to solve. So, intuitively, these machines also prove to be efficient for hard problems like MTAP in face of uncertainty. However, these machines are generally expensive, require lots of tuning, and necessitate regular maintenance. The main question arising in light of these technologies and different architectures and available approaches is which approach is more appropriate for the MTAP facing different demand and environment uncertainties? Future work of this research will be studying and modelling the MTAP from both centralized and market-based perspectives and conducting more rigorous comparisons. Thus, by electing a representative technique of each approach and compare them in an agent-based simulator where uncertainty can be controlled as a variable. Such a study will be of good interest for decision makers in order to decide on the approach to adopt for the scheduling and allocation of tasks to teams of mobile workers depending on the uncertainty faced by the system.

5. Conclusion

MTAP is a promising problem and is widely applied in many real-life fields. This paper presents two contemporary approaches, namely centralized and market-based (decentralized), used to tackle such a problem. It also addresses the question of which approach to use in order to face the dynamism and stochasticity of this problem instead of the default choice of the more classical centralized approach. In many problems facing constant uncertainty, reaching a feasible solution rapidly is preferred over having an optimal solution. Therefore a dedicated study would be of high interest to identify the conditions at which a certain approach would perform better than the other in the family of problems that deal with distributed entities and face constant uncertainty. Future directions would include:

- Formally modeling a target problem which objective is to maximize the net benefits of operation. The target problem should consist of a mobile environment, resources, demands, and dynamic events to best mimic the actual MTAP.
- Develop a suitable solution representing each approach. These candidates are taken from similar well-known problems and their solutions in literature and adapted for the studied MTAP.
- Simulate the created environment on a computer agent-based simulator.
- Compare performance and costs incurred by each approach in function of uncertainty (stochasticity and dynamism) as independent variables.

Such a comparative analysis is missing from the existing corpuses of literature and this paper is expected to serve as a foundation in terms of identifying the key concepts about the Centralized, Market-based approaches and their comparisons.

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