Dynamic Configurable Auctions for Coordinating Industrial Waste Discharges

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Abstract. The use of auctions for distributing resources in competing environments has produced a large variety of auctions types and algorithms to treat them. However, auctions have some problems when faced with some real-world applications containing renewable and perishable resources. In this paper we present a mechanism to deal with such issues by dynamically configuring some of the auction parameters taking into account the past experience. The mechanism has been used to coordinate industrial discharges and a Waste Water Treatment Plant, so that the treatment thresholds of the plant are never exceeded. We have performed some simulations to evaluate the system, and the results show that with this mechanism the coordination between the industries improves the treatment of the water.

1 Introduction

Auctions are becoming popular to coordinate agents that share resources [1]. There are two major actors in an auction: bidders and auctioneers. The bidder demands the resources, while the auctioneer provides them and decides which bidder should be assigned each resource, in what is called the winner determination or clearing market algorithm.

There is a myriad of different mechanisms to implement auctions, depending on many parameters [4]. However, recent works, such as [5], point out that current auction mechanisms may have some problems in the emerging e-service markets. The reasons for that are the renewable and perishable nature of the resources being auctioned. On one hand, renewability requires that the auctioneer offers the resources every time they become free. Thus, auctions should be repeated (recurrent auctions). On the other hand, a perishable resource cannot be stored or left unused if we are trying to optimize the resource utility.

In the scenario in which the auctioneer is repeating the auction process with the same consumers, it seems appropriate to think on using the auctioneer's experience to improve its decision (clearing the market). Such improvements involve avoiding the same winner each time (dominant bidder) [5] in order to incentivize participation. In addition, such experience can also be used to prevent failures, that is, to build robust solutions. This issue is specially important in industrial environments, as the one we are working on: waste water treatment management.

A waste water treatment plant (WWTP) accepts the contaminant waste discharges of different industries. The sum of all contaminants arriving at the WWTP should be under its design parameters, otherwise the water cannot be fully treated and the river can be contaminated. Currently, this goal is achieved by assigning a fixed amount of authorized discharges to each industry. As an alternative and more flexible coordination mechanism, we propose the use of an auction process in which the capacity of the WWTP is sold. However, the uncertainty of the application domain, due to uncontrolled discharges, or even the rainfall, can cause some incidences, leading to the failure of the solution established in the auction process, and causing terrible ecological consequences to the river basin. For this reason, the use of past experience that improves the decision process is crucial.

In this paper we present a multiagent framework in which industrial agents coordinate their discharge activities thanks to a recurrent auction mechanism that is dynamically configured according to the experience of the system. The paper is organized as follows. First we describe the multiagent system deployed, based on the waste water treatment system. Then, the auction and the methods to configure it are described. Next, some implementation details are provided. We continue by giving some results and we end with some conclusions.

2 Waste Water Discharge System and Agent Technology

The treatment of the waste water discharged from industries is vital to assure the quality level of the river. For this purpose, the water is treated in a waste water treatment plant (WWTP) [11]. Each plant has several hydraulic and contaminants capacity constraints that are defined according to its expected use (industries and cities in the surroundings that generate the waste). For example, a plant for a city of 128,000 equivalent inhabitants would have the following capacities: maximum flow allowed of 40,000 m^3/d, with at most 100 g/m^3 of Nitrogen, 650 gO/m^3 of Biological Demand of Oxygen (DBO) and 550 g/m^3 of Solids in Suspension (SST).

Discharges come from industries, as well as from cities. In our first approach to the problem, we concentrate on industries, assuming that the city discharges can be aggregated to the closest industry.

Laws regulate the amount of waste water each industry can discharge, as well as the maximum levels of the contaminant components. Moreover, each industry has to pay a given amount per unit of treated water. In addition, the industry can be billed if it discharges some non authorized waste water.

In this distributed scenario, there is a single resource (the flow entering the WWTP) and several consumers that wish to use the resources (the industries). In order to support resource coordination, we have proposed to replicate the scenario in a multiagent system, in which each industry is represented by an *industry agent* and the WWTP by the *WWTP agent* (see Figure 1). The WWTP

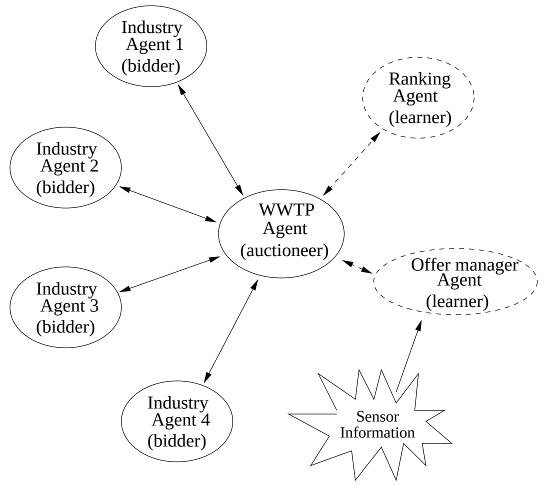

Fig. 1. Multiagent system for WWTP.

agent uses an auction process to assign discharge authorizations to the industries. Each time a conflict between industry discharges is detected, the authorization to discharge in the conflicting period is auctioned.

The multiagent approach allows to keep information of each consumer (industry) in privacy, an important issue since discharges are related to the manufacturing activity of industries. For collaboration purposes, each industry agent provides the WTTP agent in advance with a scheduling of the discharges it plans to perform for a given day. With this information, the WWTP agent can detect any overflow situation and coordinate the different industry discharges. If an industry is not allowed to discharge, it could derive the waste water to a buffer that allows the temporary retention of it up to a certain limit. If the buffer is full, the industry can either change its manufacturing activity to avoid the discharge or to discharge the waste water even if it is not authorized to do so. This is an internal decision of the industry agent that, among other issues, takes into account company policies and economic incentives (billing, cost of stopping production, etc.). The multiagent system, however, has been designed with the aim to avoid arriving to such extreme situations.

3 Dynamic Auction Configuration through Autonomous Agents

The flow is a perishable resource: it cannot be stored and leaving it unused decreases its utilization. So at some extend, the flow behaves as a e-service, inhering the problems of such kind of goods. However, the benefits of auctioning the maximum flow capacity should be balanced with the risk of other factors as the rain and agent behavior that are out of the scope of the auctioneer.

In order to deal with such factors, the auctioneer can dynamically change the amount of flow to be auctioned. For doing so, each auction is configured by means of several parameters that are set up with the help of other additional agents that take care of the previous experience of the system, namely, the *priority agent* and the *offer-manager agent*.

Finally, note that we are dealing with a recurrent auction since the process is repeated each time a conflict arises among the different industry agents schedules (see Figure 2). In this section we describe the mechanism of the recurrent auction and the agents that are used to set up its configuration

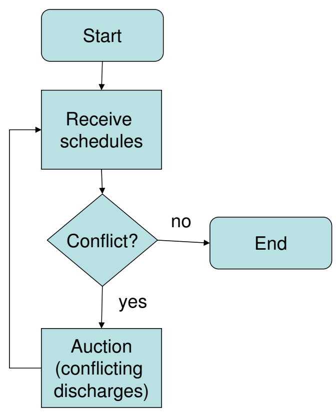

Fig. 2. Recurrent auction flow.

3.1 Recurrent Auction of Perishable Resources

For a given day, each industry provides the WWTP agent with its discharges schedule. The WWTP agent analyzes them, trying to find conflicting situations regarding its design constraints. A conflict arises when, for example, the addition of the flows scheduled by the industries exceeds the hydraulic capacity of the WWTP. It could also happen that although the flow is not above the maximum WWTP capacity, one or more of the components (Nitrogen, Biological Demand of Oxygen, etc.) exceed the permissible levels.

Even though there could be more than one conflict for a given day, they are being treated sequentially, resulting in a recurrent auction process. The parameters that set up the auction are the following:

- Agent priority list
- WWTP capacities
- Time interval
- Winner determination algorithm

First, the agent priority parameter is included to deal with the bidder drop problem of recurrent auctions [5]. This problem is related to an uneven wealth distribution of winners, so that poor bidders may starve. Dominants agents, which have been the winners on the latest auctions, have a low priority, while loser agents have a high priority. The agent priority list is computed by the ranking agent based on the previous auction outcomes, as shown below.

Second, the WWTP capacities refers to the resources thresholds to be auctioned. These thresholds are being set by the offer-manager agent based on the previous experiences of the rainfall and the trust on the agents involved in the auction, as detailed at the end of this section.

Third, the time interval is set by the WWTP agent and corresponds to the period in which industry agents have conflicting discharges.

Finally, the winner determination parameter establishes the algorithm used to clean the market. There are several algorithms in the literature, whose performance depends on the problem dimensionality, among other issues. For example, we are using a linear programming algorithm [2] since it outperforms other algorithms when dealing with low scale problems; however, with large scale problems, genetic algorithms may be more appropriate.

Once the auction is configured, it can be started. The WWTP agent sends a call for bids to all the industry agents involved in the conflict. The WWTP agent provides information on the interval to be auctioned. Then, each agent answers with its bid. Each bid is composed by the features of the discharge to be performed during the interval and the price they would pay for the discharge. The price is related to the industry's retention capacity. If it has enough buffer capacity to keep the discharge, the bid price is low; otherwise it is high since the industry has no way to retain that discharge.

The bids received from the industry agents are modified by the WWTP agent according to its priorization. For doing so, we are currently multiplying the price by the agent priority. So bids with high priority (that corresponds to agents which have lost the latest auctions) increase their chances of being the winners. In this sense, we are trying to achieve a fair behavior of the overall process, trying to avoid extreme situations in which an agent that continuously loses is forced to perform the discharges without authorization. Finally, the WWTP agent cleans the auction by providing the list of winners.

If an industry agent loses an auction, it reschedules the discharge and sends its new schedule to the WWTP agent. When the WWTP agent has all the new discharge schedules, it checks again for conflicts. This process is iterated, until a complete schedule without any conflict is obtained (see Figure 2).

3.2 Bidder Ranking

The ranking agent is in charge of providing a ranking of all the bidders involved in an auction process. It takes into account the outcomes of the bidders in past auctions. The ranking is expressed as a priority value p in $[0, 1]$. The ranking agent keeps a list of successes and failures for each bidder. A success is considered when the bidder wins the auction, while a failure is considered when the industry agent loses. Let $succ_i$ be the number of successes of agent i, and $fail_i$ the number of failures. Then, the priority of agent i is computed as follows [7]:

$$p_i = \frac{fail_i + 1}{succ_i + fail_i + 2} \tag{1}$$

Thus, all agents have an initial priority of 0.5. If an agent loses an auction, its priority is increased; otherwise, it is decreased.

3.3 Preventing Failures

The offer-manager agent is in charge of computing the thresholds of the WWTP's capacities according to the context of the auction so that possible failures can be avoided. This context include the trust on the bidders involved in the auction, and other external factors such as the weather forecast.

On one hand, the offer-manager agent keeps a trust list of all industry agents. This trust value is computed according to the information provided by the industry sensors. These sensors are in the industry pipes in order to bill industries, and can also be used to check whether the amount of discharges produced by the industry corresponds to the contracted ones.

For each agent, the number of uncomplied-contracts (*uncomp*) is being kept, as well as the number of complied-contracts (*comp*). An uncomplied-contract is the one in which the industry agent has lost the auction, but it has performed the discharge anyway. Conversely, if the agent fulfills the auction contract it is considered a complied-contract. Then, using the following equation, the trust t_i of the industry agent i is computed as follows [7]:

$$t_i = \frac{comp_i + 1}{uncomp_i + comp_i + 2} \tag{2}$$

All agents have the same neutral trust at the beginning. As the experience of the system evolves, the trust on the agents is modified, becoming a trustworthy (trust close to 1) or untrustworthy ($t \simeq 0$) agent.

When an untrustworthy agent participates in an auction, it means that there is a risk that the agent performs a discharge even if it does not get the contract. Since this situation is very dangerous for the ecology of the river basin, the offer-manager agent reserves part of the current WWTP capacities for dealing with possible inappropriate discharges. For each WWTP capacity (flow and contaminants) the offer-manager agent computes a trust reduction ΔC_i^{trust}. Let be U the set of untrustworthy agents involved in the auction, that is, agents with a trust level under 0.5. Then, ΔC_i^{trust} is computed as follows:

$$\Delta C_i^{trust} = g(f(c_i^1, t^1), \ldots, f(c_i^{|U|}, t^{|U|})) \tag{3}$$

where t^j is the trust degree of the j-th untrustworthy agent in the conflict, c_i^j is the amount requested by this agent for the i-th capacity of the WWTP, and f and g are functions that compute the individual and collective reduction caused by all the agents in U.

On the other hand, a second factor related to prevention is the rain. In order to take into account this factor we use the information of the weather forecast. When the weather forecast informs about possible rainfall, the WWTP capacities are also modified. Rain could affect in several ways the WWTP behavior. As a first approach, we decrease the WWTP capacities according to the following equation:

$$\Delta C_i^{rain} = p_r(rain) \cdot \mathit{rainfall} \tag{4}$$

where $p_r(rain)$ is the probability of rain in the weather forecast, and *rainfall* is the expected amount of rain.

Once the trust and rain reductions have been computed, the auction is set up with the following capacity thresholds:

$$C_i' = C_i - \Delta C_i^{trust} - \Delta C_i^{rain} \tag{5}$$

where C_i is the design threshold of capacity i of the WWTP.

It is important to note that decreasing the WWTP capacities could be understood as a resource waste. However, wasting the resource could be better than causing an ecological disaster in the river basin. The goal of the above equations is to establish a tradeoff between both factors.

4 Implementation

We have implemented a prototype of the system to evaluate the coordination mechanism. We have used the Repast environment [10], a free open source software framework for creating agent based simulations using the Java language. The simulation reproduces the process and the communication between the WWTP and the industries performing waste discharges. We have created an agent that represents the WWTP, another one for each of the industries and the ranking agent. The offer-manager agent is not yet implemented.

The bid with which the industry agent participates in an auction is computed taking into account the urgency for performing the discharge, based on the buffer occupation of the industry:

$$bid = \frac{\text{buffer occupation}}{\text{total buffer capacity}} \tag{6}$$

In case an industry agent has to reschedule its discharges, its behavior is the following: it first tries to store the rejected discharge into the buffer. The discharge of the buffer is then scheduled as the first activity of the agent after the conflict finishes. The rest of discharges are shifted so that they do not overlap. If the buffer cannot contain the current discharge, the industry performs it anyway.

As a first evaluation of the system, we have supposed that the industries always obey the WWTP decisions, as long as they have enough buffer capacity. We will introduce different industry behaviors in future experiments to have more realistic scenarios.

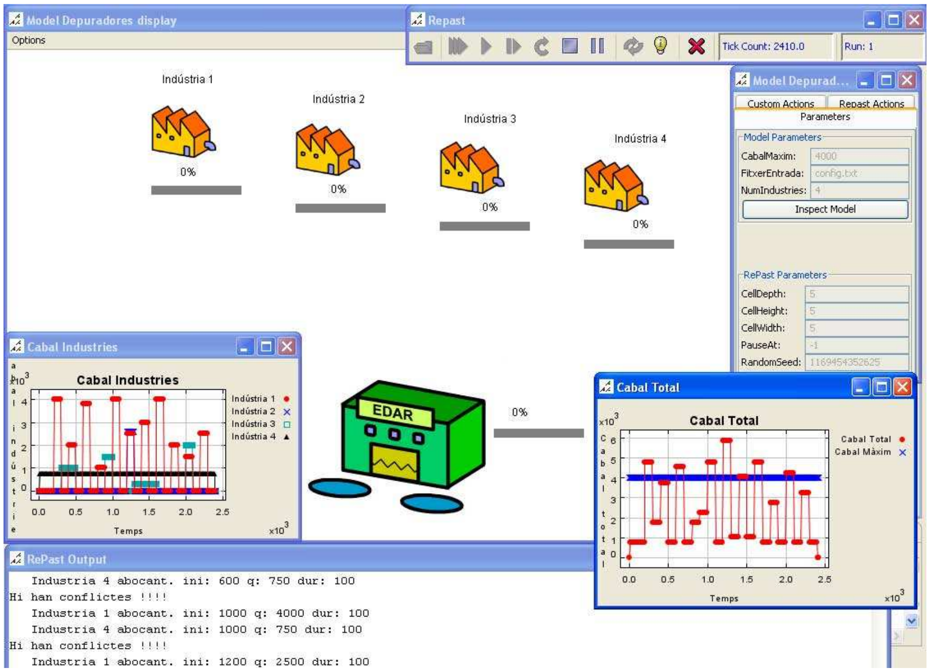

Fig. 3. User interface.

Figure 3 shows the application user interface. The graphical representation shows the buffer occupation levels of the industries and the occupation degree of the WWTP.

5 Results

In order to perform the simulation, we have used a set of real data in a period of 24 hours with 4 industries. So far we have only considered the hydraulic capacity. In the near future we will consider different contaminant components.

Figure 4 shows an example of the behavior of the system without any coordination, while Figure 5 shows the behavior of the system with the same example when using the recurrent auction mechanism with priorities. In the first figure we can see that the WWTP capacity is being exceeded seven times, while in the second the maximum capacity is never exceeded. When using coordination, there have been some losers in the auctions, but even though some industries had to reschedule their discharges, they have never caused unauthorized discharges. This shows that the priority mechanism favours the industries with high urgency to perform their discharges, so that their buffers do not overflow. However, the overall discharge plan when using coordination is almost 6 hours longer due to rescheduling. This could cause some problems with the scheduling of the following day.

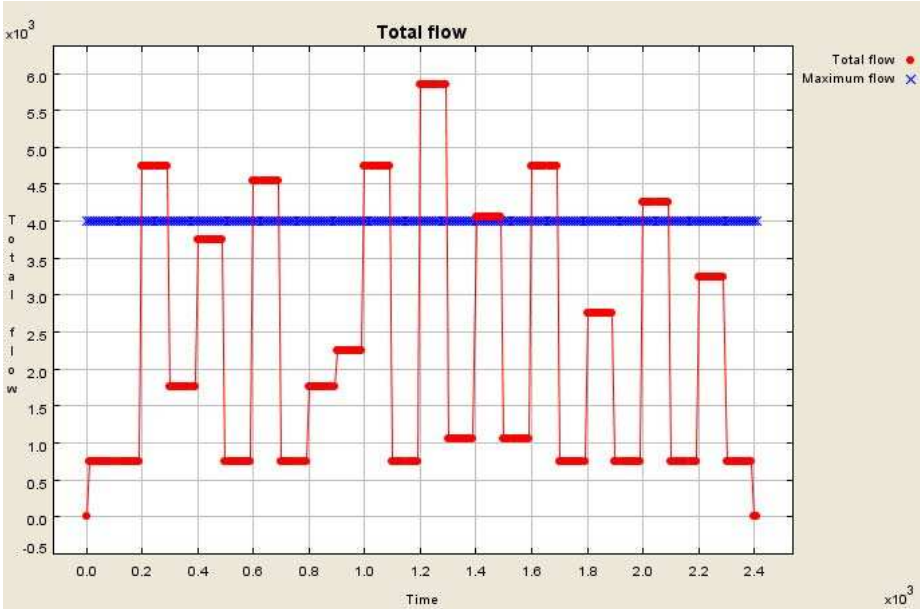

Fig. 4. Behavior without coordination.

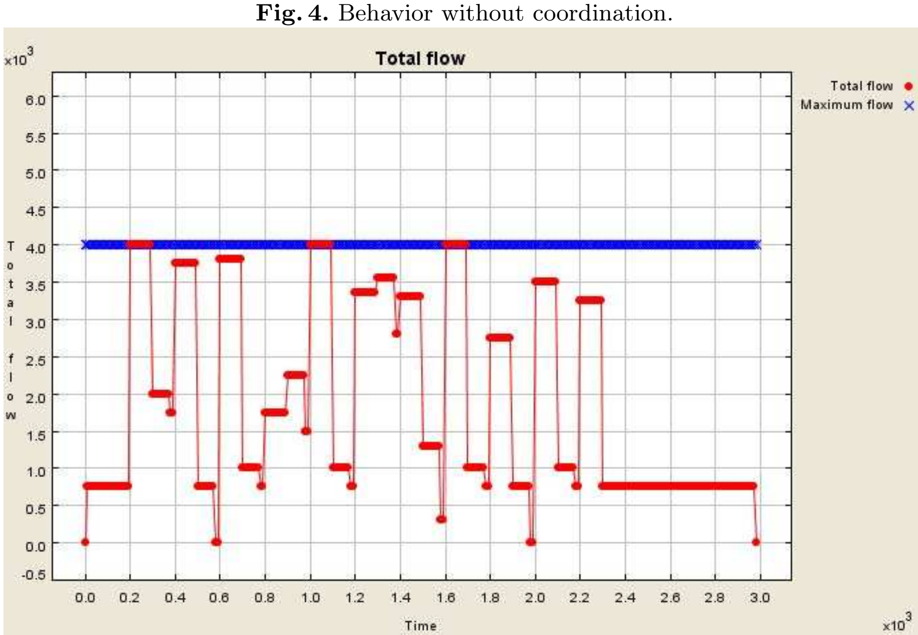

Fig. 5. Behavior with coordination.

In Figure 5 we can observe that sometimes the WWTP flow is underused. If industries were allowed to perform multiple discharges (from the buffer and from the production process) at the same time, the reschedule delays could be shortened. We need to deal with this possibility in future work.

6 Discussion

The results shown that auctions could be an adequate mechanism for dealing with the flow resource in our waste water domain. Auctions allow to keep in privacy agents information, allowing the combination of the different schedules. Other classical approaches (as for example linear or constraint programming) could take the different discharges and built a global schedule, by imposing the individual schedules to the industries. Even that a negotiation process could be established in this classical scenario, from our understanding it is easier to deal with a conflict at a time (in which at most one discharge by industry is involved) that with a set of discharges (schedules imposed by a central authority).

In addition, we think that the recurrent auctions presented here, with the dynamic configuration of its parameters, can also be extended to share other perishable resources as, for example, communication bandwidth. The use of our priorization model could be used in this kind of environments to get the maximum utility for an auction while providing a fair solution over time.

We also know that the proposed models of priority and trust are quite simple (equations 3 and 4), but they are sufficient to show the validity of our approach on finding such fair solutions over time. Our future work, however, includes the study of better computations, as for example to include the length of the interactions in the trust computation following [7].

7 Related Work

Recurrent auctions have been addressed in recent works in e-service markets. For example, in [8] auctions are used to assign advertising time in a public display. In this work, an heuristic strategy for bidders is implemented based on the history observation and the detected audience. The displaying period is divided in cycles and each agent keeps information about the number of cycles it has won in the past. So agents are using its experience for learning its bidding policy. In our system, however, we focus on the use of the experience in order to improve the clearing market process.

The work presented in [5] also uses recurrent auctions in order to deal with the e-service networking markets. The authors present a novel auction mechanism, called the Optimal Recurring Auction, which tries to overcome the problems arisen when dealing with perishable resources, as the e-service ones: the bidder drop problem and the resource waste problem. We are also tackling the bidder drop problem but with a different strategy: the use of priorities. Regarding the resource waste, we are not so much interested on the maximum utility of the resource, as [5], but on assuring that the resource will never be overused. So our strategy focus on building robust solutions more than optimal ones.

Regarding auctions, it is also important to distinguish between recurring, continuous and iterative auctions. Recurring auctions, as the one described in this paper, are related to auctions that are repeated over time, getting a solution in each execution. Continuous auctions [4] are auctions that accept bids anytime, and clear the market as soon as offers arrive. Finally, iterative auctions are the ones that are repeated, but in each round, the solution is considered an approximation. The auction ends whenever the agents repeat the bids or each agent wins some bid [6].

Concerning waste water treatment, there is recent interest on developing distributed approaches. For example, in [9] a negotiation approach to deal with the coordination of different WWTPs of the same river basin is proposed in order to improve the contaminants discharges. Even that our work could be extended to n WWTP (using, for example, a distributed auction mechanism such as the one proposed in [3]), we are currently focusing on the coordination of the industries governed by a single WWTP.

Finally, we would like to point out that our offer-manager mechanism has been influenced by the research work on resource management of broadband networks. In this field, some logical paths are reserved for backup purposes providing more flexibility to the dynamic management of the network when an incidence occurs [12]. The offer manager agent of our architecture tries to capture this room capacity of the WTTP for backup purposes.

8 Conclusions

In this paper we have presented a recurrent auction mechanism that has been applied to a waste water treatment system. The auction is used to coordinate the contaminant discharge plans of the industries in a global plan that does not exceed any WWTP capacity. Auction configuration is set up according to the past system experience. First, a priority mechanism tries to avoid starvation of poor bidders by feeding the auction process with a prioritized list of agents. And second, an offer-management mechanism is used to set up the resource capacities in order to prevent possible incidences during the execution of the contract auctions.

Results show that our approach achieves the goal of keeping the incoming flow below the WWTP capacity, ensuring that the water is completely treated before going to the river. Although the results are promising, we need to study in more detail the delay consequences of our current solution. However, we believe that auction technology could be more flexible with the industries discharges while taking more profit of the perishable resource involved.

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References

1. P.E. Chevaleyre, Y.and Dunne, U. Endriss, J. Lang, M. Lemaître, N. Maudet, J. Padget, S. Phelps, J.A. Rodríguez-Aguilar, and P. Sousa. Issues in multiagent resource allocation. *Informatica*, 30(1):3–31, 2006.
2. GLPK. GLPK (GNU Linear Programming Kit). http://www.gnu.org/software/glpk/.
3. P. Gradwell and J. Padget. Markets vs. auctions: approaches to distributed combinatorial resource scheduling. In M.-P. Gleizes, G.A. Kaminka, A. Nowé, S. Ossowski, K. Tuyls, and K. Verbeeck, editors, *EUMAS*, pages 487–488. Koninklijke Vlaamse Academie van Belie voor Wetenschappen en Kunsten, 2005.
4. J. Kalagnanam and D.C. Parkes. Auctions, bidding and exchange design. In D. Simchi-Levi, S.D. Wu, and Z.M. Shen, editors, *Handbook of Quantitative Supply Chain Analysis: Modeling in the E-Business Era*, pages 143–212. Springer, 2004.
5. J.-S. Lee and B.K. Szymanski. Auctions as a dynamic pricing mechanism for e-services. In C. Hsu, editor, *Service Enterprise Integration*, pages 131–156. Springer, New York, NY, 2006.
6. D.C. Parkes. *Iterative Combinatorial Auctions: Achieving Economic and Computational Efficiency*. Dissertation proposal, University of Pennsylvania, 2000.
7. J. Patel, W.T.L. Teacy, N.R. Jennings, and M. Luck. A probabilistic trust model for handling inaccurate reputation sources. In Peter Herrmann, Valérie Issarny, and Simon Shiu, editors, *iTrust*, volume 3477 of *Lecture Notes in Computer Science*, pages 193–209. Springer, 2005.
8. T.R. Payne, E. David, Jennings N.R., and M. Sharifi. Auction mechanisms for efficient advertisement selection on public displays. In G. Brewka, S. Coradeschi, A. Perini, and P. Traverso, editors, *ECAI*, pages 285–289. IOS Press, 2006.
9. T. Rendón-Sallard, M. Sànchez-Marrè, M. Aulinas, and J. Comas. Designing a multi-agent system to simulate scenarios for decision-making in river basin systems. In M. Polit, T. Talbert, B. López, and J. Meléndez, editors, *Artificial Intelligence Research and Development*, volume 146 of *Frontiers in Artificial Intelligence and Applications*, pages 291–298. IOS Press, 2006.
10. REPAST. Recursive agents simulation toolkit. http://repast.sourceforge.net/.
11. G. Tchobanoglous, Burton F.L., and Stensel H.D. *Wastewater Engineering. Treatment and Reuse, Metcalf and Eddy, Inc., 4th edition.* McGraw-Hill, New York, 2003.
12. P. Vilá. *Dynamic Management and Restoration of Virtual Paths in Broadband Networks based on Distributed Software Agents*. PhD thesis, University of Girona, 2004.