Simulating scenarios for decision-making in river basin systems through a Multi-Agent System

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Abstract: The complexity of environmental problems makes the management of environmental systems especially difficult to be undertaken by traditional software systems. Particularly river catchment systems are very intricate to manage in order to achieve a good quality and quantity of water at the river.
Multi-Agent systems (MAS) are able to cope with this complexity by integrating all the water systems involved at catchment scale through several agents who model real environmental situations. In this paper we describe the design of a MAS for simulating multiple scenarios in a river catchment system in order to support the decision-making of river basins management.
The River Basin MAS has been designed and their functionalities have been studied. Moreover, we have selected the agent platform Jadex as a starting software platform for our new software development. With this proposal, we intend to provide feasible solutions at catchment scale throughout modelling and simulation of different scenarios in a river basin system.

Keywords: Multi-Agent Systems, Decision Support

1. INTRODUCTION

The complexity of environmental problems makes necessary the development and application of new tools capable of processing not only numerical aspects, but also experience from experts and wide public participation, which are all needed in decision-making processes [Poch et al., 2004].

River catchments are important social, economical and environmental units. They sustain ecosystems, which are the main source of water for households, agriculture and industry. Due to population growth, industry and overexploitation, the demands made on the river basin are increasing while the capacity of the catchment to meet these demands is decreasing. Therefore the protection of all surface waters and groundwaters must be assured in their quality and quantity. The best way to fulfill these requirements is with a management system at catchment scale that integrates all the water systems involved (sewer system, Waste Water Treatment Plants and River) [Devesa et al. 2005, Rodriguez-Roda et al. 2002].

The management of river basins involve many interactions between physical, chemical and biological processes ergo these systems become very intricate. Some of the problematic features found in the river basin domain are intrinsic instability, uncertainty and imprecision of data or approximate knowledge and vagueness, huge quantity of data, heterogeneity and different time scales to name a few [Poch et al., 2004].

Multi-Agent Systems (MAS) have the ability to cope with complex problems such those related to river basin system management. Thus, we propose the design of a MAS to simulate different alternative scenarios for decision-making in river basin systems management. The authors are not aware of any related work that provides the same functionalities that we are attempting to achieve in our proposal.
This paper is organised as follows. In §2 we describe the case study for the river basin management. In §3 the river basin Multi-Agent architecture model is introduced. In §4 and §5 the functionality of the Multi-Agent system and its

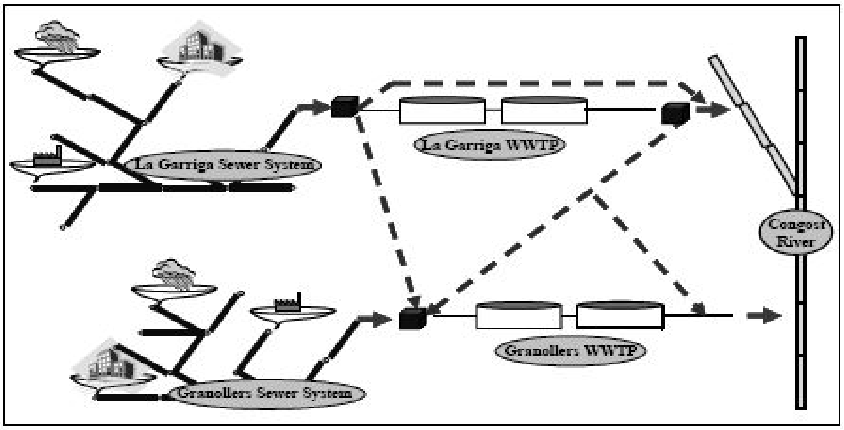

Figure 1. Elements of the environmental system

implementation are detailed. A prototype model of the Riven Basin MAS is illustrated in §6. Finally, in §7 we state the conclusions and outline future work.

2. RIVER BASIN CASE STUDY DESCRIPTION

The Besòs basin is located on the North East of the Mediterranean coast of Spain. The catchment area is one of the most populated catchments in Catalonia, having more than two million people connected. The scope of the study area is around the final reaches of the Congost River. The river sustains, in an area of 70 km^2, the discharges of four towns which are connected to two Waste Water Treatment Plants (WWTP) [Devesa et al. 2005, Raso et al., 1999].The water system has three main elements which are depicted in Figure 1: sewer system, WWTP and river.
Other considered elements are rain control stations, river water quality control stations, flow retention and storage tanks. Yet the most essential element is the sewer channel that joins the two WWTPs, allowing to by-pass the flow from the La Garriga-WWTP to the Granollers-WWTP [Devesa et al. 2005].

- *Sewer system.* There are two sewer systems, one that drains the area of the town La Garriga and another one that drains the area of Granollers and some small surrounding villages.
- *WWTP.* There are two WWTP, one for each sewer system. The two plants have a biological treatment. The average flows are 6000m3/d for La Garriga-WWTP and 26000 m3/d for Granollers-WWTP.
- *River.* The studied reach of the Congost River has a length of 17 km. The Congost is a typical Mediterranean river with seasonal flow variations. Before the two WWTP, the average flow is about 0.5 m3/s, but can easily reach a maximum punctual flow of 200 m3/s.

3. RIVER BASIN MULTI-AGENT ARCHITECTURE MODEL

Multi-agent systems are based on the idea that a cooperative working environment comprising synergistic software components can cope with problems which are hard to solve using the traditional centralized approach to computation. Smaller software entities – software agents – with special capabilities (autonomous, reactive, pro-active and social) are used instead to interact in a flexible and dynamic way to solve problems more efficiently [Mangina, 2002]. We suggest the reader to consult [Luck et al.,2004, D'Inverno and Luck, 2004] if he or she wishes to read more on the subject.

In this section, we describe our MAS proposal for simulating scenarios in a river basin system. The agent's graphic representation and the dependences among them are depicted in Figure 2.
Type of agents:

- *Sewer agents*: Subcatchements La Garriga, La Garriga Sewer system, Subcatchements Granollers, Granollers Sewer system. These agents are responsible for the management of the sewer systems. They are aware of the rainfall, the runoff produced by industrial discharges or rainfall incidence and the level of the water flow in the sewer systems

- *WWTP agents:* Data Gathering, Diagnosis, Decision support, Plans and actions, Connectors. They receive information from the sewer system agents and the storage tanks to start working on the water flow. The agents perform various processes like data gathering, diagnosis of the water using a Case-based reasoning system and a Rule based system, formulating an action plan, user-validation of the plan, etc.
- *River agents:* Data gathering (data required: meteorological, physical, kinetic, water quality). They collect valuable data in order to monitor the state of the river
- *Storage tanks agents:* Industrial parks, Rainfall. There are two types: the industrial parks control the flow from the industrial area and the rain retention can manage the rain flow:
- *Supervisor agent*. It is responsible for the coordination between all the elements of the system. This agent interacts and supports the manager in the decision-making. Among the tasks the supervisor agent performs are the alarm signal, the by-pass of water, the communication with the other agents, etc.

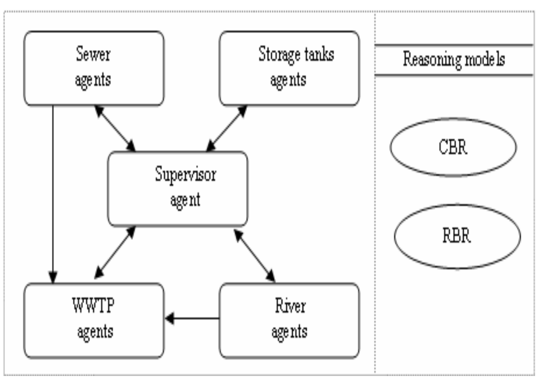

Figure 2. River Basin MAS architecture

4. FUNCTIONALITY OF THE RIVER BASIN MAS

The aim of the MAS is to simulate various scenarios in order to draw conclusions and help in the decision-making for the river basin management. There are other objectives to be fulfilled like:

- To manage critical episodes
- To minimize discharge of poorly treated wastewater
- To maximize the use of the installations treatment capacity
- To minimize the economical costs of new investments and daily management
- To maintain a minimum flow in the river guaranteeing an acceptable ecological state

In order to accomplish these objectives each agent will be provided with domain knowledge by means of Case Based Reasoning (CBR) and/or Rule Based Reasoning (RBR) or other reasoning models. Hence they can perform several tasks including:

- Storage tanks management (open-close hatchs)
- Sewer system control
- Monitoring the river basin system
- By-passing the water flow from La Garriga WWTP (WWTP 1) to Granollers WWTP (WWTP2)

For instance, the user could simulate various scenarios for a critical episode such excessive rainfall producing a peak flow in La Garriga WWTP. The River Basin MAS would take into account the consequences that could affect any element of the water system. Thus, it would provide a set of actuation alternatives (no actuation, by-pass the water flow, storage tank retention) and it would propose the best strategy to deal with the given situation.

5. IMPLEMENTATION OF THE RIVER BASIN MAS

In order to develop our River Basin MAS we have revised the state of the art of MAS platforms [Rendón and Sànchez, 2006]. Our idea is to select the most suitable platform for our goals, and afterwards, to extend it with the new required functionalities. The most essential extension will be the ability of some kinds of agents to incorporate some knowledge and reasoning models.

Nowadays, several agent platforms for the MAS development can be found in the literature. JADE [4] and TuCSoN [7] are platforms for agent communication. Jadex [5] implements the behaviour of individuals within a MAS. DESIRE [2] supports communication and behaviour modelling. There also exist Agent Tool [1] and INGENIAS [3], both attempting to link analysis and design directly to implementation. And finally there is MadKit [6] that uses an organizational model and does not restrict the internal usage of different agent architectures. Table 1 shows a comparative table of the agent platforms that suited our needs the most after a detailed analysis of main alternatives. In addition, our River Basin MAS agents could integrate some specific purpose programs such simulators, (GPS- X, InfoWorks River Simulation, etc.) to perform specific tasks.

Features	**Jadex**	**MadKit**	**AgentTool**
Model	BDI	AGR	N/A
Language	YES	NO	YES
FIPA-compliant	LGPL	LGPL	Academic
License	YES	YES	NO
Support	Vast	FAQS, demos, user guides	Very little
User-developer community	YES	YES	NO

Table 1. Comparison of three agent platforms for MAS development.

Among these platforms we have chosen Jadex due to its capacity to implement the behaviour of intelligent agents in an easy way within a MAS by addressing the limitations of BDI (Beliefs, desires, intentions) systems. Jadex is a Java based framework that allows the creation of goal oriented agents and provides a set of development tools to simplify the creation and testing of agents.

6. PROTOTYPE DEVELOPMENT

Currently we are developing a prototype for the River Basin MAS. As mentioned earlier, we have already defined the agent's roles and specifications. An example of an agent specification is shown in Figure 3. At this stage we are conceptualizing the agent's mental attitudes by setting their roles, goals and beliefs.

To illustrate our work, a problematic situation is depicted in Figure 4 along with the message passing between the agents. In this case the problematic situation is an *excessive rainfall* that is detected by the Sewer Agent La Garriga. Therefore, this agent sends a message to the supervisor agent informing about the anomaly. Then, the Supervisor Agent sends a message to WWTP1 Agent to request a diagnosis and the latter agent responds with the diagnosis informing the increasing level of water flow. The supervisor agent makes the proposal of by-passing a percentage of the water flow from WWTP1 to WWTP2. The user, usually the WWTP manager, approves this proposal, thus the WWTP1 agent by-passes the excess flow to WWTP2.

In Figure 5 we can see the same situation, *excessive rainfall,* modelled in Jadex. The figure lists the attributes needed to send/receive a message following the FIPA[1] standards.

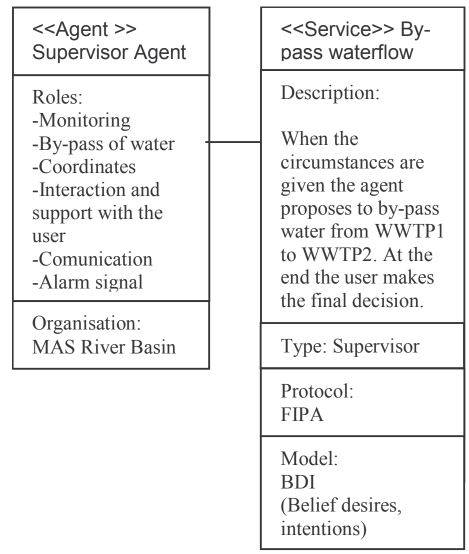

Figure 3. Example of the Supervisor Agent

7. CONCLUSIONS AND FUTURE WORK

Environmental systems, as described above, are very complex to manage. Particularly river basin systems are very difficult to manage in order to obtain a good quality and quantity of water at the river. We have proposed a River Basin MAS to simulate scenarios to support in the decision-making in river basin systems.

The work described in this paper is a work in progress. The river basin MAS has been designed and required functionalities of the system have been studied. At the moment, we have reviewed the state of the art in multi-agent systems as mentioned in the previous section. We have chosen Jadex as the agent platform for designing the River Basin MAS. CBR and RBR are the two main reasoning models envisioned for our MAS.

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[1] FIPA is an IEEE Computer Society standards organization that promotes agent-based technology and the interoperability of its standards with other technologies.
FIPA specifications represent a collection of standards which are intended to promote the interoperation of heterogeneous agents and the services that they can represent [8].

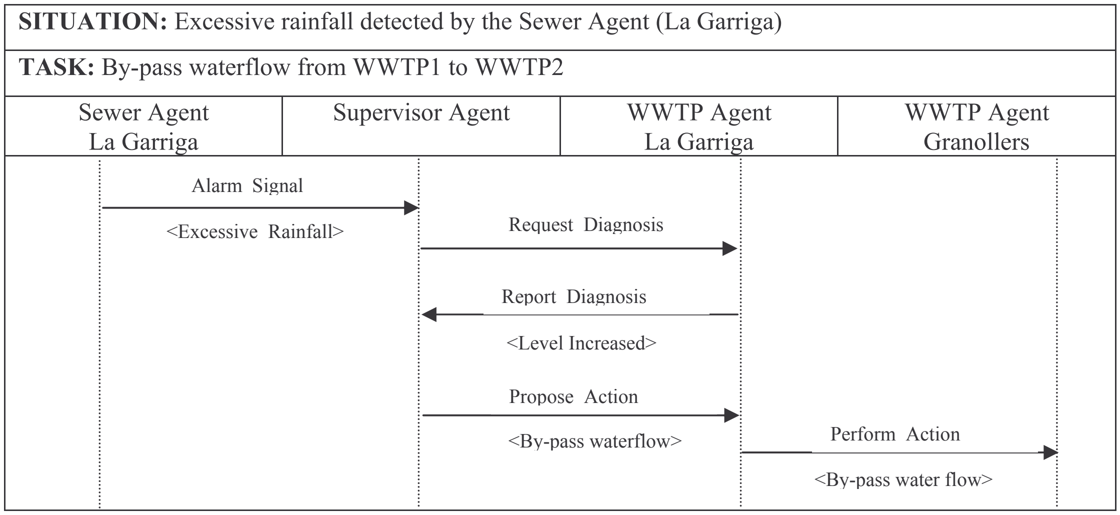

Figure 4. Message Passing between Agents

Sender	Receivers	Performative	Content	Situation
Sewer Agent La Garriga	Supervisor Agent	Failure	Alarm_Signal	Excessive rainfall
Supervisor Agent	WWTP Agent La Garriga	Request	Request_Diagnosis	Diagnosing
WWTP Agent La Garriga	Supervisor Agent	Inform	Report_Diagnosis	Level Increased
Supervisor Agent	WWTP Agent La Garriga	Confirm	Propose_Action	Proposing action
WWTP Agent La Garriga	WWTP Agent Granollers	Accept-proposal	By-pass water flow	Performing action

Figure 5. Example of Message Passing in Jadex

Also some learning mechanisms to integrate knowledge to the agents are foreseen. The River Basin MAS is designed in order to cope with the complexity of the environmental problems and to provide feasible solutions through modelling and simulation of different scenarios in a river basin system.

As future work, we plan to develop the extension to Jadex platform in order to support the required functionalities of the River Basin MAS.

Afterwards, in the near future some preliminary testing will be done and our prototype will be validated with real data coming from the real case study.

8. ACKNOWLEDGEMENTS

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