Towards the Distributed Management of Emergencies: Forest Fires Case Study

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Abstract

Every day there are environmental emergency situations which require complex reasoning and coordination procedures to solve them. Recently, the Prestige oil tanker sinking in Galicia or floods in the Mediterranean coast each autumn are situations not solved/managed for different reasons, such as not having contingence plans, lack of previous cases or the lack of coordination between the entities involved in it.

The automation of the management procedures needed to cope with such situations will not only help incident commanders in the decision making process, but also increase the performance and reduce possible human and environmental impacts.

This paper discusses the possibility of developing a large-scale open agent-based system that, in cooperation with planning techniques, could be used by incident commanders to take decisions in the management of emergencies situations. We propose a distributed emergency management framework intended to cope with dynamic environments in which incident situations arrive in an unpredictable random intervals requiring the construction and execution of an strategic plan to ameliorate the non-wishes consequences.

Our case study focuses in forest fires management of the Barcelona fire service. However, the architecture proposed can be adapted and used within different type of emergencies.

1 Introduction

Emergency situations are complex in nature, thus great effort are required to effectively coordinate all the groups involved and manage the available resources. Moreover, inadequate procedures or time-consuming decisions will result in non-wishes consequences leading both human and environmental losses. Recently, the oil tanker sinking in Galicia or even floods in the Mediterranean coast each autumn are emergency situations not properly solved due to inadequate coordination and interaction among the available resources.

During the last two decades, the fast developments in information technologies and the rapid development of new and faster hardware made the establishment of interdisciplinary research links between environmental and computer scientists possible and very fruitful [Cortés *et al.*, 2000].

Many systems were developed for emergency situations management like CHARADE [Ricci *et al.*, 1997], CARICA [Avesani *et al.*, 1997], HITERM [ESS, 2003], A-TEAM [Fedra and Winkelbauer, 1999], MOBEDIC [Doheny and Fraser, 1996], CIPRODS [Doheny and Fraser, 1996], DIAL [Leake, 1995], RIMSAT [RIMSAT, 2003]. Most of them are decision support systems that combine different planning techniques like Case Based Reasoning, Model Based Reasoning, Constraint reasoning, but do not take care of the distribution nature of the emergency situations problems.

The aim of this work is to discus the possibility of developing a large-scale open agent-based system that, in cooperation with planning techniques, will be used by incident commanders to take decisions in the management of emergencies situations. The techniques used for plan generation and adaptation are Case Based Planning and Constraint Reasoning, whereas the one used for plan coordination and execution is the adaptive task and resource allocation method proposed in [Fatima and Wooldridge, 2001].

We propose a distributed emergency management framework intended to cope with dynamic environments in which incident situations arrive in an unpredictable, random intervals requiring an strategic plan to be constructed and executed to ameliorate the non-wishes consequences.

Although our case study focuses in forest fires managed by the Barcelona fire service, the proposed architecture is abstract enough to be adapted and used within different type of emergencies.

The rest of the paper is organized as follows. Section 2 describes the abstract architecture multi agent architecture, defining the roles of the various agents involved. Section 3 summarizes the planning techniques used for plan generation and execution. Section 4 focuses on the current case study describing the general procedure followed by the Barcelona firemen and how the architecture proposed fits in this organization. Finally, section 5 gives some conclusions.

2 Emergencies Management Framework

Every day life emergency services face complex situations in which an strategic plan and its resulting actions to reach the goals have to be build and implemented in as less time as possible. Although every situation requires specific resources and to perform different actions, the architecture needed appears to be almost the same.

The general view is a system in which incident situations arrive in an unpredictable, random intervals requiring an strategic plan to be constructed in order to solve or to ameliorate the non-wishes consequences. The actions of the plan, characterized by a type, a duration, a deadline and a priority, have to be executed by heterogeneous agents in the sense that all of them have different capabilities.

2.1 Architecture

The general architecture is composed by four main types of agents characterized by the roles they can adopt and/or burdens assigned during emergency management situation (See Fig. 1).

The *General Coordinator* (GC) supervises all the incident

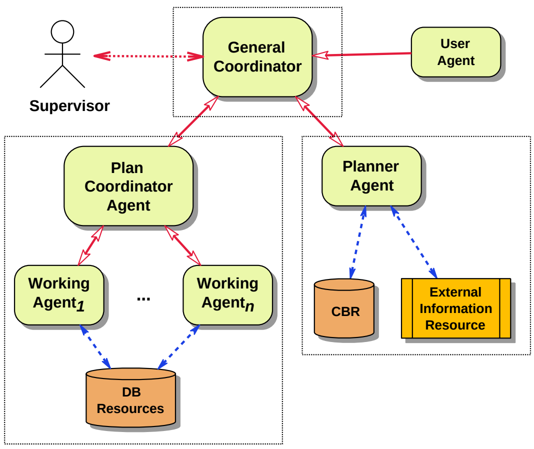

Figure 1: Emergency Management Abstract Multi-Agent Architecture

management process. GC is the responsible to obtain an appropriate strategic plan from the *Planner Agent* (PA), to adapt it when needed, to communicate the specific actions to the *Working Agent Coordinator* (WAC) and to keep track of new information from the user or from external sources to eventually update the planned actions.

The WAC receives the actions needed to face a specific incident situation. The actions are characterized as follows [Fatima and Wooldridge, 2001]:

$$\tau = \langle t, dl, dur, prior \rangle$$

where t is the type of the action; $dl \in \mathbb{N}$ corresponds to the deadline of the action, i.e., the latest time at which the action might usefully be carried out; $dur \in \mathbb{N}$ denotes the estimation of the duration of the action; and finally, $prior \in \mathbb{N}$ establishes the priority or importance of the action.

The type of action denotes the capabilities that an agent has to have in order to successfully carry it out. Therefore, not all agents will be able to do whatever type of action, but only these included in their capabilities.

Each *Working Agent* (WA), based on the TRACE system [Fatima and Wooldridge, 2001], has a set of capabilities and an agenda. The capabilities denotes the types of actions that the agent is capable to perform. The agenda contains the set of actions that the agent has committed to fulfill.

The WAC requests WA to perform the actions of a given plan. These requests arrive randomly to the WAs that, if they have the appropriate capabilities and are able to perform it before the deadline, they commit with the task. Notice that we assume that the WA are benevolent, that is, if they have the capabilities and the needed time, then they will agree to carry out the action. However, if no agent is able to complete the task successfully, the WAC can re-schedule the agenda of a certain WA decommiting it to a given action and assigning it the new one.

The worst case scenario will be if there is no possibility for the WAC to reschedule the agenda of any *Working Agent*. In that case, the WAC will contact other organizations to ask for the specific working agents needed for the task. Although this architecture enables this kind of behavior, the collaboration and commitments among different organizations are left as a future research.

3 Planning

There are different techniques for reasoning and planning used for plan assessment like Case Based Reasoning (CBR), Model Based Reasoning (MBR), Rule Based Reasoning (RBR) and Constraint Reasoning. They create, individually or combining them, a reasoning system for plan generation.

Independently of the paradigm used there are different levels of abstractions for the reasoning task: *the strategy or plan generation level*, where global or partial plans are generated in accordance to the current emergency situation; *the tactic level*, where tactics (sets of ordered actions) are created and they must be execute in order to complete a plan; and, *the action level*, the lowest level, where actions are perform using different resources.

In order to build a planning system for a complex domain which is highly dynamic and unpredictable, like forest fire, we have the necessity to integrate different planning techniques. In this section we generally describe the planning paradigm applied in this work, that is, Case Base Reasoning for plan retrieval and generation, Constraint Reasoning for plan adaptation and an adaptive task and resource allocation proposed in [Fatima and Wooldridge, 2001] for plan execution.

3.1 A Case Based planning approach

In order to efficiently fight an emergency situation we need a system that reacts immediately when this arises. In addition, we have to deal with an unpredictable world. A planning paradigm that could face these matters is the case based planning (CBP). CBP allows plan reuse which save computational time, use expert experiences that facilitates plans representation and it has no necessity of a theory of world evolution [Ricci *et al.*, 1993].

Case representation: Plan tree structure

For plan representation we use the tree structure proposed in [Macedo *et al.*, 1996]. This representation shows to improve the functioning of CBR systems reaching the solution of problems by the contribution of multiple sub cases [Barletta and Mark, 1988; Macedo *et al.*, 1996].

With a plan tree structure for a case representation (see Fig. 2), a plan can be represented as a set of sub plans and actions, and each sub plans is treated as an individual case inside the global case (global plan). Global goals and all the features describing the situation are in the root of the tree. Each node contains a sub plan with its corresponding features and sub goals. We go along this tree until reaching the leaves where actions are set.

For each tree, two kinds of links among plans take place: *hierarchical* and *temporal links*.

Hierarchical links relate the global plan with sub plans and finally sub plans with actions. In Fig. 2, the global goal G is achieved by achieving the sub goals G_1, G_2 and G_3. Similarly, the sub goal G_1 is reached by reaching G_{11}, G_{12} and G_{13}. Continuing this way, actions are reached at the leaves of the tree. Then, to execute the plan we dynamically allocate the task for action (A_j) execution among a collection of multiagent organization (see §2) and begin to achieve the lower sub goals until the global goal is reached. Temporal links establish the temporal relation among sub plans and are used mainly for plan generation and adaptation using constraint reasoning.

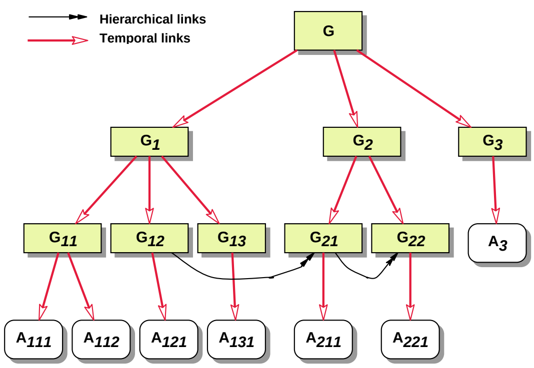

Figure 2: Case (plan) structure. The G_i's represent de goals and sub goals, and the A_i's represent actions

Node structure Each node represents by itself a complete and individual case (and it is part of the global case at the same time) but the components of each case are the same for all of them:

a) Name that identifies it, unique and individual.

b) Name of the general case (global plan) retrieved from de case data base.

c) Address that indicates position in the tree.

d) Set of Attribute/value part of the set of attribute/value of the general case (global plan).

e) Constraints established in order to reach the goal. They are also attribute/value pairs and are used to determine whether or not a node is candidate to occupy a free position in the solution in the plan generation and adaptation process.

f) Antecedents are causal links that follow from other sub plans.

g) Consequents are causal links that follow to other sub plans.

Some of these elements will be used to retrieve a case from the case database and others to generate a new plan according to the current situation.

Plan retrieval and generation

A plan is retrieved from memory by the *Planner Agent* following a hierarchical order. A set of attribute/value and goals is extracted from the environment and a case that better fit this initial case (case built by the *Alpha30 Agent* that represent the emergency) is retrieved. The retrieved case contains a set of attribute/values and general goals and is placed in the root of a tree. Since no more specification takes place, the planner agent begins plan generation at this point and the tree is constructed dynamically, that is, no predefined plan exist in the case data based. Once the main node is retrieved and allocated, the system continues the plan generation process with only those candidates that satisfy the constraints established by the real situation (i.e., the ones able to occupy the sons free positions), and with others nodes already allocated in the tree (i.e. temporal relations among them). Note that the constraints are represented as a node component and that the system also uses attribute, antecedent-consequent information, addresses, etc, to retrieve node sons from the memory. This process will continue until the leaves of the tree are reached.

At this point, temporal relations among actions are already defined due to the temporal constraints checking made in the plan generation process and due to the characterisation used to represent them (deadline, duration and priority). Therefore, planning process find a plan composed by a set of sub plans and actions that must be executed in order to achieve a general goal.

The dynamic environment requires the *Planner Agent* to continuously adapts and generates plans according to new situations. When an adaptation is needed a new set of attribute/value is established and new constraints appear (also in the form of attribute/value). Part of the tree (or the whole tree) must be pruned and new nodes occupy free positions in the solution depending on the coherence of the attribute/value pairs among its hierarchical ascendants.

Plan execution

In order to execute the plan, we use the adaptive task and resource allocation proposed in [Fatima and Wooldridge, 2001]. Tactics execution is divided into task and resource allocation subproblems.

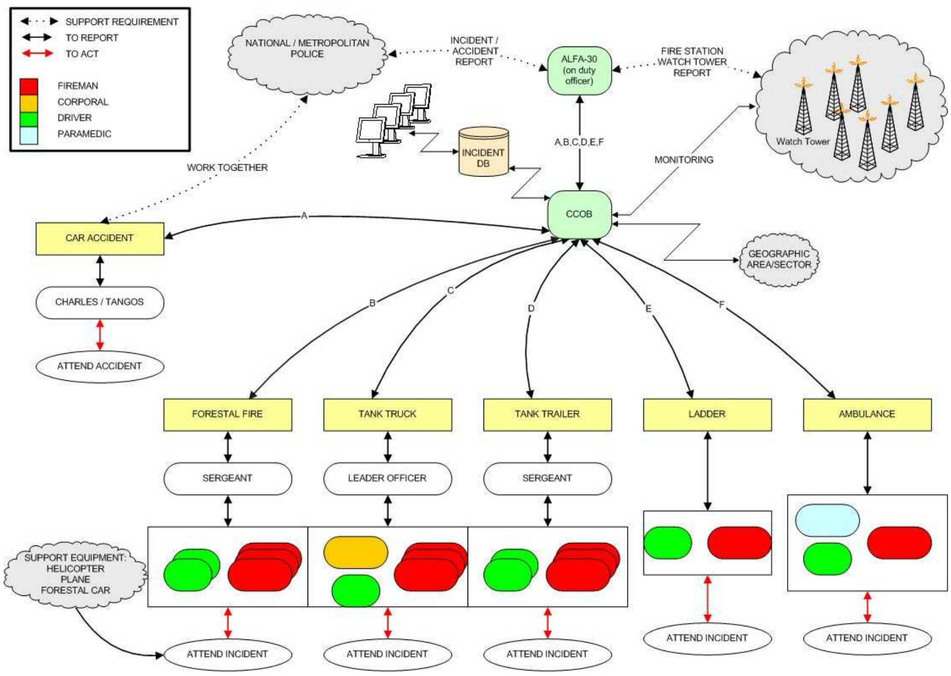

Figure 3: Related entities and its interactions in the management of emergencies in forest fires

A set of task are dynamically allocated among multi-agent organizations composed by agents with different capabilities that enter and leave these organizations depending on the tactic that must be executed. As described before, for plan execution, the *Working Agent Coordinator* (WAC) requests *Working Agent* (WA) to perform the actions of the plan and if they are able to perform it before the deadline, they commit with the task. Each agent also have a schedule that defines in which task the agent is working on and when. This is useful for the cooperative allocation of the task in order to execute a tactic.

4 Case study: forest fire-fighting

The current case study focuses on how to react in an environmental emergency situation as is a forest fire. Our goal is to use the abstract architecture already described within an specific fire-fighters organization to assist the incident commander in the action planification and resource organization processes.

Emergency services in general, and fire-fighters organizations in particular, have their own procedures and modus operandis. This paper is centered in the Barcelona's fire-fighter service and thus, the way they are organized and the strategies followed has been our guides.

4.1 Barcelona fire-fighters' general procedure

There are three main steps to be followed in every incident situation that determines how the fire-fighters should act:

1) *Register the call*. All the calls first arrive to the Control Center and once there, those who take the message and feed it in a database inform the person in charge of inning(day) about the incident.

2) *Validate the call*. The call could be a request to one of the fire station elements or a new incident notification. In the first case it is communicated directly to the respective actor/s and in the second one a new incident handling begins.

3) *Evaluate the problem, planning and estimate consequences*. One expert in the domain must coordinate all actors and resources and build plans to all of them. These assignments depend on the seriousness of the problem. These tasks have to be monitorized because of the dynamism of the environment and consequent changeability of the actions planned.

The real hard problem is how to handle the third point, that is, how to minimize the time needed to select and process all the valuable information to build strategic plans and how to organize the available resources to achieve the goal of decreasing non-wishes environmental consequences.

The general Barcelona fire-fighters organization is composed of heterogeneous entities, in the sense that they have different responsabilities and capabilities, requiring a well-defined coordination among them. In Fig. 3 we summarize the elements to consider and its interactions.

The concept of emergency is too ambiguous and firemen refer only to incident, distinguishing several types depending on its gravity. They identify *accident* (automobile, personal obstructed in an elevator, etc), *controllable fire*, *fire difficult to control*, and *forest fire*, sorted in higher degree of complexity.

Firemen are organized following the hierarchical paradigm in which four levels of burdens are distinguished. The lowest level is represented by the resources like tank truck, ladders, trailer tank, ambulances, airplanes and helicopters. The use of these resources depend on the gravity of the accident, for example, a fire difficult to control requires a trailer tank at minimum, but another resources like tank truck, ladders and ambulances could be called if it is necessary.

The next level is composed by commands that control the resources. At this level there are sergeants and charles/tangos. On one hand, a sergeant is in charge of some resources and s/he has some level of autonomy to give orders to accomplish the goals. On the other, a charles/tango is only in charge of the accidents (without resources).

The sergeants and charles/tangos are coordinated and supervised by the Alfa 30, the third responsability degree. The Alfa 30 evaluates the situation, builds the plans, estimates the consequences, and takes decisions. Moreover, Alfa 30 is always keeping track of new information to eventually update the planned actions.

Finally, the CCOB (higher degree in the hierarchy) is the major supervisor. S/He authorizes the use of expensive resources such as helicopters and airplanes, and receives the report of damages from sergeants, charles/tangos and Alfa 30.

4.2 Specific architecture

From the description of the current organization of the firefighters service in Barcelona city, the abstract architecture defined seems to fit quite well. Fig. 4 depicts the concrete architecture proposed.

Each of the agents described in §2.1 has its corresponding instance in the specific architecture, inheriting the generical abstract burdens and acquiring new functionalities from the concrete fire service organization.

Agents Roles

The MAS is composed by the *Call Center agent* (CA), the *Alfa 30 Agent* (A30A) who is the main coordinator of the system, the *Planner Agent* (PA), the *Sergeant Agent* (SA) who is the plan coordinator and the concrete *Working Agent* (WA) that represent each of the resources the system has to deal with as the tank truck, tank trailer, ladder and the ambulance (see §4.1).

The *Call Center Agent* (CA) is the interface between the user and the system. Therefore, CA is the responsible for data reception and validation (filtering the most relevant inputs), and for storing the current incident into a database to keep track of the ongoing actuations.

The *Alfa 30 Agent* (A30A) represents the real Alfa 30 commander and is the concrete instance of the *General Coordinator* agent in Fig. 1. Therefore, A30A is the main coordinator with the highest hierarchical degree of the whole system. A30A is the responsible to request an strategic plan generation for facing a concrete incident, to update the actions planned when needed or to communicate with the real Alfa 30 commander for confirming the procedure to be implemented. Moreover, A30A is always receiving or getting incident information updates. From that data, A30A is able to decide whether to cancel, replace or update the actions planned in an ongoing execution.

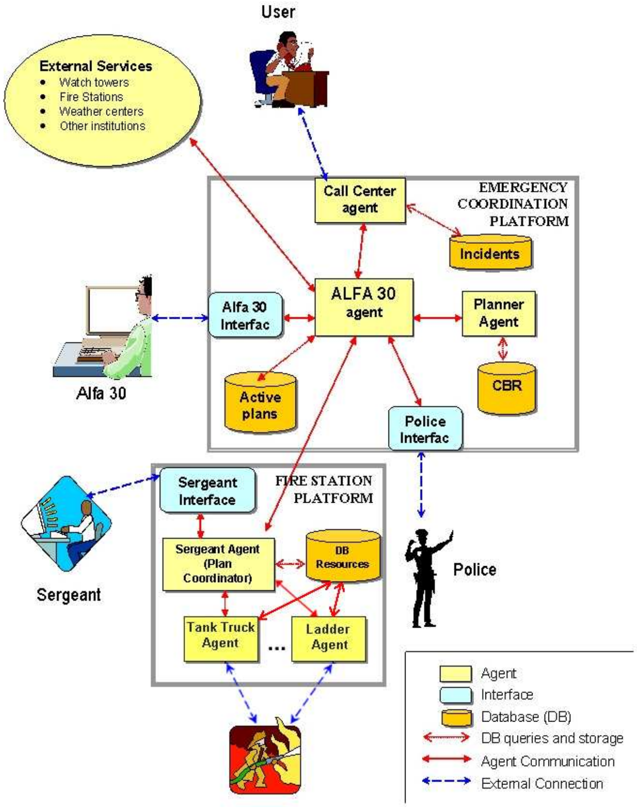

Figure 4: Architecture of the system

The *Planner Agent* (PA) is the responsible for generating strategic plans using the techniques described in §3. Once the plan is build, the PA sends it to the A30A. As the incidents arrive randomly, the load of the planning task changes over time in unpredictable way. That is the reason why PA can replicate itself to handle simultaneous plan generation requirements.

The *Sergeant Agent* (SA) acts on behalf of the real sergeant commander, and is the specific instance of the Plan Coordinator Agent in the abstract architecture. The SA receives the concrete actions planned represented as $\tau = \langle t, dl, dur, prior \rangle$ for facing the concrete incident situation. As a plan coordinator, the SA is responsible for ensuring the execution of all that actions and to obtain its results.

Finally, the specific working agents in the current scenario are the *Tank Trailer Agent*, the *Tank Trunk*, the *Ladder Agent* and *Ambulance Agent*. Each of them has specific capabilities and thus, requiring different resources as drivers, firemen or paramedics. Moreover, all of them have an agenda to allocate the actions to carry out.

5 Conclusions

How to react to emergency situations, how to organize the groups involved and how to handle the available resources are key issues in the effective management of this kind of situations. Inadequate procedures or decision delays will result in non-wishes consequences. Therefore, the automation of these tasks will not only help incident commanders in the decision making process, but also increase the performance and reduce possible human and environmental impacts.

We propose a Multiagent System (MAS) which in collaboration with Case Based Planning and Constraint Reasoning techniques will be usable for incident commanders to make decisions in environmental emergency situations management. The main idea behind this approach is to deploy the available suitable emergency plan and to coordinate the different groups involved in the minimum possible time hence reducing undesirable consequences.

The agent paradigm provide us with the most important characteristics for dealing with emergency situations as proactivity, autonomy, reactivity or sociability. Thus, agent systems give us a coherent framework for facing the tremendous work involving emergencies.

The case study chosen focuses on how to react in an environmental emergency situation as is a forest fire. The specific example provides us with a real framework in which to use the abstract architecture thus obtaining feedback about its capabilities and problems.

Finally, and as a consequence of the high difficulty level of the environment described, this work hopes to raise discussion about how to react and act in complex environments as emergency situations.

6 Acknowledgements

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