A Generic Multi-Agent Architecture for the Virtual Enterprise

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Abstract. This paper presents a generic architecture for the development of a virtual enterprise (VE). This architecture, which is based on the notion of agent, includes all the concepts necessary to ensure all the phases of virtual enterprise life-cycle. Thus, we propose several types of agent, namely, the enterprise agent representing an individual enterprise, the broker agent, which is the initiator of the VE (creation phase), the VE manager (operation and dissolution phases) and the electronic market manager agent. The co-ordination and communication mechanisms recommended in the agent-based approach are also specified. The basic idea is to use the concepts of multi-agent systems (MAS) to perform the different activities of the virtual enterprise life-cycle, and thus, to adapt the solutions provided by the MAS paradigm to solve the different problems encountered while establishing a virtual enterprise.

1 Introduction

Today, face to the needs of ever more exacting customers and in order to be able to suit continuously to unpredictable events and market uncertainties, companies are compelled to adopt new forms of organisation that are mobile and reactive (decentralisation of decisions and production units, network-based structures). In such conditions, enterprises are brought to focus on their skills and contract alliances so as to satisfy the needs of customers. These alliances must permit the constitution of teams with members coming from different enterprises to work together on a specific project, so as to accelerate production, while improving the quality and reducing substantially the costs. These groups (alliances) are called "virtual enterprises". A virtual enterprise (VE) is a more or less temporary network of legally independent enterprises or individuals unifying their means, skills and other resources to work on a common project possibly transcending the capacities of each unit considered separately. This network aims at exploiting volatile opportunities, access new markets, and share costs and risks, with using new information and communication technologies.

Given the variety of the activity fields of the VEs, it is difficult to find a standard architecture that could serve as a reference. A generic architecture including all the
concepts necessary to model and guarantee the activities of the life cycle could be the basis for a variety of VEs (industry, commerce, and other sectors). A designer could use such an architecture as a starting point to develop a VE, while adapting the basic concepts of this architecture to the particulars of a sector. In this context, we use "activities" to refer to those that are performed whatever the nature of the VE to be developed (e.g. partner selection, negotiation, etc.).

Recently, the MAS became the dominant paradigm for developing complex distributed systems, distributed information systems, and human-machine interfaces. The importance of the concepts of this paradigm lies on its aptitude to model complex knowledge and systems that are distributed, co-operative and intelligent. These aspects make the adoption of the agent-based approach interesting for establishing virtual enterprises.

This paper is a contribution to the efforts made in several research undertakings aiming at the realization of standard models and reference architectures of a VE. Within this perspective, we will propose a generic architecture adopting the multi-agent approach.

In the following, we first present a number of agent-based VEs, and describe the approach we use and motivate this choice. Then, we present the internal structure of the various agents, along with their roles in the virtual enterprise, and propose a negotiation model that manages the inter-agent interactions during the initial phases of the VE creation. Furthermore, we try to cover the operation/evolution phase by proposing a “VE manager agent”.

2 Related Work

Several research work and projects related to the development of VEs, such as NIIP [NII95], PRODNET-II [CAR02], MASSYVE [RAM01], and others, are empirical in nature. They are meant to develop standards and reference architectures for the VE that apply to specific sectors of activity, industry for example. It is difficult, sometimes impossible, to use an architecture developed for a given project in another one, which is concerned with a different sector of activity.

Generally, we use one of the following approaches, which are all suited for the development of VEs: the Layer Approach [CL98], the Agent-based Approach [RO99, BR00], and the approach based on service federation [SUN99].

Research work using the agent-based approach inspired the idea of modelling the virtual enterprise as a distributed multi-agent system, where each agent represents an individual member enterprise of the VE considered in the work of Fisher et al. [Fi96]. Camarinha et al. [CAR02], Rocha et al. [RO99] proposed frameworks to develop virtual enterprises for specific sectors (e.g. mould industry). The co-ordination mechanisms existing during the various phases of the VE’s life cycle have been considered in several research works. Here, we can cite Oprea’s work [Om03] concerning co-ordination in a distributed MAS modelling the VE, that of Petersen et al. [PM03] using intelligent agents to model and select partners in a VE, and that of Florea [Fa98], which presents a MAS model to support business processes. The various research work using agent-approach aroused, do
not present complete models for the VE, they study only some aspects of the VE (e.g. Co-ordination, Business Process modelling). Agent-based models adopted for the VE handle generally only of the first phase of VE life-cycle (partners selection and contracts negotiation). Some studies [Om03] claim that the operation phase is implicitly handled by the proposed model, without explaining how this phase is covered and without giving so much, the structures details of the agents in this model.

The introduction of MASs in the development of VEs can be achieved in several ways: a MAS model can be used for the conception, simulation, and execution of the VE, as in the case of the COOL and ADEPT systems [Fa98]. Other approaches use a federated architecture in which the agents are organized into groups [CO95]. For each group, a dedicated agent, called "facilitator", identifies the agents that will join or quit the system, and enables to communicate directly with other agents regardless of their location. Moreover, the facilitators provide anonymous communication between agents and perform massage translation.

Most of architectures follow three agent-based approaches [SN99]: the facilitator-based approach, the broker-based approach, and the mediator-based approach.

The use of the agents in the VE environment brings a significant advantage, thanks to the high degree of distribution, autonomy, cooperation and the coordination mechanisms which they offer. The autonomy of enterprises is thus preserved and the flexibility of the VE is increased. Moreover, activities such as, search and selection of partners and contract negotiation perfectly adjust to agents specifications.

Although the agent technology is a promising paradigm for the development of VEs, it presents some problems such as the lack of a standard communication language. In this respect, FIPA-ACL and its predecessor KQML were proposed to become standards of the inter-agent communication. The problems met in the MASs, which we shall consider as disadvantages, are due essentially to the novelty of this domain of research.

In the architecture we propose, we tried to present all the necessary concepts to ensure all the life-cycle phases, starting from the creation phase to the dissolution phase.

3 A Multi-Agent Approach for the Virtual Enterprise

The choice of the agent-based approach is motivated by several considerations:

- The nature of the virtual enterprise (a set of autonomous enterprises, geographically scattered, wishing to collaborate to achieve a common goal) is well adapted to the "Distributed Multi-Agent Systems" approach, and thus, mapping the VE into a MAS comes naturally. While the multi-agent approach is frequently used for VE projects in the industry sector, we do think that this powerful approach can suit more or less any type of VE, with certain adaptation for the basic concepts.

- The introduction of this paradigm in the VE environment allows us to benefit from the solutions provided by the research undertakings in the fields of Artificial Intelligence and of Agents (modelling, negotiation, planning, etc.).
- The MAS infrastructure is a set of services, conventions and knowledge supporting complex social interactions between agents. The co-ordination and resolution of distributed problems are critical for VE management. These problems can be given acceptable solutions within a multi-agent approach. Every phase of VE’s life cycle requires the completion of several different activities that are well adapted to MAS approach. The agents are able to co-ordinate tasks by exchanging services and information, to follow complex negotiation protocols, to agree to commitments, and to execute other complex social operations.

- A multi-agent approach provides a good implementation solution for the VE, while taking into account sensitive requirements that must be met satisfactorily, namely: co-operation and co-ordination, execution of distributed business process, and preservation of autonomy as well as confidentiality of enterprises.

### 3.1 The proposed Architecture

The proposed architecture is agent-based and is designed to support all the processes of VE’s life cycle. That is, the proposed architecture is meant to include all the concepts necessary to perform all activities related to the life cycle.

The life cycle of a VE is made up typically of the following phases: creation, operation/evolution, and dissolution [CAR02]. Furthermore, some research works consider a preliminary phase, which is that of the identification of a market opportunity [Kj97].

We shall adopt a generic, broker-based architecture. The enterprise members are represented by autonomous agents, geographically scattered, which are able to co-operate to achieve a common business goal. The enterprises are considered to be within a unique electronic market1. In addition to the agents representing the enterprises, a broker agent is introduced in the MAS community. This agent reacts by seizing deal opportunities present in the market, and proceed thus to establish the corresponding virtual enterprises.

The various agents constituting the virtual enterprise assume the following roles:

1. **The broker**, which is the creator (initiator) of the VE.
2. **The enterprise agent**, representing an individual enterprise.
3. **The electronic-market manager**, which is responsible for registering market members.
4. **The VE manager**, which is a temporary agent, associated by the broker to a created VE.

### 3.2 Structure of the electronic market

To remain attentive and responsive to the changing and increasing economic demands, the enterprises are compelled to join their skills in a network of high flexibility and agility.

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1 In the industry, the appellation is a “cluster”.

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The electronic market provides an infrastructure to support the creation of virtual enterprises, offering to the various participants the opportunity to co-operate on a common project/business.

In this study, the electronic market participants are autonomous enterprises, geographically scattered, willing to unify their skills and effort to seize opportunities present in the market. This is made by the creation of virtual enterprises according to the demands of these opportunities.

The set of individual enterprises in the electronic market is modelled as a multi-agent system, in which an autonomous, intelligent agent represents each enterprise, with, additionally, a broker to take care the process of VE creation.

We propose an "electronic-market manager" performing the following tasks:

- Keeping a yellow pages register in which are registered the enterprises member of the market (with their corresponding profiles). The agent permits an external enterprise to register as a member of this market (according to the conditions required for the exploitation of this market), and also erases the enterprises willing to quit the market from the register (together with related products and services).
- Registering the profile of an individual enterprise. That profile includes a list of the products/services it offers, together with its capacities and skills, in order that they are made available to the clients. The enterprise can, at any time, modify, add or erase a product/service it offers.
- Establishing social communications with enterprises external to the market, willing to join this market. The agent informs them about the nature of the market and the conditions necessary to join it.
- Supporting the broker during the life cycle of the VEs this latter establishes. The e-market manager provides all the necessary information relating to the enterprises candidate to membership in the VE that the broker intends to create.

3.3 Structure of the enterprise agent

According to [RO99], we consider the enterprise agent as an entity including a communication module, a planning and co–ordination module, and an execution module. It has also an interface for the interaction with the user and two other knowledge bases: the individual knowledge base and the VE knowledge one (Fig. 3.1):

- **The Communication Module**: containing all the processes required to handle the messages, namely: reception, filtering, and translation of incoming messages, and formulation and sending of outgoing messages.

- **The User Interface**: permits the interaction between the enterprise agent and the human agent (user). It is a support interface for the human agent. This latter assumes deciding role, whether to take part in a virtual enterprise by accepting the terms of the contract established with the broker, or in matters relating to the exchange of confidential information.
• **The Planning and Co-ordination Module**: is the module responsible for managing the co-operation and formulating the offers for achieving sub-goals (parts of the decomposition of the global goal) announced by the broker; it allows the agent to compete with other agents for membership in the VE.

• **The Execution Module**: contrary to what Rocha [RO99] proposed, this module does not contain the resources of the individual enterprise, but only information about the internal resources of the individual enterprise (application, users, knowledge sources, etc.), which makes possible the performance of local tasks that are assigned to the enterprise. This module has the function of establishing the correspondence between the sub-goal (the task) assigned to the agent and the internal resource(s) of the enterprise capable of achieving this sub-goal.

• **The VE–Knowledge Module**: contains the information relating to the organisational and operational rules defined by the VE (e.g. to which VE agent should it submit results). It contains a list of all other agents, member of the VE(s), which this agent is a member. This module also contains the information pertaining to the rights and obligations of the individual enterprise.

• **The Individual–Knowledge Module**: contains information about the agent itself: its capacities and skills, and the current state and workload, i.e. for each skill, indicators are assigned to determine availability, as well as the cost of such skill.

### 3.4 Structure of the broker agent

As, the broker is the initiator of the VE, its role is to look for and identify the business opportunities in the market, to select appropriate partners to seize this opportunity, and to co-ordinate the activities of the VE. It is the primary contact with the clients of the VE. Once the broker finds out the description of the global goal from the information...
supplied by the customer, it proceeds to the decomposition of the global goal into sub-goals (the global process is translated into a set of partial processes using appropriate modelling techniques). Then, the broker allocates the sub-goals to the agents potentially capable of contributing to their achievement.

The components of the broker agent are represented in Fig. 3.2:

- **The Communication Module**: This module handles the whole communication process with the agents of the electronic market. It provides for the formulation of the messages according to the language adopted (ACL or KQML), and assumes the function of translating messages received from various agents during the creation of the VE.

- **The User Interface**: the broker provides a graphical interface for interaction with the customer and another one for interaction with the human broker (the expert).

The interface with the client is made of:
- A list of products/services offered by the broker. This list is developed starting from the profiles of the enterprises registered in the electronic market, and is subsequently enriched from the experience the broker acquires through its execution. That is, once a product is made by a VE, a trace of this product is kept even after the VE had been dissolved.

- Dialog boxes allow the customer to order a product not present on the list, or to customise a product according to the client’s needs and wishes. The customer is assisted all along the formulation of his request, so that the customer is kept within the services and products offered by the electronic market.

The interface with the expert (human broker) provides for decision taking, whether concerning answers to offers made by partners, or during the decomposition of the global goal.

![Fig.3.2: Structure of the broker agent](image)
The Reasoning Module: contains the following parts:

- The "Global-Goal Description" Module: the human broker (the expert), with the assistance of the broker agent, fetches the order of the customer and formulates a description of this order as being the global goal to be achieved, or, more precisely, the "Business Process".

- The "Global-Goal Decomposition" Module: the broker agent proceeds to the decomposition of the global goal (described beforehand) on the basis of human expertise and/or learning from the cases encountered previously (use of knowledge acquired from past experience).

Several research work try to automate the process of the decomposition of a global goal into sub-goals in MAS. We argue that in a VE environment, where the primary objective is to satisfy customers by offering the possibility of acquiring customised products upon request, it is difficult to recommend an automated decomposition module operating without the intervention of an expert.

This consideration brought us to propose a decomposition module interacting with a human expert in the field (when considering a new product) and using knowledge acquired from past experience for products similar to others already achieved. In order to decompose a task, some criteria doubtless have to be taken into account, such as control, data, and resources. It is necessary to make the sub-goals (tasks) as independent from each other as possible, so as to facilitate their allocation to the corresponding partners and to considerably diminish the co-ordination and communication between the agents.

The decomposition process allows the determination of the set of independent tasks required for the realisation of a product or service. It thus provides a list of the skills necessary to reach this goal.

One idea is that the assembly of the achievements of the sub-goals is itself also defined as a sub-goal. It is assigned to one of the partners in the VE. This makes it possible to avoid a problem that is often related to the MASs, that of finding global solutions starting from partial solutions.

- The "Selection and Allocation" Module: the function of this module is to formulate announcements corresponding to the sub-goals resulting from the decomposition.

The “e-market manager agent” keeps a register (Yellow Pages) of membership for the electronic market. Each enterprise member (agent) in the market has an entry in this register. This entry includes a list of all the skills offered by this enterprise. For each sub-goal, the broker broadcasts a first announcement to determine potential candidates, agents possessing the necessary skills for the completion of this task, and invites them to take charge of this sub-goal (Sub-Goal Announcements). Among the agents, which answer the announcements (the bidders); the broker selects the one making the best offer. After negotiation of a contract with the latter, and once they achieve a mutual agreement, the broker notifies this agent of the assignation of the task to it (the agent) for completion.

Knowledge: The knowledge of the broker is of two sorts:
- Knowledge acquired through learning, i.e., new knowledge that the broker acquires from past experiences with formerly requested products, about which it keeps information (description, decomposition, member agents of the corresponding VE, etc.).

- A priori knowledge, concerning its environment (electronic market).

Let us consider the following example, in which we show briefly the broker's functioning: when a request for the construction of a “gear-box” is made by an individual or a company; the broker agent assisted by a human expert proceeds to the decomposition of the global goal (construction of a gear-box) into a set of sub-goals (independent tasks) and determines the necessary competence(s) for their realization. The broker agent launches a call for bids for the different tasks, and succeeds thus in creating a VE, which contains: an enterprise of construction or supply of gables, a second one for the “carters”, and another one for the “bearings”, etc. The assembly task will be the object of a call for bids, and probably, it will be assigned to an enterprise already selected for another task, or to a new enterprise, that collects all components and achieves the assembly of the requested “gear-box”.

3.5 Co-ordination

In our context, each agent has its own plan, intentions, and knowledge that it uses during the satisfaction of its own local goals. For the global goal of the system, a co-ordination mechanism is necessary for the solving of the conflicts that may arise, and for the composition of the global solution out of the local solutions provided by the various agents. Similarly, it is necessary to define mechanisms of co-ordination during all the phases of the life cycle of the VE.

3.5.1 Co-ordination protocols during the creation phase

In a VE, an agent acting through a well-defined negotiation protocol represents each member enterprise. In an electronic market, the creation of a VE requires the initiation of competition among the various agents that send offers in answer to the announcements made by the broker, and this in view of being selected as partners in the VE. Negotiation is the technique we use to be the co-ordination mechanism during the creation phase of the VE. We will detail the negotiation protocol associated to the proposed architecture so as to allow the definition of a frame for co-ordination during this phase.

The broker, which is the initiator in this approach, asks the various potential agents to tender their offers, i.e., to give the necessary information concerning their activities (experience) in order that the broker agent checks them. Then, the latter decides (or not) to initiate negotiation for finding an agreement between the two parts (the initiator of the VE and the future partner in the VE). Such a negotiation can end upon withdrawal of either of the parts [PM03].
Based on the Contract-Net protocol [FIP99], the generic interaction protocol of the agents during the creation of the VE is the following:

1. The broker (initiator of the VE) announces the creation of the VE and the allocation of tasks through posting of an announcement or call for proposals meant for interested participants in the electronic market. For each task to be completed, the broker announces a specification containing its description and a list of the requirements and constraints relating to this task;

2. The interested participants answer the announcement by making bids. The broker according to well-determined criteria evaluates the bids. Through this evaluation, potential partners are determined;

3. The broker gets ready to negotiate with the potential partners (those which fulfil the requirements);

4. Finally, after negotiation, and rejection by the broker of certain uninteresting offers, certain potential partners will become entrepreneurs (members of the VE), each one with signed contract to be executed.

3.5.2 Coordination during the Operation/Evolution phase

Once the VE is created, the "operation" phase can start, i.e., after decomposition of the global goal into sub-goals and allocation of these to the appropriate partners in the VE, each partner (agent) completes the task that was assigned to it. The composition of the individual results leads to the achievement of the global goal.

During the "operation" phase, several unexpected events could occur: a partner cannot honour his contract (complete his individual task), for lack of resources for example; or a partner wants to modify certain clauses of his contract because they have become contradictory to his other obligations. In such situations, the partner (the agent) proceeds to a new round of negotiations (re-negotiation) to modify its contract(s) or terminate its commitment(s) outright. In this last case, his replacement becomes necessary.

During the "operation/evolution" phase, we propose that the broker, which assumes the function of initiator/creator of the VE, creates, for each VE established, a "VE manager" agent entrusted with the role of supervisor during the "operation" phase.

The VE manager is a temporary agent responsible for the achievement of the product/service requested by the customer. Once the product is realized, it transmits to the broker all the new knowledge acquired during the operation and proceeds to dissolve the VE. When one or several partners fail during the "operation" phase of the VE, or the global goal changes (the request of the client), the manager agent starts a new reconfiguration/evolution phase to recruit new partners in place of those failing or in answer to the new requirements.
4 Conclusion

In this work, we have presented a generic, agent-based architecture permitting the establishment of a VE, independently of the sector of activity (field of application) of such an enterprise.

Despite the difficulties of the development of a multi-agent approach, due to the lack of certain important features that should characterize a virtual enterprise such as security mechanisms, anti-viral protection, etc., the MAS paradigm stays a basic area for the design of standardised models for the VE, due to its aptitude for modelling knowledge and systems that are complex, distributed, co-operative and intelligent.

Indeed, some VE requirements such as security have not been handled at this stage of study. We think that these points, being of a general character, depend much more on the implementation phase, than the modelling one. So, they depend more specifically on the adopted platform of development.

Form the implementation viewpoint; we consider the use of an agent-based platform to implement the different agents and concepts. The choice of such a platform is based on several criteria such as, the nature of the agents, the communication language used and the negotiation protocol. The chosen platform offers besides the programming packages and an inter-agent communication support, a security model and thus, it permits the simulation of the VE functioning.

Subsequently, we intend to complete this work with a case study to evaluate our ideas in a real environment. This case study will concern enterprises containing several subsidiaries and scattered units and/or SMEs aiming at the creation and development of partnerships in order to offer products and/or services beyond their own competences.

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