AGENT-BASED SYSTEM TO SUPPORT COLLABORATION AMONG AUTONOMOUS MICROGRIDS

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Abstract

Maintaining the sustainability of organizations on the market and their performance in a competitive market is very difficult to accomplish. In this dynamic environment, organizations decide to cooperate, becoming partners in a virtual enterprise. To work efficiently, the partners must collaborate and coordinate their negotiation activities to find the optimal solution unanimously accepted.

This paper proposes an agent-based system to support collaborative activities among autonomous microgrids grouped in a virtual enterprise to better meet customers' energy requirements. To maintain the autonomy of each microgrid within the virtual enterprise, it is proposed a decentralised and flexible negotiation solution that combines diverse technologies, such as multi-agent systems in dealing with negotiation interactions issues, and middleware-level coordination facilities for all aspects related to coordination of multiple parallel negotiations. Currently, interoperability among the involved autonomous microgrids in a negotiation is often not reached or maintained due to failure in adapting to new requirements, parties, or conditions. The use of an adaptive agent-based system as proposed will result in a seamless, sustainable interoperability which favours its maintenance across time. The proposed negotiation solution enhances the ability to reach and interoperate with more parties that leads to more business opportunities and to stronger and healthier interactions.

Keywords: *Smart Microgrid, Intelligent Agents, SME, Virtual Enterprise, Negotiation.*

1. Introduction

To be able to perform, enterprises need to exchange information, whether this exchange is internal (among departments of the enterprise), external (between the enterprise or part of it and an external party), or both. Enterprise Interoperability (EI) is thus defined as the ability of an enterprise to seamlessly exchange information in all the above cases, ensuring the understanding of the exchanged information in the same way by all the involved parties[1]. Large enterprises accomplish this by setting market standards and leading their supply chain to comply with these standards. Small and Medium Enterprises (SMEs) are more sensible to the oscillations of the environment that involves them, which leads them to the need to constantly change to interoperate with their surrounding ecosystem. Sustainable EI (SEI) is thus defined as the ability of maintaining and enduring interoperability along the enterprise systems and applications' life cycle. Achieving a SEI in this context requires a continuous maintenance and iterative effort to adapt to new conditions and partners, and a constant check of the status and maintaining existing interoperability[2].

The electric power system must continually adapt to the new requirements of environmental compliance and energy conservation. In addition, the recent natural disasters and other destructive events that caused significant power outages have shown that a more robust and reliable power grid is needed.

According to Wang[3], a smart grid is an intelligent and flexible power network that manages and coordinates a Distributed Energy Resource (DER) system, having a key role in supplying energy on demand and monitoring power outages. Moreover, in the context of reducing energy losses during transmission and distribution, particular attention has been paid to microgrids (MGs).

Modern smart microgrids represent a major technology breakthrough due to a decentralized and decarbonized energy infrastructure made up of interconnected DER ensuring stability and resiliency energy systems. However, in dynamic energy networks, the pressure to reach sustainability goals requires to find viable solutions for improving microgrids' performance. One of the solutions consists in achieving the microgrids' cooperation and ensuring the interoperability among their distributed systems to work more seamlessly together.

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[1] M.-S. Li, R. Cabral, G. Doumeingts, and K. Popplewell, *Enterprise Interoperability Research Roadmap*, no. July. European Commision - CORDIS, p. 45, 2006.

[2] R. Jardim-Goncalves, A. Grilo, C. Agostinho, F. Lampathaki, and Y. Charalabidis, *Systematisation of Interoperability Body of Knowledge: the foundation for Enterprise Interoperability as a science*, Enterprise Information Systems, vol. 6, no. 3, pp. 1-26, 2012.

[3] W. Wang, Y. Xu, and M. Khanna, *A survey on the communication architectures in smart grid*, Computer Networks, vol. 55, Issue 15, 27 October 2011, pp. 3604-3629.

Given this general context, the objective of the present paper is to develop a conceptual framework and the associated informational infrastructure that are necessary to facilitate the collaboration activities and the negotiations among independent microgrids that participate in a Network Enterprises.

The concept of "Virtual Enterprise (VE)" or "Network of Enterprises" has emerged to identify the situation when several independent companies decided to collaborate and establish a virtual organization with the goal of increasing their profits. Camarinha-Matos[4] defines the concept of VE as follows: "A *Virtual Enterprise (VE)* is a temporary alliance of enterprises that come together to share skills and resources in order to better respond to business opportunities and whose cooperation is supported by computer networks".

In this paper the negotiation we want to model involves several participants negotiating for a negotiation object described by several interdependent attributes and each agent manages its own information regarding the strategy used, to achieve the proposed objective. Thus, to conduct one or more negotiations, in an effective manner, considering all dimensions of negotiations, coordination mechanisms with well-defined functionalities are needed.

The negotiation process was exemplified by scenarios tight together by a virtual alliance of the autonomous microgrids. Typically, these are competing companies. However, to better meet customer energy demands, they must enter in an alliance and must cooperate to achieve common tasks. The manager of a microgrid wants to have a complete decision-making power over the administration of his contracts, resources, budget, and clients. At the same time, the manager attempts to cooperate with other microgrids to accomplish the global task at hand only through a minimal exchange of information. This exchange is minimal in the sense that the manager is in charge and can select the information exchanged.

Section 2 presents the theoretical background. In Section 3 we are describing the collaborative platform for coordinating concurrent negotiation activities[5]. In Section 4 we define the Coordination Components that manage different negotiations that may take place simultaneously. In Sections 5 we present the collaborative approach and the proposed solution, and, finally, Section 6 concludes this paper.

2. Theoretical Background

2.1. Generic coordination of negotiations

Many research papers highlight the importance of microgrids as a valued energy solution where distributed (renewable) sources respond to local demand (Carrasco et al., 2006). However, due to the different capacity and weather-based characteristic of various distributed sources, microgrids may not provide the best solution to cover the load with stable output. For instance, the power output of solar panels and wind turbines may drop down a large amount in a short time, requiring other sources (*e.g.*, batteries) to cover the drop to sustain power delivery. To solve this issue several solutions regarding a flexible and optimal collaboration approach among microgrids have been proposed. In this context, the authors in (Arefifar et al., 2012) advocate a clustering approach of the distribution system into a set of virtual microgrids with optimized self-adequacy. Reference (Saleh et al., 2015) emphasizes the advantages of multiple microgrids clustering in improving their stability, supply availability and resilience during blackouts.

Whereas these papers mainly focus on a central coordinator of different interactions related to energy trading among interconnected microgrids (*i.e.*, market agents), or between the main grid and microgrids, this work attempts to provide a decentralized solution with minimum information exchange based on a collaborative framework that fully maintains the autonomy of microgrids grouped in an alliance. For this purpose, a lot of coordination, and a flexible and optimal communication among distributed microgrids partners are required to be reach by the alliance cloud infrastructure.

Therefore, the proposed generic collaborative framework refers to define and coordinate the negotiation interactions at communication middleware level, allowing to be integrated in any Multi-agent system (MAS) or directly as a support in a human interaction negotiation system.

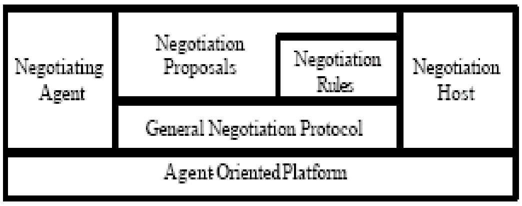
The architecture of a framework is structured on several layers (see Fig.1). The Agent Oriented Platform (AOP) bottom layer offers basic services such as: communication between agents or negotiation lifecycle management. Above the PDO layer are:

(i) General Negotiation Protocol (GNP);
(ii) taxonomy of negotiating rules;
(iii) language for defining negotiating rules;
(iv) language for expressing negotiating offers.

[4] Camarinha-Matos L.M. and Afsarmanesh H.,(2004), *Collaborative Networked Organizations,* Kluwer Academic Publisher Boston.

[5] Cretan, A., Coutinho, C., Bratu, B., and Jardim-Goncalves, R., NEGOSEIO: A Framework for Negotiations toward Sustainable Enterprise Interoperability. Annual Reviews in Control, 36(2): 291–299, Elsevier, ISSN 1367-5788, 2012, http://dx.doi.org/10.1016/j.arcontrol.2012.09.010.

Fig. 1. The architecture of a negotiation framework



The general negotiation protocol is composed of coordination rules that indicate when an agent can send a message and what message it can send.

In this type of negotiation process, agents can have two roles which, according to our approach, are the following: participating agent (negotiating agent) and mediating agent (negotiation host). To negotiate, participants send their offers to a common space (local negotiation), which is controlled by a mediator. This negotiation space is a blackboard on which each agent - participant or mediator - can write. However, only the mediator has full visibility into the information. Its role is to create and enforce the rules of coordination that may impose constraints on the execution of the negotiation protocol, on the validation of offers, on the completion of the negotiation and, of course, on the communication between the participants. So, the negotiation process is modeled as a centralized market in which the mediating agent has the role of coordinating all ongoing negotiations. Depending on the types of rules, the role of the mediating agent is broken down into several sub-roles attached to a taxonomy of declarative rules that can be used to capture a wide variety of negotiation mechanisms. These sub-roles and the types of rules attached are as follows:

- Gatekeeper: establishes the rules for the admission of participants in the negotiation;
- Proposal validator: manages the validity rules that stipulate that each offer must be in accordance with a negotiation format and sets the constraints on the attributes of the negotiated objects and their values;
- Enforcer protocol: establishes several types of rules for fulfilling the negotiation protocol: signaling rules - specifies when a participant can send an offer; improvement rules - specifies which new offers can be sent; withdrawal rules - specifies when the offers can be withdrawn and what is the policy on the expiration period of the offers;
- Agreement maker: establishes several types of rules, especially for updating the status of participants and the information to which each participant has access. These rules are: update rules - specify how the negotiation parameters change under the influence of certain events; visibility rules - specify which participants can access a certain offer; display rules - specifies whether certain information (a new offer or a new agreement) is visible to a participant and how this information will be shared between participants;
- Information updater: establishes the rules for accepting an agreement; this set of rules determines which agreements should be concluded given a set of offers of which at least two are compatible;
- Negotiation terminator: sets the rules for the life cycle of the negotiation process, indicating when the negotiation should stop.

The mediating agent, with his role and sub-roles, behaves like a system of cooperative agents that communicates with the help of a blackboard. From the participants' point of view, these agents are seen as a single mediating agent coordinating the negotiation. This centralization of the coordination process leads to the non-existence of a distribution of control over the interactions between the participating agents and the mediating agent. Each agent participating in a negotiation sends offers to the mediating agent and it is the one who, using the set of coordination rules as filters, decides if the offer is valid and who can access this offer. Thus, in the proposed system, the coordination process not only manages the dependencies between the initial and final state of negotiation, but also the dependencies between the intermediate states of negotiation. In other words, the mediating agent is able to check the constraints for each offer sent. These constraints aim to synchronize communication in negotiations. Although all the submitted offers are available at the level of the mediating agent, he cannot fix the dependencies on the values of these offers without having any information about the purpose and strategies of the different participating agents. In conclusion, the system allows modeling and coordination of n-type negotiations to n participants as a lot of one-to-one type negotiations, but always having the mediating agent as one of the participants. This approach has advantages in terms of optimizing the coordination of interactions but limits the autonomy and power of the participating agents through the various rules imposed and managed by the mediating agent.

2.2. Interaction Oriented Programming

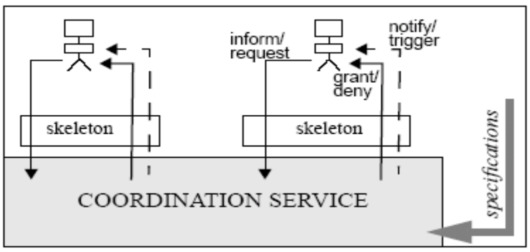
In order to implement a multi-agent system, with autonomous agents that can interact with each other, not only the application-specific aspects must be coordinated, but also the aspects related to the agents' behavior and the possible interactions between them. The IOP (Interaction Oriented Programming) approach achieves this type of coordination based on the communication protocol or on the organizational characteristics of the system. These means are rigid and can sometimes limit the autonomy of the agent. In order for the agents to maintain their autonomy, Singh proposed separating the coordination of a multi-agent system into a separate service[6]. Singh's approach to coordinating agent autonomy is structured on two levels. First, at the programming level, where agents may be implemented differently and their internal details may be unavailable. And, secondly, at the level of the agent's behavior, where the agents act autonomously and can perform certain specific actions.

Coordination refers to the actions that the agent performs externally and which are considered as potentially significant for the coordination service. These actions are called events and can be of four types:

- flexible: events that show that the agent is willing to delay the action or withdraw it;
- inevitable: events that show that the agent is only willing to delay the action;
- immediate: events that show that the agent does not want to delay or withdraw the action;
- triggerable: events that show that the agent can execute the action but only at the request of the system.

An agent's events are then organized into a framework (skeleton) to provide a simple model of agent-level coordination. Each event was associated with a "guard" that expresses the conditions in the system for which the exemption must be executed. The expressed conditions fix the constraints on the eventual execution of the event and of other events on which it depends in order to be executed. Figure 2 shows how the coordination service interacts with the agencies. Agents inform the coordination service about immediate events and request permission for unavoidable and flexible events. The coordination service grants or does not grant permissions on flexible events, delays unavoidable events or triggers triggerable events depending on the "guards" associated with them.

Fig. 2. I.O.P. - Interaction between the coordination service and agents



For effective coordination between events performed by multiple agents, the approach proposed by Singh requires that the following characteristics be met:

g) the dependencies between actions (events) are known from the beginning of the system implementation;

h) the agents communicate with each other, exchanging relevant information on the execution of their actions.

So, the approach proposes a generic coordination service that is implemented in a distributed way between the component agents of the system, as well as the execution of a single workflow that describes the actions necessary to fulfill a single task. Each agent can be seen as an entity that encompasses part of the coordination service and makes decisions about the execution of events based on local information.

In conclusion, we chose to present this system in the end because Singh demonstrates a clear separation between agent-modeled decision-making processes and coordination processes modeled by an outside service. This feature is similar to one of our goals. In Singh's approach, the coordination service is interested in synchronizing interactions between agents without taking into account any information about the content of messages or the purpose of the conversation between agents. Assuming the particular case where conversations between agents refer to negotiation, the only dependencies that the service can manage are the dependencies between the execution of different actions (*i.e.*, sending offers) that make up a negotiation to ensure a coherent flow of conversation.

Depending on the different dimensions of the negotiation process, we can see that the type of strategic coordination is directly influenced by several factors such as: participants and their role, time, object of negotiation and negotiation protocol. Also, given that this type of coordination is implemented in the decision-making process, strategic coordination is therefore strongly influenced by the negotiation strategy. Strategic coordination fixes the dependencies between the initial and final states of negotiation, between the objects of negotiation or between the attributes that describe these objects. Regarding the generic coordination, it does not take into account, at the level of the negotiation process, only the events related to the management of the interactions between activities, actions or messages. Neither the objects of the negotiations nor the participants in the negotiations are taken into account. So, in general, generic coordination is not influenced by any of the dimensions of the negotiation process.

In the different coordination systems presented, we can observe that no coordination is proposed between the intermediate phases of negotiation in order

[6] Singh., M. P., *Interaction-Oriented Programming: Concepts, Theories, and Results on Commitment Protocols*, in AI 2006: Advances in Artificial Intelligence, LNAI 4304, pp. 5-6, 2006.

to dynamically correct the proposals made during the negotiations. This limitation may result from the fact that, in a generic coordination, the necessary data are unavailable. In the case of a strategic coordination, although the necessary data are available, the coordination through a decision process is not the optimal solution for the implementation of the management of the types of dependencies. In other words, strategic approaches that try to take into account dynamic data are hit by the fact that every change that occurs on the data, involves a restart of the decision process, because the decision process is based on history. Certain features of the presented systems meet our objectives, but our problem is much more complex due to the fact that we want to coordinate actions (negotiations) that are performed by competing agents to perform not only a certain task, but several different tasks. An additional aspect is given by the fact that the dependencies to be managed refer to the values of the attributes of the proposals changed during the negotiations. Thus, in addition to coordinating the initial and final states of the negotiations, we will also coordinate the intermediate states, verifying and modifying the content of the messages exchanged during the negotiations.

3. Collaborative Platform

Our approach in terms of coordination of negotiations is structured on two models:

- strategic coordination managed at the agent level;
- generic coordination managed at the middleware level.

This approach (multi-agent and middleware) allows the development of a multi-agent system based on a distributed and competing architecture. Aspects related to the synchronization of the negotiation process are left to the middleware.

In the context of this approach, we break down the negotiation process into three distinct processes:

i) coordination process;
ii) decision process;
iii) communication process.

This structuring of the negotiation process is justified by its complexity, involving multiple dimensions and different mechanisms.

The implementation of a negotiation presupposes the existence of a well-structured coordination mechanism or process. In this sense, we call the *coordination process*, the process that has a global vision on the negotiation, to manage the parallelism and dependence between the actions executed in a complex negotiation. Thus, we will approach the negotiation as a process that preserves the autonomy of the participants - each of them manages their own negotiations and their own information (description of tasks, contracts, partners, etc.). In addition, two important aspects of the negotiation process need to be highlighted:

i) for a single task, one participant is involved in several bilateral negotiations - one for each participant interested in contracting the task;

ii) at the same time, the same participant is engaged in other bilateral negotiations on other different tasks. So, the coordination process is the process that manages, for each participant, three important aspects:

1) coordinating the different proposals received in a bilateral negotiation (one to one) for modeling a multi-phase negotiation on a multi-attribute negotiation object;

2) coordinating several bilateral negotiations to model a multi-participant negotiation;

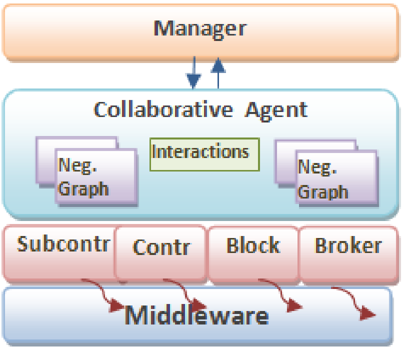
3) coordination of several negotiations in which the participant is engaged.

The aim of this paper is to propose basic mechanisms for coordinating negotiations. These represent mechanisms for interfacing between the generic communication process and the decision process in order to implement negotiation schemes that manage the simultaneous evolution of several negotiations. These coordination mechanisms must maintain the coherence of the agent's decisions in terms of actions that can be executed (initiating or finalizing a negotiation) and proposals that can be sent. This coherence must also be guaranteed both locally (for a single negotiation) and globally (for all negotiations in which a participant is involved).

The main objective of this software infrastructure is to support collaborating activities in virtual enterprises. In VE partners are autonomous companies with the same object of activity, geographically distributed.

Taking into consideration, the constraints imposed by the autonomy of participants within VE, the only way to share information and resources is the negotiation process.

Figure 3 shows the architecture of the collaborative system:



This infrastructure is structured in four main layers: Manager, Collaborative Agent, Coordination Components and Middleware. A first layer is dedicated to the Manager of each organization of the alliance. A second layer is dedicated to the Collaborative Agent who assists its microgrid manager at a global level (negotiations with different participants on different jobs) and at a specific level (negotiation on the same job with different participants) by coordinating itself with the Collaborative Agents of the other partners through the fourth layer, Middleware[7]. The third layer, Coordination Components, manages the coordination constraints among different negotiations which take place simultaneously.

The initialization step allows to define what has to be negotiated (Negotiation Object) and how (Negotiation Framework)[8]. A selection of negotiation participants can be made using history on passed negotiation, available locally or provided by the negotiation infrastructure (Zhang and Lesser, 2002). A Collaborative Agent aims at managing the negotiations in which its own microgrid is involved (e.g., as initiator or participant) with different partners of the alliance.

Each negotiation is organized in three main steps: initialization; refinement of the job under negotiation and closing[9].

In the refinement step, participants exchange proposals on the negotiation object trying to satisfy their constraints (Barbuceanu and Wai-Kau, 2003). The manager may participate in the definition and evolution of negotiation frameworks and objects (Keeny and Raiffa, 1976). Decisions are taken by the manager, assisted by his Collaborative Agent (Bui and Kowalczyk, 2003). For each negotiation, a Collaborative Agent manages one or more negotiation objects, one framework and the negotiation status. A manager can specify some global parameters: duration; maximum number of messages to be exchanged; maximum number of candidates to be considered in the negotiation and involved in the contract; tactics; protocols for the Collaborative Agent interactions with the manager and with the other Collaborative Agents (Faratin, 2000).

4. Coordination Components

In order to handle the complex types of negotiation scenarios, we propose the negotiation components[10]: *Subcontracting* (resp. *Contracting*) for subcontracting jobs by exchanging proposals among participants known from the beginning.

These components are able to evaluate the received proposals and, further, if these are valid, the components will be able to reply with new proposals constructed based on their particular coordination constraints[11].

The novelty degree of this software architecture resides in the fact that it is structured on four levels, each level approaching a particular aspect of the negotiation process. Thus, as opposed to classical architectures which achieve only a limited coordination of proposal exchanges which take place during the same negotiation, the proposed architecture allows approaching complex cases of negotiation coordination. This aspect has been accomplished through the introduction of coordination components level, which allows administrating all simultaneous negotiations in which an alliance partner can be involved.

The coordination components have two main functions such as: i) they mediate the transition between the negotiation image at the Collaboration Agent level and the image at the Middleware level; ii) they allow implementing various types of appropriate behavior in particular cases of negotiation. Thus, we can say that each component corresponding to a particular negotiation type.

Following the descriptions of this infrastructure we can state that we developed a framework to describe a negotiation among the participants to a virtual enterprise. To achieve a generic coordination framework, nonselective and flexible, we found

[7] Bamford J.D., Gomes-Casseres B., and Robinson M.S., *Mastering Alliance Strategy: A Comprehensive Guide to Design*, Management and Organization, San Francisco: Jossey-Bass, 2003.
[8] Smith R., and Davis R., *Framework for cooperation in distributed problem solving*, IEEE Transactions on Systems, Man and Cybernetics, SMC-11, 1981.
[9] Sycara K., *Problem restructuring in negotiation*, in Management Science, 37(10), 1991.
[10] Cretan A., Coutinho C., Bratu B. and Jardim-Goncalves R., *A Framework for Sustainable Interoperability of Negotiation Processes*. In INCOM'12 14th IFAC Symposium on Information Control Problems in Manufacturing, 2011.
[11] Vercouter, L., *A distributed approach to design open multi-agent system*. In 2nd Int. Workshop Engineering Societies in the Agents' World (ESAW), 2000.

necessary to first develop the structure of the negotiation process that helps us to describe the negotiation in order to establish the general environment where the participants may negotiate. In the next sub-sections we will describe the *Subcontracting* and *Contracting* components.

4.1. Subcontracting Component

The *Subcontracting* component is the main component of a negotiation. The automatic negotiation process is initiated by creating an instance of this component starting from the initial negotiation object. Further, this component must build the negotiation graph by following the negotiation requirements (*i.e.*, assessment and creation of proposals and coordination rules). The component meets these requirements by manipulating the Xplore primitives [14].

Besides these functionalities, the *Subcontracting* component has to interpret and check the negotiation constraints, which are set up in the following two data structures: *Negotiation Object* and *Negotiation Framework.*

The information provided by the structure of the Negotiation Object on the possible values of the attributes to be negotiated allow easily the *Subcontracting* component to check whether the proposals received concern the attributes negotiated in the current negotiation and if they are associated to the values of the intervals specified.

For example, assuming that the Negotiation Object requires that the price should be (*cost <= 10k)*, the *Subcontracting* component can stop the continuation of the negotiation in the phases associated to the white nodes where the proposals are outside the interval.

Also, by using the *partner* coordination attribute, the *Subcontracting* component can make known to the other components the participants imposed by the Negotiation Object or whether other components instantiate this attribute. In this regard, the *Subcontracting* component can easily check if the associated value confirms the constraints imposed by the Manager.

At middleware level, the *Subcontracting* component has also the function of administrating the transactional aspect of the negotiation. This component is seen like a *coordinator* and has the role to conclude an agreement among the component instances participating in the same negotiation.

Another *Subcontracting* component functionality is to interpret and execute the tactics specified in the Negotiation Framework structure by connecting a combination of different instances of the other components.

Thus, the *Subcontracting* component as well as the *Contracting* component described below are those connecting the aspects specified at the Negotiation Agent level and their implementation at the coordination components level.

4.2. Contracting Component

The *Contracting* component manages the negotiation from the organization side deciding to accept a task proposed in the collaborative networked environment, with some functionalities similar to those of the *Subcontracting* component.

The differences come from the fact that this component does not have a complete picture on the negotiation and that, at the beginning of the negotiation, it has no information about what is negotiated or about the constraints of its Manager.

Therefore, looking to the differences, we can say at first that the image of the *Contracting* component on the negotiation graph is limited to the data referring only to its direct negotiation with the *Subcontracting* component or with another component negotiating for the organization having initiated the negotiation.

Secondly, unlike the *Subcontracting* component, which, from the beginning, has constraints specified by the Manager within the data structures of the *Negotiation Object* and the *Negotiation Framework*, the *Contracting* component has a close interaction with its own Manager on the new aspects required in the negotiation.

Thus, depending on attributes required by the negotiation initiator the *Contracting* component can progressively build the data structures describing the Manager's preferences on the negotiation object and on the negotiation process.

5. Collaborative Approach

In the proposed scenario, a conflict occurs in a network of enterprises, threatening to jeopardize the interoperability of the entire system. The first step consists in identifying the Enterprise Interoperability issue. The following steps refer to analyse the problem, evaluate possible solutions and select the optimal solution. The proposed solution for conflict resolution is reaching a mutual agreement through negotiation. The benefit of this approach is the possibility to reach a much more stable solution, unanimously accepted, in a shorter period of time.

The design and coordination of the negotiation process must take into consideration:

- Timing (the time for the negotiation process will be pre-set);
- The set of participants to the negotiation process (which can be involved simultaneous in one or more bilateral negotiations);
- The set of simultaneous negotiations on the

same negotiation object, which must follow a set of coordination policies/ rules;

- The set of coordination policies established by a certain participant and focused on a series of bilateral negotiations[12];
- Strategy/decision algorithm responsible for proposals creation;
- The common ontology, consisting of a set of definitions of the attributes used in negotiation.

The negotiation process begins when one of the enterprises initiate a negotiation proposal towards another enterprise, on a chosen negotiation object. We name this enterprise the Initiating Enterprise (E1). This enterprise also selects the negotiation partners and sets the negotiation conditions (for example sets the timing for the negotiation) (Schumacher, 2001). The negotiation partners are represented by all enterprises on which the proposed change has an impact. We assume this information is available to E1 (if not, the first step would consist in a simple negotiation in which all enterprises are invited to participate at the negotiation of the identified solution. The enterprises which are impacted will accept the negotiation) (Kraus, 2001).

After the selection of invited enterprises (E2 … En), E1 starts bilateral negotiations with each guest enterprise by sending of a first proposal. For all these bilateral negotiations, E1 sets a series of coordination policies/rules (setting the conditions for the mechanism of creation and acceptance of proposals) and a negotiation object/framework (NO/NF), setting the limits of solutions acceptable for E1. Similarly, invited enterprises set their own series of coordination policies and a negotiation object/framework for the ongoing negotiation.

After the first offer sent by E1, each invited enterprise has the possibility to accept, reject or send a counter offer. On each offer sent, participating enterprises, from E1 to E2 ... En follow the same algorithm.

The algorithm is shown below: Pseudocode representation of the negotiation process

Inputs: Enterprises *E1...En; NO(Negotiation Object); NF(Negotiation Framework)*

Outputs: The possible state of a negotiation: *success, failure*

```
BEGIN
on receive start from E1{
        send initial offer to partner;
}
on receive offer from partner{
        evaluate offer;
        if(conditions set by the NO/NF are not met){
                offer is rejected;
                if(time allows it){
                        send new offer to partner;
                }else{
                        failure;
                }end if;
        }else{
                send offer to another partner;
        }end if;
        if(receive an accepted offer){
                if(offer is accepted in all bilateral negotiations){
                        success;
                }else{
                        if(time allows it){
                                send new offer to partner;
                        }else{
                                failure;
                        }end if;
                }end if;
        if(receive a rejected offer){
                if(offer is active in other bilateral negotiations){
                        failure in all negotiations;
                }end if;
        }end if;
}
    END
```

[12] Ossowski S., *Coordination in Artificial Agent Societies.* Social Structure and its Implications for Autonomus Problem-Solving Agents, no. 1202, LNAI, Springer Verlag, 1999.

6. Conclusions

This paper proposes a collaborative system for sustainable interoperability by modeling and managing of parallel and concurrent negotiations, which aims to open the market to broader discovery of opportunities and partnerships, to allow formalization and negotiation knowledge to be passed to future negotiations and to properly document negotiation decisions and responsibilities.

We have addressed the issue of collaborative interactions among distributed autonomous microgrids grouped in a virtual enterprise to improve their power supply availability with minimal work and, thus, to better satisfy the customer power needs during the peak demand periods.

The proposed architectural design of the negotiation system of each microgrid is in line with our distributed approach of splitting the negotiation process into three separated processes (i.e., decision-making process, coordination process and communication process). Therefore, communication process is ensured by the middleware layer, which provides generic synchronization mechanisms of communication among several agents based on Xplore protocol.

The coordination process is fully distributed on several coordination modules corresponding to specialized negotiation components, which can be used in real case negotiations.

The decision-making process is ensured by the Negotiation Agent that supports human user in dealing with all the aspects related to the negotiation strategy in terms of evaluating and generating offers, and the protocol for sending offers to the other agents. This feature allows the separation of decision-making process from agents that reinforces the generic applicability of our negotiation framework.

The sequence of this research will comprise the completion of this negotiation framework with the contract management process and a possible renegotiation mechanism.

With respect to the framework middleware, future research shall include handling issues regarding the security and resilience of the stored negotiation data in the cloud and managing privacy aspects as the negotiating parties should be able to seamlessly interoperate but still to maintain their data free from prying eyes; also, several issues need to be solved from non-disclosure of participating parties to secure access to the negotiation process.

References

- M.-S. Li, R. Cabral, G. Doumeingts, and K. Popplewell, *Enterprise Interoperability Research Roadmap*, no. July. European Commision - CORDIS, p. 45, 2006;
- R. Jardim-Goncalves, A. Grilo, C. Agostinho, F. Lampathaki, and Y. Charalabidis, *Systematisation of Interoperability Body of Knowledge: the foundation for Enterprise Interoperability as a science*, Enterprise Information Systems, vol. 6, no. 3, pp. 1-26, 2012;
- W. Wang, Y. Xu, and M. Khanna, *A survey on the communication architectures in smart grid*, Computer Networks, vol. 55, Issue 15, 27 October 2011, pp. 3604-3629;
- R.H. Lasseter, *Smart Distribution: Coupled Microgrids*, Proceedings of the IEEE, 99(6), 1074-1082, 2011;
- F. Katiraei, R. Iravani, N. Hatziargyriou, and A. Dimeas, *Microgrids management*, IEEE Power and Energy Magazine, 6(3): 54-65, 2008;
- Camarinha-Matos L.M. and Afsarmanesh H., *Collaborative Networked Organizations,* 2004 Kluwer Academic Publisher Boston;
- Singh M.P., *Commitments among autonomous agents in information-rich environments*. In Proceedings of the 8th European Workshop on Modelling Autonomous Agents in a Multi-Agent World (MAAMAW), pp. 141–155, May 1997;
- Cretan, A., Coutinho, C., Bratu, B., and Jardim-Goncalves, R., *NEGOSEIO: A Framework for Negotiations toward Sustainable Enterprise Interoperability*. Annual Reviews in Control, 36(2): 291–299, Elsevier, ISSN 1367-5788, 2012. http://dx.doi.org/10.1016/j.arcontrol.2012.09.010;
- J. Carrasco, L. Franquelo, J. Bialasiewicz, E. Galvan, R. Guisado, M. Prats, J. Leon, and N. Moreno-Alfonso, *Power electronic systems for the grid integration of renewable energy sources: A survey*, IEEE Trans. Power Electron., vol. 53, no. 4, pp. 1002-1016, Aug. 2006;
- M. Shahabi, M. R. Haghifam, M. Mohamadian, and S. A. Nabavi-Niaki, *Microgrid dynamic performance improvement using a doubly fed induction wind generator*, IEEE Trans. Energy Convers, vol. 24, no. 1, pp. 137-145, Mar. 2009;
- H. Kanchev, L. Di, F. Colas, V. Lazarov, and B. Francois, *Energy management and operational planning of a microgrid with a PV-based active generator for smart grid applications*, IEEE Trans. Ind. Electron., vol. 58, no. 10, pp. 4583-4592, Oct. 2011;
- S. A. Arefifar, Y.A-R.I. Mohamed, and T.H.M. EL-Fouly, *Supply-adequacy-based optimal construction of microgrids in smart distribution systems*, IEEE Transactions on Smart Grid, vol. 3, no. 3, pp.1491-1502, Sept. 2012;

- M. S. Saleh, A. Althaibani, Y. Esa, Y. Mhandi, and A. A. Mohamed, *Impact of clustering microgrids on their stability and resilience during blackouts*, 2015 International Conference on Smart Grid and Clean Energy Technologies (ICSGCE), Offenburg, 2015, pp. 195-200;
- Bartolini, C., Preist, C., and Jennings, N., *A generic software framework for automated negotiation*, Technical Report HPL-2002-2, HP Laboratories Bristol;
- Singh., M.P., *Interaction-Oriented Programming: Concepts, Theories, and Results on Commitment Protocols*, in AI 2006: Advances in Artificial Intelligence, LNAI 4304, pp. 5-6, 2006;
- Bamford J.D., Gomes-Casseres B., and Robinson M.S., *Mastering Alliance Strategy: A Comprehensive Guide to Design, Management and Organization*. San Francisco: Jossey-Bass, 2003;
- Sycara K., *Problem restructuring in negotiation*, in Management Science, 37(10), 1991;
- Smith R., and Davis R., *Framework for cooperation in distributed problem solving*. IEEE Transactions on Systems, Man and Cybernetics, SMC-11, 1981;
- Zhang X. and Lesser V., *Multi-linked negotiation in multi-agent systems*. In Proc. of AAMAS 2002 July, Bologna, pg. 1207 – 1214;
- Barbuceanu M. and Wai-Kau Lo, *Multi-attribute Utility Theoretic Negotiation for Electronic Commerce*. In AMEC III, LNAI 2003, pg. 15-30;
- Keeny R. and Raiffa H., *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. JohnWilley & Sons, 1976;
- Bui V. and Kowalczyk R., *On constraint-based reasoning in e-negotiation agents*. In AMEC III, LNAI 2003, pp. 31-46;
- Faratin P., *Automated component negotiation between autonomous computational agent*. Ph.D. Thesis, Department of Electronic Engineering Queen Mary & West-field College, 2000;
- Cretan A., Coutinho C., Bratu B. and Jardim-Goncalves R., *A Framework for Sustainable Interoperability of Negotiation Processes.* In INCOM'12 14th IFAC Symposium on Information Control Problems in Manufacturing, 2011;
- Vercouter, L., *A distributed approach to design open multi-agent system*. In 2nd Int. Workshop Engineering Societies in the Agents' World (ESAW), 2000;
- Muller H., *Negotiation principles.* Foundations of Distributed Artificial Intelligence, 1996;
- Hurwitz, S.M., *Interoperable Infrastructures for Distributed Electronic Commerce.* 1998, http://www.atp.nist.gov/atp/98wpecc.htm;
- Ossowski S., *Coordination in Artificial Agent Societies*. Social Structure and its Implications for Autonomus Problem-Solving Agents, No. 1202, LNAI, Springer Verlag, 1999;
- Schumacher M., *Objective coordination in multi-agent system engineering – design and implementation.* In Lecture Note in Artificial Intelligence, No. 2093, Springer Verlag, 2001;
- Kraus S., *Strategic negotiation in multi-agent environments.* MIT Press, 2001.