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DYNAMIC VIRTUAL ORGANIZATION MANAGEMENT FRAMEWORK SUPPORTING DISTRIBUTED INDUSTRIAL COLLABORATIONS

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Abstract

Virtual Organizations seem as a natural paradigm for the globalized and dynamic nature of modern business environments. In a truly globalized world, organizations should be able to participate with other organizations that can provide the needed capabilities at optimal cost and quality. However, in order to foster the adoption of this concept, several missing gaps within the IT technology have to be addressed first. In this paper we present a framework supporting creation and management of dynamic virtual organizations in distributed IT environments. The framework, called FiVO (Framework for Intelligent Virtual Organizations) addresses all major issues related to VO lifecycle including partner discovery, contract negotiation, VO deployment and contract enforcement. In this paper we focus on presentation of integrated functionality of the system and analysis of feasibility of our solution for industrial applications.

Key words: Virtual Organization, Virtual Enterprise, Knowledge management, Industrial process management

1. INTRODUCTION

Over the past decade the shift in organizational practices from physical to virtual has been very rapid. Accounting, human resources, security, document management, information and knowledge handling, customer relationships, business processes and B2B integration – all these aspects of organizational processes have been to most extent virtualized through various emerging technologies including CRM (Customer Relationship Management) and ERP (Enterprise Resource Planning) solutions, SOA (Service Oriented Architecture) based architectures and various standards for information representation. The natural consequence of this process, is that organizations could now become much more competitive and ambidextrous, by the process of virtualizing the entire organization concept. However, very few solutions exist so far, which aim at supporting a generic process of Virtual Organization creation and management. In the literature the concept of Virtual Organization has been present for several years, and many of its aspects had been clearly identified. In a nutshell, a Virtual Organization should allow real organizations to share their resources (including tangible and intangible capital) in order to pursue some emerging and challenging market opportunity. So far very few attempts had been undertaken, to support this process from top down, i.e. by providing an environment in which the organizations can find partners, propose ideas for new ventures, discuss conditions of participation among potential partners and finally execute business processes within Virtual Organization. For instance dealing with the issues of supply chain management and

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high performance computing simulations for industrial manufacturing processes combined into a single business process. Furthermore, existing frameworks do not support dynamic inception of the VO, which requires that most of the processes related to VO creation are automated thus minimizing the time of setting up the VO. Most existing frameworks are rather cumbersome and require substantial time for configuration and preparation phase. In this paper, we present our approach to this problem, through the FiVO framework (Framework for Intelligent Virtual Organizations) (Kryza et al., 2009; Skalkowski et al., 2010b), which employs state of the art technologies in order to provide unified solution for creation and management of Virtual Organizations (see figure 1).

contracts between companies into rules processable by the computer systems and lack of interoperable security infrastructure allowing services from other organizations accessing resources within the organization according to precisely defined rules. We believe that our solution can address this issue and allow several organizations to create and execute business processes spanning several organizations simultaneously.

For instance let's imagine a large European company developing high-end multimedia devices with R&D department located in Europe and several manufacturing plants located in Asia. Quality control in these plants can vary and different parameters such as air quality or temperature on the production

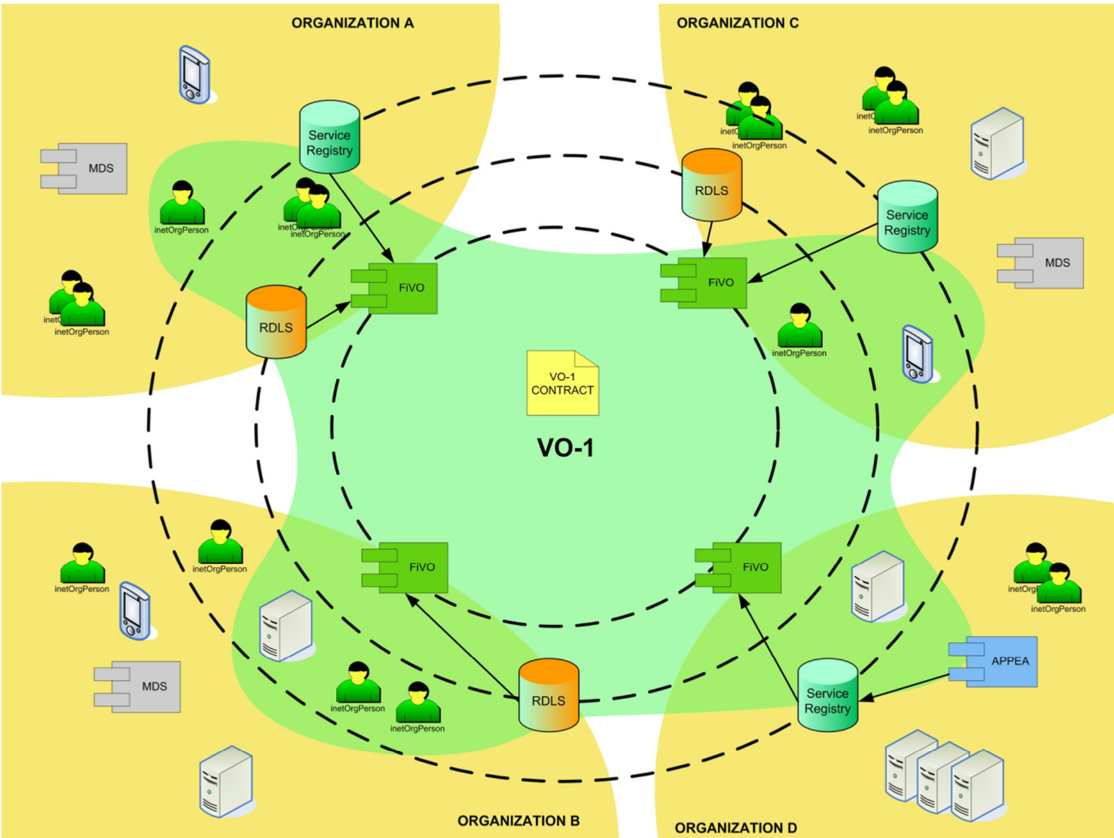

Fig. 1. Overall vision of the FiVO framework.

The main motivation for this work in the scope of industrial scenarios is bringing together of the Internet connected business services of enterprises with the shop-level production and supply lines. Nowadays, most aspects of the industrial processes are computerized, from low-level sensors in production lines, through bar code readers in the magazines to ERP systems and web based online stores. However, currently the integration of these systems rarely goes beyond the organizational boundaries. This is related to several factors including lack of universal integration tools, problems with translating paper

line can result in different defects in the products shipped to customers, who would file complaints first to their local stores and then to the producer. Then the producer would have to investigate how defect occurred. The VO approach would enable integration of these organizations directly from a signed contract which would specify what kind of data and services each of the parties will share with the others, what kind of obligations and penalties are expected, etc. This would allow for instance automation of identifying problems directly on the processing line by the R&D department of the producer.

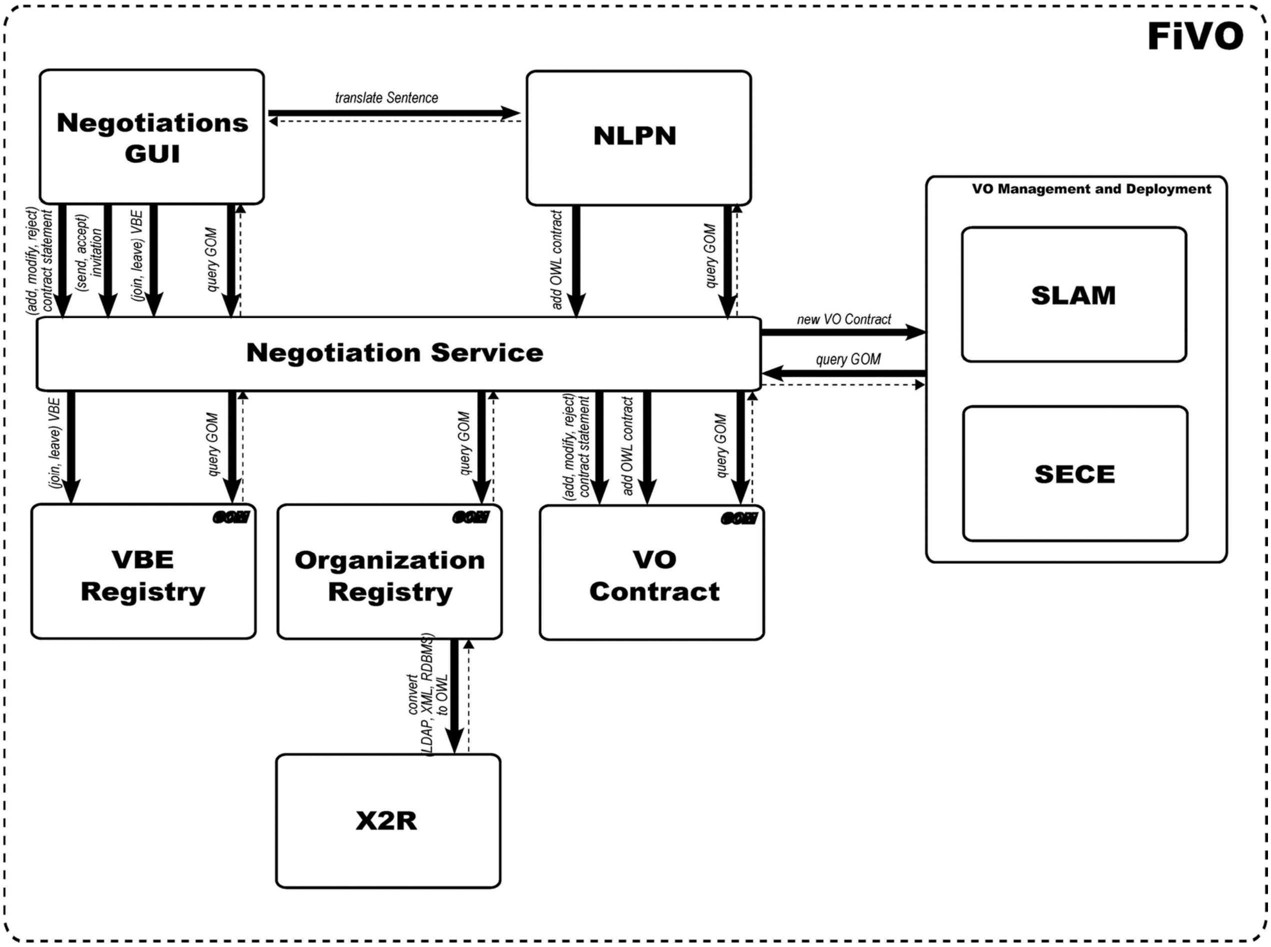

Fig. 2. *FiVO overall architecture and interconnections.*

Examples of other potential areas of interest which we have studied include:

– Tele-medical consultancy system
– Crisis management and urgent computing applications
– Online tourism applications
– Distributed stroke rehabilitation infrastructure

In this paper we present results of research on supporting automatic Virtual Organization creation and management in the form of an IT framework composed of tools supporting various phases of Virtual Organization life cycle. All the functional components described in this paper have been developed by our team. The objective of the research is to provide modern knowledge based organizations with support for pursuing dynamically emerging business opportunities by leveraging the possibility of cooperating with other similar organizations. This challenge requires from the IT framework several features such as:

– Seamless integration with existing IT infrastructure
– Allowing organizations to publish and discover their interests, capabilities and capacities
– Provide organizations with means to quickly reach a formal agreement on the rules of cooperation
– Automatically deploy and enforce the rules agreed upon during the execution phase

In the consecutive sections we present how our framework addresses these challenges.

2. RELATED WORK

The concept of Virtual Organization has been present in the business and IT communities for several years now, however it's understanding between these communities has been somewhat different. While in the business communities, the Virtual Organization is usually understood as a distributed organization or collaboration of organization without centralized control (Werner & Witzel, 2004), then in the IT, and in Grid computing in particular, it is more oriented on scientific collaborations using advanced IT infrastructure (Cummings et al., 2008). In our approach we try to merge these approaches by reusing some of the Virtual Organization management technologies from IT communities to the business scenarios. Although no single definition of Virtual Organization exists, some general characteristics common to all of these definitions have been identified. These include Dematerialization, Delocalization, Asynchronization, Integrative atomization, Temporalization, Non Institutionalization and Individualization (Kurumluoglu et al., 2005). Katzy et al. (2005) have proposed a VO reference model which was extrapolated from over 100 research papers on the subject. They have introduced 3 types of VO topologies that are most common in practice: supply-chain, star and peer-to-peer, and claim that all of analyzed projects could be categorized to one of these models. In the area of industrial manufacturing, several areas of research related to Virtual Organizations have been addressed. For instance (Hints et al., 2011) presents an approach to Virtual Manufacturing allowing simulation of the entire production chain for the optimization purposes. A good overview of industrial research projects based on the concept of Virtual Organization and Virtual Enterprise are presented in Santoro and Bifulco (2005). Authors (Cui et al., 2010) present a Virtual Enterprise management system for industrial sector based on Grid computing infrastructure. The proposed solution is based on 3 main modules: project management, partner management and business process management. The authors raise some interesting issues such as partner evaluation criteria or business process management in virtual enterprise, however they do not present any actual solution but rather a theoretical framework. Hardwick et al. (1996) give one of the first general ideas for IT infrastructure requirements and possible architecture, including common metadata format and communication bus. Our solution addresses most of these aspects, however using much more advanced and modern IT technologies. In Su et al. (2005), authors present an example of Virtual Enterprise support framework for the semiconductor industry. The proposed framework integrates such processes as sales, production planning, design and customer relations, however the tools used make it specific for this type of industry.

Although several solutions and tools supporting Virtual Organizations (or Virtual Enterprises) exist, most of them deal either with some specific aspects of the VO management process or require substantial administrative work in order to support VO operation, thus not enabling dynamic, on demand VO creation and monitoring.

3. METHODOLOGY

Supporting Virtual Organization life cycle requires support for the following phases: inception, execution, evolution and dissolution. In case of FiVO all these phases are supported to some extent, as detailed below. First of all, using our framework organizations can create and participate in various Virtual Organization Breeding Environments (VBE) (Konstantas et al., 2006), i.e. groups of organizations that are willing and ready to participate in Virtual Organizations, where each organization can publish their competencies and capabilities in a distributed semantic knowledge base (which is also part of FiVO). The VBE registries, which can also be managed by FiVO, store these profiles of organizations in a semantic form and allow for manual or automatic partner discovery based on the requirements for the particular VO. This allows the organizations to discover potential partners for new enterprises and invite them to negotiations (Skalkowski et al., 2010b).

Next, representatives of invited organizations can proceed to the distributed negotiation process, which results in a formally defined semantic contract describing the rules of cooperation for the new VO. The process is supported by graphical user interface that allows the negotiators to visually create the statements about the resources, obligations and commitments of each partner, and accept and reject statements made by other partners. Eventually, when all statements are accepted by participants, the resulting contract can be signed and used to automatically configure the IT infrastructures of the participating organizations in order to allow for execution of the new VO. The automatic deployment phase is supported by a set of FiVO components that are responsible for configuring monitoring and security layers of the organizations, so that they can ensure that the contract between partners is respected during the VO execution. Additionally FiVO components can automatically run predefined services in the organizations, if required by the contract. All these functionalities aim at minimizing the administrative effort required for the VO deployment and thus increase the dynamics of the VO, which allows the organizations to come together within a VO and thus react to a new business opportunity in several hours instead of several days. During the operation of the VO, the monitoring components constantly validate the statements from the contract and react on and report on any irregularities, such as quality of service violations. This ensures that the partners can focus on the actual functionality of the Virtual Organization and the pursued market opportunity and do not have to constantly control each other.

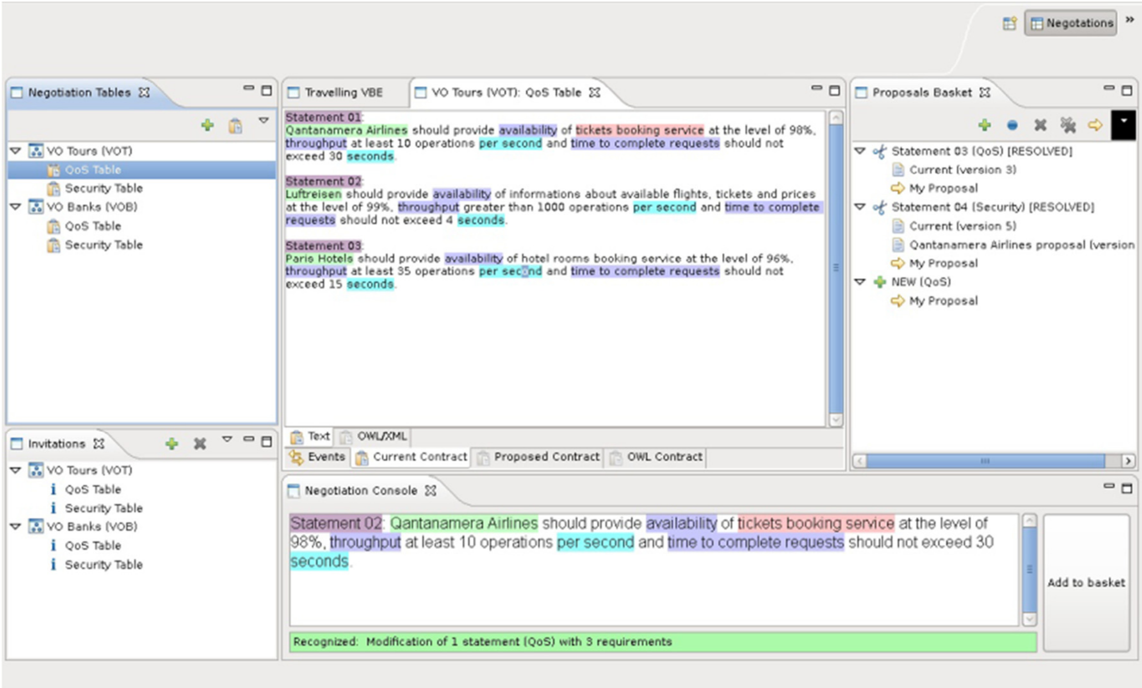

__Fig. 3.__ FiVO negotiations graphical user interface.

Finally, as all information about the operations within the VO is tracked within the knowledge base of the VO, during the dissolution of the VO the provenance information can be tracked, and the contract can specify how the results of the VO operation are split among the partners.

4. TECHNOLOGY DESCRIPTION

The FiVO framework is based on the Service Oriented Architecture technology, in order to ensure its interoperability with most modern business integration solutions as well as internal business solutions in various companies. The backbone of the system is a distributed communication layer, called DCNS (Stelmach et al., 2011), based on the Enterprise Service Bus (ESB) (Chappel, 2004) technology, which provides communication and synchronization between all the system components (see figure 2).

4.1. Negotiations

The negotiation process is supported by an Eclipse (Holzner, 2004) based user interface (see figure 3) and a set of components responsible for distributing and synchronizing the negotiation messages between the partners of the negotiation process. The negotiation process is additionally supported by a natural language processing library (NLPN – currently supporting Polish and English) (Pastuszko et al., 2010), where individual comments or statements can be made using textual form automatically converted to OWL (Web Ontology Language) (Bechhofer et al., 2004) statements using base ontology, obtained from the generic as well as domain specific ontologies of the particular organizations. The negotiation process cannot be described in detail here, but briefly the contract negotiation is based on creation of proper OWL individuals representing particular statements of the contract (Zuzek et al., 2008). Negotiation can take place only within the negotiation tables. Each negotiation table is created as an individual of class NegotiationTable and statements can be created only within a selected negotiation table. Each negotiation table has a list of partners who participate in it at a given time. In particular, the entire negotiations can be performed within one negotiation table. The negotiation states are used to track the state of each entity (statement, negotiation table and the contract as a whole). The available states include Ongoing, Paused, Accepted and Rejected. The conditions for switching the negotiation table state are the following:

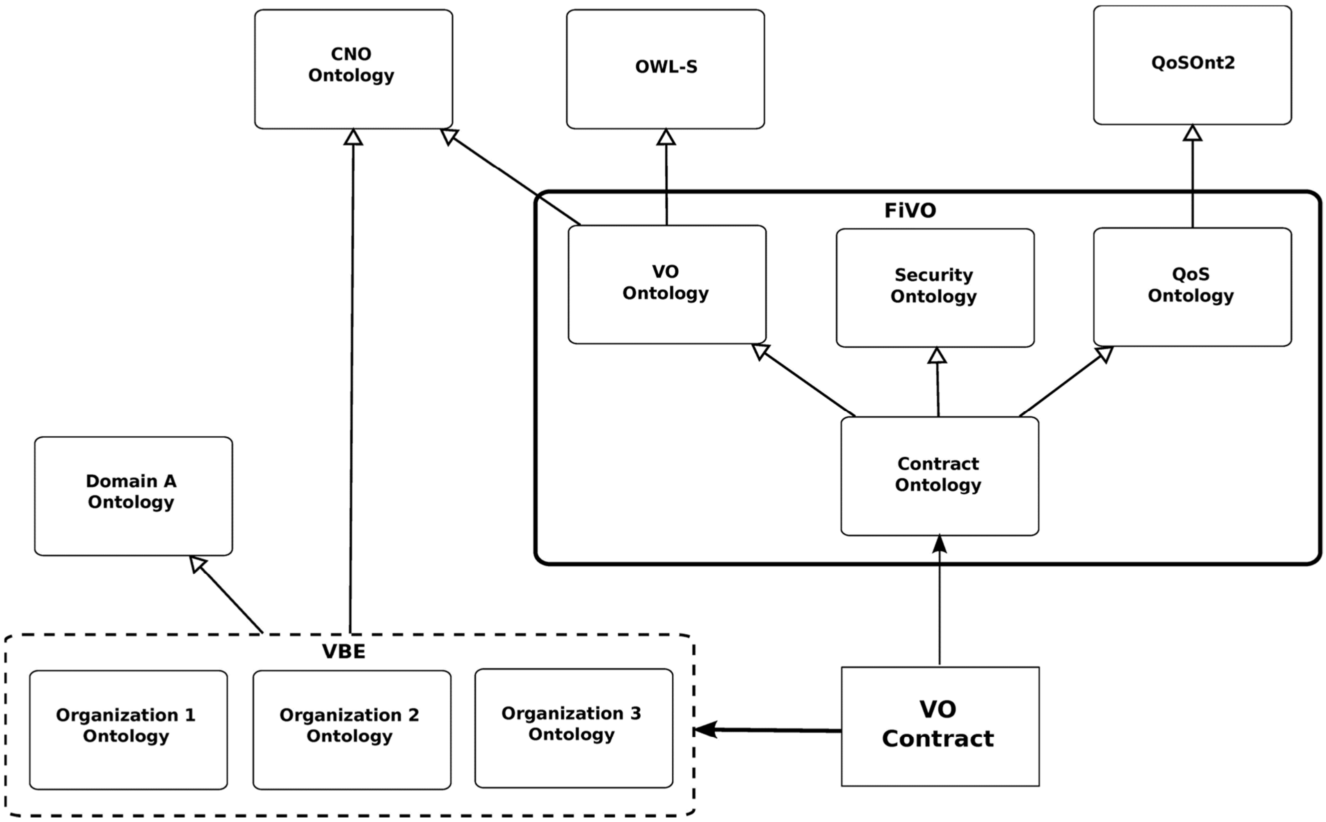

Fig. 4. *Structure of ontologies and their dependencies.*

- When the negotiation table is created the state is set to *Ongoing*
- When all partners participating in the negotiation table have set the *acceptedBy* property the state of the negotiation table is set to *Accepted*
- When all partners participating in the negotiation table have set the *rejectedBy* property the state of the negotiation table is set to *Rejected*
- When any partner adds/modifies the statements in the negotiation table, the *(acceptedBy/ rejectedBy)* properties are cleared
- If the administrator of the negotiations puts the negotiations on hold and the status of the negotiation table is *Ongoing* it is changed to *Paused* (and no modifications can be made)

After the negotiations are complete (i.e. all negotiation tables are accepted or rejected), the partners can accept the contract as a whole and signed contract is distributed over ESB to all components involved in VO deployment – see figure 5.

4.2. Knowledge base and ontologies

All information is stored in a distributed semantic knowledge base (Grid Organizational Memory - GOM) (Kryza et al., 2007), which provides SOA compatible interface for management and evolution of knowledge in the Web Ontology Language (OWL) format. The knowledge base is distributed and the knowledge is organized into components related to particular aspect of VO scope, e.g. VBE Registry, Organization Registry or VO Contracts, comprising of several ontology components presented in figure 4. The contract itself is defined using the OWL ontology, which provides set of concepts and relations describing different types of statements supported by our solution. The monitoring component creates a new context for the new VO in order to discover anomalies from data collected from lower level monitoring systems within each organization. One major issue when introducing semantic layer in organizational processes is the need to translate the existing resource and capabilities definitions into semantic form. In order to make this process easier we have developed an X2R (Mylka et al., 2011) tool, which automates this process to a large extent, i.e. using a mapping (defined for instance within the VBE for the particular domain ontologies) it can extract information from relational databases, LDAP (Lightweight Directory Access Protocol) catalogues or XML files and store it in unified form in the GOM knowledge base.

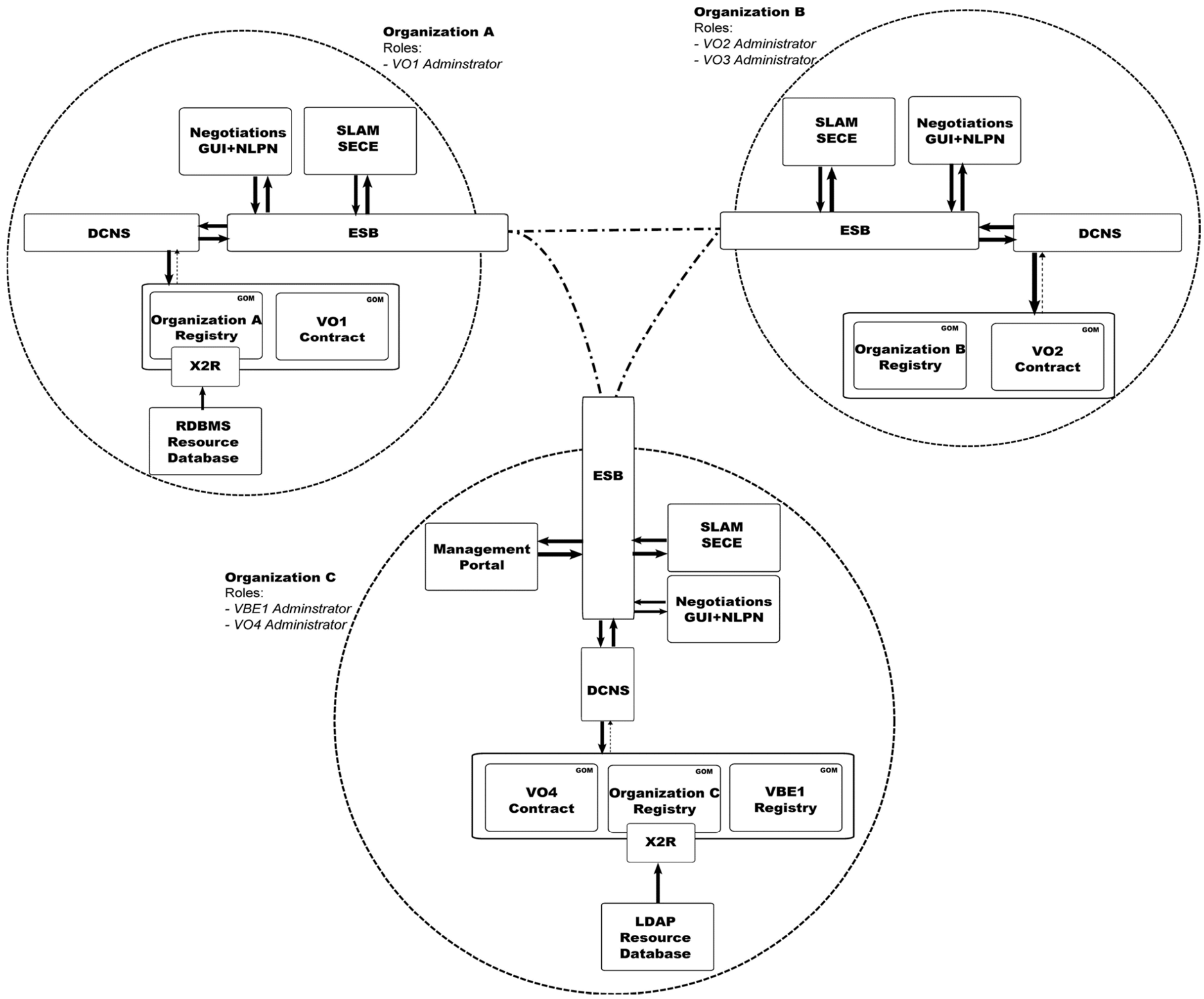

Fig. 5. Sample deployment of FiVO framework in several organizations.

4.3. Security configuration component

The security component (SECE – SECurity Enforcement) (Fibinger et al., 2010) translates the security related statements into appropriate formats e.g. XACML (eXtensible Access Control Markup Language) (XACML, 2011) for access control rules, which are then used to configure security layers in the particular organizations IT infrastructures. This allows usually to skip time consuming and error prone step of manual security policy configuration in a distributed infrastructure, involving often several administrators and which makes truly dynamic VO deployment impossible. As far as functioning of systems, which use XACML is based on applying policy documents, the solution to the problem was to create new policy sets and add them to the existing system. Entities such as resources, actions and subjects mentioned in the contract are defined as OWL concepts and instances, which allows uniform naming of resources throughout the entire IT infrastructure.

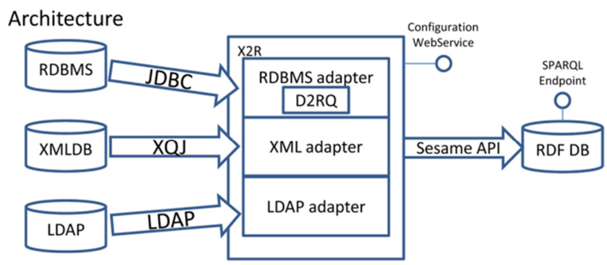

Fig. 6. Architecture of the X2R tool.

4.4. Monitoring component

The contract fulfilment-monitoring component (SLAM – SLA Monitoring) (Skalkowski et al., 2010a) is responsible for analysing low level logs from internal organizational monitoring systems in order to identify any irregularities in the process of VO operation. This can include failure of some organization to deliver a service according to agreed Quality of Service parameters or misuse of some resource provided by other organizations. The SLAM component takes appropriate actions predefined in the contract as penalty clauses, which allow automatically handling the problem or notifying a responsible person in order to solve the issue manually.

5. RESULTS

In this chapter we present an example application of the framework in a holiday travel domain. In this use case we have a single Virtual Breeding Environment called *Travel VBE*, where currently 3 organizations (*CostaRica Airlines, Good Guides* and *Chataqua Hotels*) participate. Each of these organizations has some resources, services, staff and competencies related to that particular domain, described in the knowledge base using concepts from the domain ontologies related to the travel domain. This allows the FiVO framework to 'understand' the semantic descriptions of various aspects of these organizations and to facilitate the process of matchmaking and negotiation. Depending on the size and IT infrastructure these organizations can host parts of the FiVO internally or can depend on the services hosted by larger partners (technology facilitators) within the VBE. In either case, all organizations upon joining the VBE can use the X2R functionality (Mylka et al., 2012), see figure 6, to export the description of their resources and capabilities stored in e.g. relational database to the semantic form, which will be interoperable between the organizations in VBE.

Next step assumes that one of these organizations identifies a business opportunity requiring the capabilities, which it cannot provide on its own, thus it invites the other organizations in this VBE, which can provide these services. Then a negotiation process is initiated, which is performed in a fully distributed manner, with GOM knowledge base ensuring the consistency of the contract at any point in time. After the negotiations are complete, each of the partners can sign the contract electronically, and the Virtual Organization can be deployed. An excerpt from the contract in this domain is presented in figure 7.

As can be seen from the above example, the semantic description of the domain knowledge and organizational assets allow for formal and unambiguous representation of the contract between the organizations. Such contract, can now be forwarded to the SLAM and SECE components responsible for configuration and deployment of proper components in the IT infrastructure of the organizations, dealing with such aspects as infrastructure monitoring and security configuration, which allows the organizations to collaborate in terms of actual low level communication over their IT services (Skalkowski et al., 2010b).

```
...
<!-- Resource provision statement -->
<ContractOntology;ResourceProvision rdf:about="#Stmt2">
       <ContractOntology:hasPenaltyClause rdf:resource="#Stmt5"/>
       <ContractOntology:resource rdf:resource="&CNO;AirbusA360"/>
       <ContractOntology:provider rdf:resource="&CNO;CostaRicaAirlines"/>
       <ContractOntology:consumer rdf:resource="&CNO;GoodGuides"/>
</ContractOntology;ResourceProvision>

<ContractOntology:PenaltyClause rdf:about="#Stmt5">
       <ContractOntology:hasPenaltyAction rdf:resource="#Stmt5Action"/>
</ContractOntology:PenaltyClause>

<ContractOntology;Notification rdf:about="#Stmt5Action">
       <ContractOntology:notificationTarget rdf:resource="&CNOntology;SafariGuide3"/>
</ ContractOntology;Notification >
...
<!-- Role assignment statement -->
<SecurityOntology:Role rdf:about="#TourGuide">
</SecurityOntology:Role>

<ContractOntology:RoleAssignment rdf:about="#Stmt6">
       <ContractOntology:hasRoleID rdf:resource="#TourGuide"/>
       <ContractOntology:actor rdf:resource="&CNOntology;MariaGonzalez"/>
</ContractOntology:RoleAssignment>
...
```

Fig. 7. *Excerpt from a sample contract.*

This approach provides several direct and indirect business benefits summarized below:

- Grouping of organizations into communities of interest, i.e. Virtual Breeding Environments,
- Support for discovery of organizations providing particular capacities and capabilities based on their portfolios published in a machine processable semantic form,
- Support for dynamic on-demand creation of Virtual Organizations among participants of the VBE, which allows to quickly respond to emerging business opportunities,
- Support for sharing common conceptualization of the problem domain within the VBE through distributed knowledge base and semi-automatic translation of existing organizational metadata and information to unified semantic representation,
- Facilitating the process of reaching and formalizing the agreement between the organizations participating within the VO,
- Automation of the VO deployment process based only on the formal contract
- Verification and enforcement of the contract during VO execution based on the low level monitoring data.

6. FEASIBILITY FOR INDUSTRIAL SCENARIOS

This section presents a recapitulation of the FiVO framework features and functionality scope with respect to typical industrial requirements. We have based this section on the generic VO framework requirements for industrial application presented in Santoro and Bifulco (2005) – see table 1.

7. CONCLUSIONS

In this paper we presented our solution to the problem of dynamic Virtual Organization creation and management. The main impact of the proposed approach is in its versatility and provision of unified solution to the Virtual Organization management problem. This includes distributed contract negotiation using both ontological concepts as well as natural language support, automatic Virtual Organization configuration and deployment based on a formal agreement within the IT infrastructure of the participating organizations as well as the monitoring of execution of the Virtual Organization and verification whether the negotiated contract is respected by the parties. The paper discussed detailed architecture of the system including dependencies and roles of the components. Furthermore, negotiation process has been described and excerpts from real contracts were presented. Finally, sample application in tourist domain was discussed along with other potential applications.

Table 1. *FiVO features addressing VO requirements for industry sector.*

Industrial VO requirements
VO Constitution
FiVO framework provides means for setting up a Virtual Organization Breeding Environment registries, which allow multiple organization within a single domain (e.g. metallurgy) to publish their competencies and interests so that it possible to either manually or automatically discover and invite potential partners for emerging VOs.
Business Model & Organization
Since the FiVO framework is based on a semantic knowledge base, it supports flexible definition of such aspects of organizational structure and business models as roles, resources, permissions and even engineering know-how. These allow the organizations to integrate with other organizations within a VO according to several business models such as supply chain or peer-to-peer.
Legal framework
FiVO framework provides full support for contract negotiation for a VO which results in creation of a formal document (in a form of ontology) which details the roles, obligations, permissions and penalties of all participants in the VO.
VO Management
During VO execution phase, FiVO components monitor all activities in the VO, which are attached to the FiVO monitoring infrastructure and automatically report on any irregularities with respect to the contract.
ICT infrastructure
The ICT infrastructure support from the FiVO framework provides means for inter-organizational application integration by means of the Enterprise Service Bus backbone of the system, which enables standards compliant message exchange between different legacy applications (such as Enterprise Resource Planning software), which already exist in participating organization.

The future work will be focused on further evaluation of the framework in other application scenarios including telemedicine and telecommunication environments. The future development will be oriented towards turning the framework into a product, in particular preparation of various virtual machine images, which can be applied in Cloud based organizations.

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ŚRODOWISKO DO ZARZĄDZANIA DYNAMICZNYMI ORGANIZACJAMI WIRTUALNYMI WSPIERAJĄCE ROZPROSZONĄ WSPÓŁPRACĘ PRZEMYSŁOWĄ

Streszczenie

Organizacje Wirtualne wydają się być naturalnym paradygmatem w przyszłych zastosowaniach biznesowych, biorąc pod uwagę obecną globalną i dynamiczną naturę tych środowisk. W prawdziwie zglobalizowanym świecie, organizacje powinny być w stanie nawiązać współpracę z dowolną inną organizacją, która jest w stanie dostarczyć pożądaną usługę, pozwalając optymalizować jakość i koszt. Jednak aby umożliwić i rozpowszechnić tą ideę wiele istniejących braków w technologii informatycznej musi zostać rozwiązanych. W tym artykule prezentujemy system wspierający tworzenie i zarządzanie Organizacji Wirtualnych w rozproszonych systemach informatycznych. Nasze rozwiązanie, pod nazwą FiVO (ang. Framework for Intelligent Virtual Organizations), adresuje większość problemów związanych z cyklem życia Organizacji Wirtualnej takich jak wyszukiwanie partnerów, negocjacja kontraktu, uruchomienie Organizacji Wirtualnej oraz przestrzeganie reguł kontraktu przez partnerów. W tym artykule koncentrujemy się na przedstawieniu zintegrowanego systemu oraz analizie przydatności tego podejścia do przedsięwzięć przemysłowych.

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