A Semantic Marketplace of Peers Hosting Negotiating Intelligent Agents

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Abstract. Achieving interoperability and automation in job execution is of utmost importance in the current economic trading sphere. This paper proposes a design that integrates three prominent technologies for improving next-generation e-Commerce applications; autonomous software agents, peer-to-peer networking and the Semantic Web. SeMPHoNIA is an architecture for an agent-based marketplace, utilizing knowledge from RDF product repositories, in an open peer-to-peer environment. The platform defines the basic stages of the process of e-trading, facilitating users in closing deals in an automated manner. The implementation of our approach is demonstrated in the context of auction scenarios.

1 Introduction

The emergence and rapid development of electronic commerce has influenced many fields of human activity and business industry, providing a "gravity well", which pulls a variety of diverse technologies and novel research efforts into closer collaboration. Recent years have seen an enormous increase in the role of information technology in markets, in particular the emergence of electronic marketplaces [2]. The current economic trading sphere is structured on top of an open, distributed, heterogeneous and, most often, unreliable environment.

Human participants are still actively involved in all stages of the buying process. As the trend of e-Commerce continues though, an inevitable growth in the number and features of on-line markets is observed, causing the task of monitoring and effective decision-making to become trivial and time-consuming for humans. The increasing degree of heterogeneity and sophistication on both the business and the customer side will render interoperability and automation in execution the most challenging tasks that next generation e-Commerce applications will face.

In this paper we introduce the design and implementation of a system, called SeMPHoNIA (Semantic Marketplace of Peers Hosting Negotiating Intelligent Agents), for addressing issues of current e-trading. The system integrates and exploits three enabling technologies, namely intelligent software agents, peer-to-peer systems and the Semantic Web, into a unified platform. It is an architecture for an

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agent-based virtual marketplace structured on top of a peer-to-peer network, utilizing semantic approaches. SeMPHoNIA could be considered as what [4] describes as the third key actor in agent-mediated e-Commerce applications, apart from buyers and sellers: the "market owner", an environment that sets and controls the rules, in which buyers and sellers trade. The implementation of our approach is demonstrated in the context of auction scenarios, intending to facilitate users in discovering and bidding across multiple interrelated auctions with varying start and end times and protocols. Still, auction scenarios are just a paradigm of multi-agent negotiation. The platform is designed to be extensible at various levels, intending to encourage experimentation with aspects of domains that go beyond auction theory.

2 SeMPHoNIA Platform Architecture

The SeMPHoNIA platform models aspects of market mechanisms that represent a common interaction medium for users on the Internet. It integrates three existing technologies; JXTA [6] for configuring the peer-to-peer network, Grasshopper [3] for managing the multi-agent character of the system and ICS-FORTH RDFSuite [5] for exploiting technologies of the Semantic Web. The JXTA Engine module is responsible for implementing JXTA protocols to allow the application to function as a peer, collaborate with other peers and deploy peer-to-peer services. The Grasshopper Middleware module is the component that undertakes the role of automating the negotiation procedure by creating, controlling and monitoring software agents that represent human users. Finally, the Semantic Search Engine module facilitates semantic publish and discovery of products on the network, exploiting software tools provided by the ICS-FORTH RDFSuite, such as RDF validation, storage and querying [1]. At the highest layer, the user interface is defined, displaying information about the progress of a user's auctions.

Three layers of functionality synthesize the platform's behavior; its semantic, its multi-agent and its peer-to-peer character. Before going into details regarding the platform as a whole, we elaborate on the different layers and their role in the system.

2.1 Semantic Character

Traditional Web-based product searching based on keywords appears to be insufficient and inefficient in the 'sea' of information [7]. Especially in e-auction sites, the current trend of searching catalogues of available products is a rigorous procedure. Instead, next generation e-markets should be able to handle customer queries, such as "Find all running English auctions of paintings created by impressionists of the 16th century". Ontologies have shown to be the right answer to knowledge structuring.

For that purpose, in SeMPHoNIA project we have developed two types of ontologies; process ontologies, which are specifically about auction-related concepts and attributes, and domain ontologies, which enrich product descriptions with metadata to accurately describe their features.

Until now, systems based on centralized ontology schemes suffer from difficulties concerning development and maintenance [8]. The SeMPHoNIA infrastructure, on the other hand, takes advantage of local ontologies, allowing participants to build and maintain their own RDF knowledge databases for describing products for sale.

More specifically, each item auctioned is related to a specific domain. A retailer describes metadata about products in the corresponding domain ontology of that product. The auction ontology captures the characteristics of a particular auction session combining knowledge from auction protocols and other common trading concepts to specify the context, in which the system operates. This ontology type is used to model all information needed for an auctioneer to initiate a new auction session and for a customer to determine a desired session based on criteria, such as the broker's identity, payment accepted etc.

2.2 Peer-to-Peer Character

SeMPHoNIA's peer-to-peer network is an asynchronous-message-passing super-peer system that implements the auction marketplace environment. The peer-to-peer network structure harnesses the computing power of capable peers (resource sharing) and impels efficient ontology distribution across nodes (knowledge sharing).

Three are the basic types of SeMPHoNIA peers: customer, auctioneer and operator peers. *Customer* and *auctioneer* peers serve as individual end users. The latter have the additional functionality of making ontologies available on the network. Therefore, they are always accompanied by an ontology database, describing the selling products, along with the corresponding RDFServer, which acts as a mediator between the database and the network. The third type of peer is the *operator* peer that acts as a super-peer and provides zero or more agencies to the platform. Agencies are places, where software agents can exist and interact. Simple peers connect with operator peers to ensure greater reliability and scalability. Thus, they supply the medium, where all auction operations take place. Operator peers interconnect forming a backbone of peer clusters, bridging remote clusters and permitting the application of message propagation algorithms to the underlying peers of each cluster, avoiding message flooding to the entire network.

SeMPHoNIA peers advertise their services in language-neutral metadata structures, represented as XML documents, called *advertisements*. An advertisement is the basic unit of data exchanged between peers that provide information about available resources. All peers contribute to increasing the level of connectivity to the overall network, by caching locally XML advertisements and automatically delivering them to interested peers upon request, without any need for human intervention. Another important notion of the SeMPHoNIA peer-to-peer network architecture is the peer-grouping concept. *Peer groups* promote trusted services by segmenting the network space into distinct communities of peers. In SeMPHoNIA, for every auction listed on the network a new peer group is created by the auctioneer peer. Whenever a customer decides to participate in an auction, it must first join the corresponding auction peer group and, only after the admission is granted, the peer is allowed to send its agents to the auction place. A variety of authentication mechanisms and trust models for allowing peer group registration can be applied.

2.3 Multi-agent Character

Agent technology represents a flexible way of conceptualizing and implementing e-Commerce transactions. Agents in SeMPHoNIA are used to facilitate the connection of buyers and sellers and to automate the process of negotiation at the context of auction scenarios. Users may decide to participate in multiple auctions at the same time, when the result of one auction may affect the action taken for the other. Agents automate bidding actions and make inferences to determine the optimum path, when interrelated auctions are involved, based on the human user's preferences and on their internal knowledge. The platform currently supports three types of auctions; English, Vickrey and a hybrid Peer-to-Peer auction.

We identify three types of agents operating in the SeMPHoNIA platform: A-, C- and CL-agents. The *A-agent* is the auctioneer's representative in the SeMPHoNIA network. It coordinates the execution of a specific auction and is responsible for the enforcement of rules governing the negotiation among all involved parties. The A-agent is aware of its owner's preferences, such as the type, the reserve price, etc. This information is captured in the product's domain ontology that the user publishes on the network.

Customers in SeMPHoNIA may initiate one or more auction sessions, participating concurrently in one or more auctions in each of them. Each session has one coordinator agent, the *C-agent*, whose role is to manage the distinct sub-tasks that a session is decomposed into. The C-agent controls the allocation of bids across auctions, relying on information about their progress and on its internal strategy for pursuing its objectives, but does not participate in any of them directly.

CL-agents are the actual participants in auctions conducted in the SeMPHoNIA marketplace. These agents are created by the C-agent inheriting the initial knowledge concerning their user's preferences, i.e., the maximum price they are allowed to spend for an item, the number of items they should intent to acquire etc. They react to notifications sent by both the A-agent, informing them about the progress of the auction they participate in, and the C-agent, instructing them to continue bidding or postpone their execution, in case this serves best the session's evolution. CL-agents are specialized according to the type of the auction that has been assigned to them (English/Vickrey CL-agent etc.) and the bidding strategy that the user intents to follow (aggressive, greedy, last-minute bidding etc.). They all possess the primal attributes and knowledge of their C-agent, but present specializations in their behavior, justifying their characterization as clones of the C-agent.

An important aspect of the multi-agent layer of the system is that it takes advantage of the mobility features of agents for enhancing its performance; CL-agents migrate to place, where the auction is conducted to communicate locally with the A-agent, eliminating possible delays due to network traffic. A C-agent may have multiple clones scattered across different agencies on different operator peers.

2.4 The SeMPHoNIA Platform

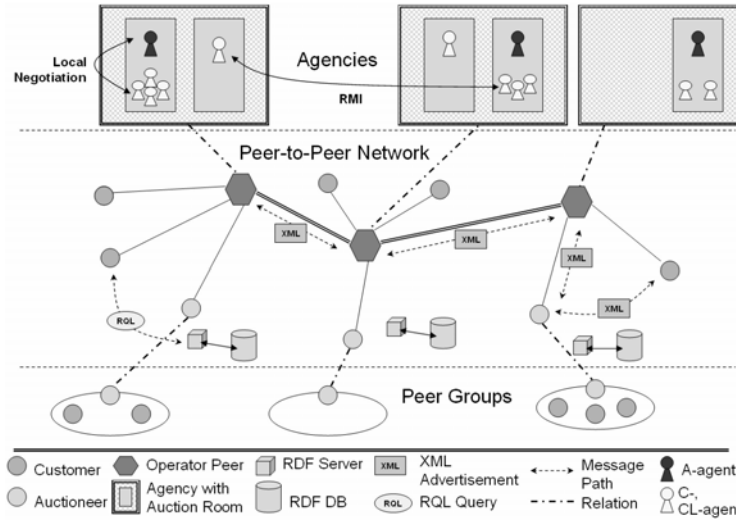

Fig. 1. SeMPHoNIA platform elements, relations and interactions

The previously described characters of the system are integrated in the SeMPHoNIA platform to implement a complete and well-defined e-trading environment. This section presents how the different layers of functionality co-exist and collaborate.

Figure 1 displays a snapshot of the system's state at a random moment. The middle part shows a fraction of the peer-to-peer network. Simple peers connect with operator peers, which in turn interconnect with each other to form a network of main channels. Advertisements travel between peers on the same cluster or between operator peers and are cached locally at various nodes throughout their path. These advertisements may describe various resources, such as product domains, ontologies, auction peer groups, agency addresses or simply the presence of peers. The lower part of the image depicts the correspondence between auctioneer peers and their own auction peer groups. Auctioneers may create multiple peer groups, one for every auction they conduct. This layer also shows the virtual presence of customer peers in each peer groups. Last, the upper part displays the multi-agent layer of the system, which is the component that implements all auction sessions. The dashed lines imply the relation between an operator peer and the agencies it offers. The other peers create places for supporting negotiations and agents that travel between agencies.

3 Advanced Features

SeMPHoNIA is a multi-purpose virtual market architecture that includes numerous advanced features for supporting human users in accomplishing electronic negotiation tasks. One of these is the statistical information support, that is absent in most current on-line auction sites. A special kind of agent, the Statistical Agent, automates the process of monitoring multiple auctions by sending clone agents,

while at the same time it records the history of bidding and analyzes statistical data, such as average winning bids, price convergence behavior, equilibrium price etc.

Moreover, the design of SeMPHoNIA's agent architecture offers flexibility and extensibility. Application developers can manipulate CL-agents as "black boxes" and utilize different CL-agents, that integrate various strategies, to enhance their interaction with the system, without any need to re-design the entire negotiation template. As a proof of concept we have created a hybrid peer-to-peer auction that required as sole modification the enrichment of the auction ontology with the features of this auction to allow A-agents to recognize and manage it appropriately.

In addition, emphasis has been given in designing the platform to support human involvement in sophisticated tasks and to sustain operations in an autonomous manner, even when the user is not connected on the network. Autonomy is promoted at different levels of abstraction, both at the peer-to-peer and at the agent layer (i.e., advertisement caching, controlled message propagation, inter-agency migration etc.).

4 Conclusions

We have briefly presented the design and implementation of the SeMPHoNIA system that integrates three emerging technologies; intelligent software agents, peer-to-peer networking and the Semantic Web. Our primary motivation in creating this platform has been to demonstrate the power of combining these three technologies in facilitating the participation of users in next-generation e-Commerce transactions. The system realizes a number of auction scenarios as a general negotiation framework, while maintaining a flexible design that allows it to be easily extended with new scenarios and techniques.

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