ELECTRONIC TRADING ON ELECTRICITY MARKETS WITHIN A MULTI-AGENT FRAMEWORK

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Abstract. Specific features of trade on electrical energy markets make the automation of certain negotiation and contracting processes attractive and desirable. Multi-agent systems are a natural solution for automating processes in a distributed environment, where individual market entities posses their own objectives. In the paper we consider a concept of a multi-agent framework for an electronic market trade. Since both energy markets and trade mechanisms are complex and permanently evolving, we require the highest expressiveness from this concept. Development of such a system involves solving several design issues related to embedding the agents in the environment, agent communications schemas, language, and offers modeling, especially in the case of the distributed, multilateral trade. We present a solution for the most important design issues. Our concept, including new information technologies supplementing multi-agent systems and Web services, are capable to support enterprises in the decision processes, to facilitate the buy/sell offers preparation, to select parties and enter into business relations with entities, and to support contract negotiations.

1 Introduction

Negotiations and contracting on electrical energy markets are usually supported by computer aided systems. Typically, the software tools available to the energy market entities provide forecasting modules and some methods for evaluation of trade offers and energy delivery schedules, with estimation of the risk measures. Only few of them are capable to perform the optimization process of selecting the best trade offers under some conditions. A decision maker (DM) tries to achieve the best trade decisions through the process of his/her interactions with computer-aided system. DM controls the process of taking the decisions by using expert knowledge, intelligence and intuition. Nevertheless, taking into consideration the specific energy market trade requirements (i.e., real time and resource-constrained requirements), the needs for more sophisticated computer support and wider automation of trade processes becomes more evident. Based

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on some strategy, automation may comprise some decision processes related to trade up to a certain stage, after which DM may enter into the process. In typical interactions between DM and commercial computer-aided systems, this strategy is usually only a domain of DM and is not represented in software.

The need for automating decision processes for trade on energy markets results from specific requirements on the intra-day and real-time (security-constrained) balancing markets and repeatability of some processes. For instance, the detailed schedules of energy delivery are negotiated repeatedly within the framework resulting from the long-term contracts.

Multi-agent systems (MAS) approach is a natural solution for process automation in distributed environment since it imitates well the human being trade methods. There are several application areas related to electrical energy markets, including modeling and simulation of power systems, distributed control and monitoring and diagnostics. A comprehensive picture of state of the art is presented in [8] and [9]. However, in the literature, there is very little pertaining to electronic energy trading. In [12] a MAS system is used for support negotiate-based decision making, but it is used only as a simulation tool without trade automation.

In the paper we consider a multi-agent model of a local electrical energy market, where agents are software components, which independently take actions tending to make agreements at the most attractive conditions. We use this case to prove, that multi-agent systems are proper solution for process automation in distributed environment. The power system (at the distribution network level) is being balanced in a complex, multi-stage process. At each stage of this process, the trade mechanisms can take different forms: from bilateral distributed trade, to formalized and centralized trade platforms, like power exchanges. The MAS-based system for an electronic energy trading should be capable to support as much of the trade mechanisms from this wide range, as possible. Thus, there are strong expectations for achieving high expressiveness of the system, due to changing environment, e.g. emerging new technologies for generation, dissemination of dispersed generation, micro grids and new equipments for demand side management.

In the literature, only a few aspects of MAS applications as the market simulation tools are relatively close to applications considered in this paper. Most of the current simulation agent-based platforms are limited and targeted to some specific market mechanisms. For instance, PowerWeb is limited to a single uniform auction with fixed demand [2], the Auction Agents for the Electric Power implements Dutch auction [3], work [6] concerns model of market in England and Wales, [13] is targeted at hydroelectric power stations, MASCEM is quite interesting, but is also limited to a given market structure [11].

A proper implementation of MAS-based electronic trading requires solving several design issues. In this paper we present the solutions of the most important ones: the issues related to the environment organization, agent communication mechanisms, comprehensible data interchange mechanism for diversified negotiating entities, and modeling of offers. In the case of the distributed trade, also the issues pertaining to localization of the potential contractors and their offers are addressed.

Our concept, with the new information technologies supplementing multi-agent systems and Web services, is capable to support enterprises in the decision processes, to facilitate the buy/sell offers preparation, to select parties and enter into business relations with entities, and to support contract negotiations.

2 Trade models

2.1 Distributed markets

In the distributed market, participants (or agents) are directly engaged in exchange of goods, by negotiating the best, from their point of view, contracts. In such markets the various agents reach bilateral or multilateral agreements, usually after some, often complex negotiations. The simplest type of agreement is a bilateral contract. Note, however, that in the case of multicommodity trade (e.g. simultaneous energy and ancillary services trade), contracts may affect not only many goods, but also a number of suppliers and customers. Such agreements will be called multilateral.

Morris column concept Agents, to be able to negotiate, need to obtain some information about other agents, and particularly on the current negotiation process. We can certainly imagine situation, where each agent broadcasts the messages about initiating negotiations to all other agents. However, in large systems, such a solution would involve a massive communication effort. Moreover, agents would obtain a huge amount of unnecessary information. In the centralized systems it is possible to create a repository, which collects the data about the agents, and existing and planned negotiation processes.

As the distributed systems do not have (and often cannot have) any central repository that could collect such information, there is a need to share this information in a different way. For this purpose we define a special agent called *Morris column* [7]. The task of such agent is to offer some public location, where other agents may "hang a notice" to report certain information about their negotiations. In addition, the Morris column should provide functionality of searching and removing the information. In a broader context, agents may leave a notice on initiating various types of auction processes with some market-specific characteristics.

Both in distributed and in centralized market systems, there can be more than one agent who plays the *Morris Column* role. However, in distributed market system, there is a strong need for multiple instances of such agents. Every single *Morris Column* stores only a part of global information, and particular pair of such agents shares some parts of information.

2.2 Exchange-like markets

In this class of the markets there are central agents (e.g. the market operators), which collect offers, bids and asks sent by other agents involved in the trade. Such agents balance the demand and supply on the market, according to some established rules (generally in the best possible way). The operator distributes the balance results to all agents involved. The operator of balancing market may further ensure compliance with various restrictions, e.g. including physical constraints associated with the production and transmission of electricity.

The simplest type of such mechanism is the stock market, where there are no physical limitations for delivery. The bids can be ordered by price and most favorable offers are accepted, while others are rejected. In the simplest case, the equilibrium price and total volume are determined in the intersection of supply and demand curves. Such rules are used e.g. in the wholesale electric power exchanges. However, there is often a need to reflect the above-mentioned physical limitations in the balancing processes.

3 Key elements of the framework

To design MAS in a context of electronic trade, several requirements must be met. Below, we discuss the most important ones.

3.1 Communication models in multi-agent environment

Agents, implemented as software components, must be embedded in some environment. FIPA (Foundation of Intelligent Physical Agents) standards form a framework for agents operations [1]. FIPA has developed standards pertaining to inter-agents communications, and detailed communicative acts and certain schemas for inter-agent communication.

Mechanisms defined by FIPA are not satisfactory for modeling communication in a case of multilateral negotiations and distributed environment (without central entity). Nevertheless, FIPA standards are a good basis for developing communication schemas meeting the requirements. Necessary modifications of FIPA standards are described later.

3.2 Communication language

Expressiveness of the system manifests, among the other things, in rich possibilities of definition various commodities, offers and other information elements required for negotiation process. Information necessary for negotiation process is passed as a content of a message. A language of this content must be defined by MAS developer. An interpretation of message content is determined by two elements: language and ontology. Language defines the syntactic of message content and ontology can provide semantics for elements used in message content and expressed by defined language. FIPA has four languages, however none of them has a potential for modeling data in a manner sufficiently flexible for our needs. To our best knowledge, there exists only one standard proposition, which can meet strong requirements for our system. It is the Multi-commodity Market Model M^3 which is an open general data model for trading many commodities simultaneously [14].

3.3 Modeling of offers

One of the most challenging issues is a method for expressing the entity preferences during the bidding process. In both bilateral negotiations and wide spectrum of organized trade mechanisms, bids and offers can take diversified forms. Moreover, these forms evolve during market development, mechanisms and software development, and market entities knowledge and requirements growth. Thus, it is extremely important to have ability to express a wide range of possible offer forms. This target can be reached due to open data model of M^3. M^3 standard generalizes the offer objects expressed by volume and offered price, including possibilities for offering bundles of commodities (e.g. bundling energy in the consecutive hours to offer a complex block of energy), and including complex bindings (e.g. flexible offer for storing energy in dispenser that considers buying energy for charging, then losses and efficiency depended on selling moment). Till now, there are no examples of specific important requirements on the electrical energy market with market data that could not be modeled by M^3.

4 Agent model

4.1 Agents and their roles

Multi-agent platform should allow efficient exchange of goods between participants represented by some software agents. Consistency and unambiguous communication must be ensured. The platform should allow agents to carry out multilateral negotiations.

The main type of agent is a Dealing Agent (DA). It intermediates between the actual decision entity (e.g. marketing company, power plants etc.) and the multi-agent system. Its mission is to establish the most advantageous (from the point of view of company which it represents) agreements, preceded by the process of negotiations. Negotiations are conducted in accordance with implemented strategies. We assume that the role of dealing agent can be extended to the role of a broker (intermediary trade), which also buys and sells goods, drawing profits from such turnover.

To provide a means of communication between the agents, we have to ensure that there are some agents, which will act as the repositories that provide information about the location of DA. Repository includes, in the simplest case, the URI address of the individual agents. Agent acting for this role is called Bilateral Transaction Broker (BTB). In the M^3 model, the roles of repositories in the distributed trade may be played by Morris columns. Thus, Bilateral Transaction Brokers can be implemented with the features of Morris column.

4.2 Information flow

To assure trade, agents have to exchange some information. Specified agent, which wants to start negotiations, has to declare willingness to negotiate by sending a message to BTB agent. Other agents could send queries concerning ongoing negotiations. Other information being exchanged between agents is related to the estimates of demand and supply, or physical conditions.

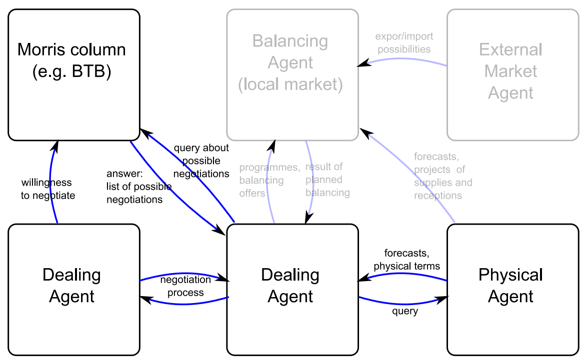

Fig. 1. Information flow between agents

Figure 1 presents basic types of agents and acts of communication. Agents marked with grey colour exist on additional market segments located closer to the real-time realisation of the contract.

5 Agents' interactions

Agents interact using some typical messaging schemas. FIPA systematized these schemas and called them 'protocols'. From our point of view, two of them are interesting: Contract Net Interaction Protocol and Iterated Contract Net Interaction Protocol.

Contract Net Interaction Protocol defines messages interchange for centralized trade (in auction or exchange). Agent, which submits an offer using this protocol, has no possibility to negotiate.

Iterated Contract Net Interaction Protocol is an extension of the preceding one. This protocol assumes that offers may be negotiated, so it can be used on markets, where negotiations are necessary, e.g. for bilateral or multilateral trading.

In the following sections our extension of these two protocols is presented, which enables them to be used for multi-commodity trade.

5.1 Centralized markets

On the centralized market there is a system operator that is responsible, among other things, for creating and maintaining a platform, where market participants can submit their sell and buy offers. The operator specifies the market model (under some regulation rules), determines the range of traded commodities, their characteristics, the rules for transaction making and clearing, infrastructural (e.g. network) constraints, other system requirements and constraints, etc. The operator usually defines all necessary dictionaries (sometimes defined in the form of ontologies): lists of commodity kinds, market entities, etc. The operator defines also a calendar, which determines time periods in which commodities can be offered.

Agents willing to trade on the centralized market must know where such platform can be found and how it can be used. If such a platform is not commonly known, it must be somehow announced to interested agents. It is of course impossible to notify all potentially interested agents directly, because they are numerous, and much of them are probably not known to the operator. A Morris column can be used to publish necessary information. An operator submits announcements to one or more Morris columns, where they become available to all interested agents.

A sequence diagram in Figure 2 presents a modified Contract Net Interaction Protocol. The operator submits a cfp (*call for proposal*) message to Morris col-

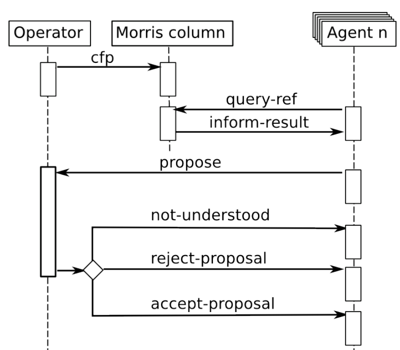

Fig. 2. Modified Contract Net Interaction Protocol

umn(s), which informs that the platform is available and waits for offers. Agents scans commonly known Morris columns, looking for interesting trade opportunities. They use *query-ref* messages that contain patterns specifying, which information is interesting to the sender. A Morris column responds to these queries sending *inform-result* messages, which contain only information fitting the patterns.

Agents interested in trade on the particular platform submit their offers, using *propose* message, to the platform announced on the Morris column. Depending on market model, offers should be submitted in specific time window, or can be submitted at any time. If the offer is not correct (e.g. it can not be understood or is incomplete), a *not-understood* message is sent to the offeror. The operator joins the offers using algorithms specific to the market model. Next, *accept-proposal* messages are send to the offerors, whose offers succeeded, and *reject-proposal* are send to the agents, whose offers failed. In this kind of market an offer is binding – an agent, which submits the offer, is obliged to fulfil the commitment.

5.2 Decentralized markets and negotiations

Decentralized markets lack of a central institution, where offers can be placed, and which determines the rules and common dictionaries for the market. Such markets are based on bilateral or multilateral trade, but before any trade can take place, potential participants must find each other. One of possible methods is the use of Morris columns, on which agents place their announcements.

Figure 3 shows proposed scenario of such bilateral interaction.

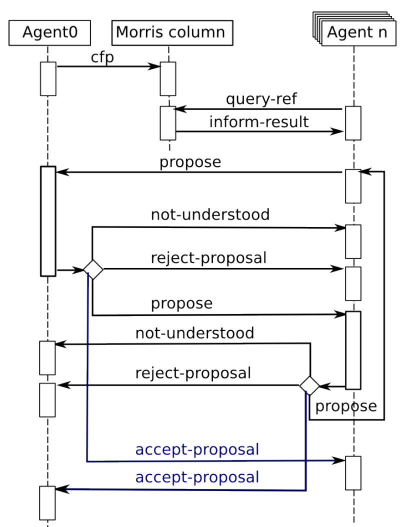

Fig. 3. Modified Iterated Contract Net Interaction Protocol

Agent submits a *call-for-proposal* message to one or more Morris columns. The message contains detailed description of the offer: commodities, quantities, time windows, etc. Other agents looks for interesting offers, sending *query-ref* messages to appropriate Morris columns. As a result of the query they obtain an *inform-result* messages containing lists of offers that fit the query; these lists contain also URL addresses of agents-offerors. Next, agents enter into direct bilateral or multilateral negotiations. They send *propose* messages to each other in one ore more iterations, negotiating the terms of trade. If negotiations succeed, one of the agents sends *accept-proposal* message the other one.

Unfortunately, this quite simple schema does not work if any of the parties continues searching for better offers simultaneously to negotiations. Offers on this type of market usually are not binding, and each party can break off the negotiations at any time, whenever it finds a more profitable solution, even when the negotiations are almost finished. So, submitting *accept-proposal* message does not confirm the transaction, it must be additionally committed using special protocol, which ensures that all the parties involved in the transaction accept the result of the negotiations.

5.3 Two-phase commit

An adaptation of two-phase commit protocol (2PC), well known in distributed OLTP (On-line Transaction Processing) systems, can be used as a method for accepting transactions in decentralized markets. It guaranties safe completion of transactions, ensuring that all involved parties ultimately accept the contract.

Figure 4 presents a two phase commit protocol.

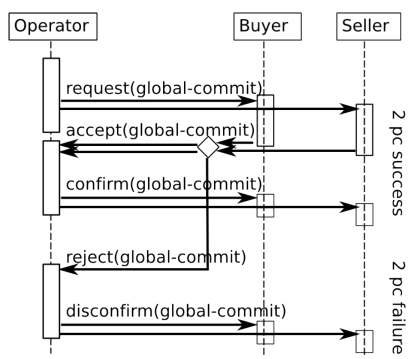

Fig. 4. Two Phase Commit Protocol

Unfortunately, FIPA standards do not directly define this protocol, but it can be quite easily defined on base of communication acts existing in the standards. In [10] an appropriate communication schema is proposed for bilateral transactions, but the 2PC protocol can also be used for multilateral ones.

Agent, which initiates completion of the transaction, sends *request(global-commit)* message to the other participants of the transaction. The parties should answer using *accept(global-commit)* message if they accept the transaction, or *reject(global-commit)* otherwise. If all of the parties accept the transaction, an initiating agent sends *confirm(global-commit)* message and the transaction is irrevocably accepted. If any of the parties rejects the transaction, a *disconfirm(global-commit)* is send and the transaction fails. If any of the parties does not answer in a given time, the transaction is timed-out and it also fails.

6 Communication acts

Single communicative act contains some portion of control data, e.g. sender's and receiver's identifiers, type of the message (including semantic meaning), etc. This is defined in FIPA specifications, so we do not consider it in this paper. The body of the message contains the main content. This content can be understood differently, depending on used language and ontology [1]. In this section, the proposals for the content-language of particular messages are presented.

Call For Proposal This communicative act is used to report willingness to negotiate, or to the declaration that some kind of market/auction begins. Such communicative act should contain elements like, e.g., unique identifier of market/negotiations, kind of market/negotiations, time window on offers/proposal submitting, list of commodities, which are available for trade, etc.

We propose the following notation of these elements, using the XML notation (due to the fact that some items, as the commodities or the time windows, are defined by means of XML-based language M3-XML). An exemplary structure of the message is as follows:

```
(cfp
 :sender ex:Agent0
 :receiver ex:MorrisColumn01
 :content (
      <market id="ex:001" type="stock" quotation="continuous">
         <m3:calendar>
            <m3:CalendarPeriod id="ex:Y2009" periodType="ex:one-year"
                                  startTime="2009-01-01T00:00:00"
                                  endTime="2010-01-01T00:00:00"/>
         </m3:calendar>
         <m3:commodities>
            <m3:Commodity dref="op:ElectricEnergy" id="ex:eY2009">
              <m3:description>Energy on Copper Plate</m3:description>
              <m3:availableAt ref="op:CPNode" />
              <m3:CalendarScheduledCommodity ref="ex:Y2009" />
            </m3:Commodity>
         </m3:commodities>
      </market> )
 :language xml+m3
 :ontology EnergyMarket )
```

Query-ref Such communicative act is used by agents to submit a query to Morris column. Agent, which wants to obtain a list of advertisements, sends a query to the Morris column. Since the advertisements are XML documents, the most appropriate tool is XPath language [4] or XQuery language [5].

Let us assume that agent wants to query the Morris column about all advertisements, which comprise selling electric energy in negotiations process. An exemplary message, containing a query written in XPath language, is as follows:

```
(query-ref
 :sender ex:Agent2
 :receiver ex:MorrisColumn01
 :content ([/announces/announce/market[@type = 'negotiations' \
           and @offerType = 'ask']/m3:commodities/ \
           m3:Commodity[@dref = 'op:ElectricEnergy']] )
 :language xpath
 :ontology EnergyMarket
 :reply-with xpath:query02 )
```

A similar query in XQuery language is as follows:

```
for $x in doc("MorrisColumnAnnounces.xml")
  where $x/announces/market/@type = 'negotiations'
     and $x/announces/market/@offerType = 'ask'
     and $x/announces/market/m3:commodities/m3:Commodity/@dref =
                                         'op:ElectricEnergy'
return $x
```

Inform-result The content of this communicative act is a list of the announcements. As the advertisements are formed in the XML language, the answer contains a list of inform-results; each result is related to particular XML advertisement.

Propose This act contains an ask/bid (proposal in the negotiation process may also be regarded as a type of a deal). Thus, for this communicative act we propose to use M3-XML as a language for defining offers. An example of a message is presented below.

```
(propose
 :sender ex:Buyer
 :receiver ex:Operator
 :content (
      <m3:Offer id="ex:o12345-67" offeredPrice="-140.00">
        <m3:description>Buy offer</m3:description>
        <m3:offeredBy ref="ex:Buyer"/>
        <m3:volumeRange minValue="0" maxValue="100"/>
        <m3:ElementaryOffer>
         <m3:offeredCommodity shareFactor="-1"
                       ref="ex:energyOn2007-04-09T08:00:00"/>
        </m3:ElementaryOffer>
      </m3:Offer>)
 :language m3
 :ontology EnergyMarket
 :reply-with ex:o12345-67)
```

7 Summary

The presented MAS framework enables distributed trade activities by autonomous agents and, in the result, increases the efficiency of the market processes. To make it possible, several conceptual and technical issues must be resolved. In the paper the solutions of the most important issues are presented, that result in a flexible open system, ready for applications in a wide range of possible market processes, ranging from distributed, multilateral trade up to more centralized approaches. Our concept is based on general acknowledged FIPA standards with some minimal extensions required for achieving a desirable level of flexibility. We have also pointed out some open solutions and technical standards, developed in scientific groups, that are ready for transfer into some important practical areas. In further research works the proposed solution should be verified by a simulation.

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