A P2P-BASED INFRASTRUCTURE FOR VIRTUAL-ENTERPRISE'S SUPPLY-CHAIN MANAGEMENT*

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Abstract: This paper proposes and describes a prototype of a peer-to-peer based infrastructure to support virtual enterprise's supply chain management. Because of a virtual enterprise is composed of autonomous, distributed, and continuously evolving entities, we have naturally modelled each business entity like a peer's agent platform that can play several roles according to the task to be fulfilled. To this end, we describe and apply such roles, required to the organizational architecture, into a virtual storehouse scenario.

1 MOTIVATIONS

Nowadays, especially in Italy, several organizations, characterized by common market interests in terms of products and services they manufacture and deliver, are collaborating together sharing both their specific expertise and entrepreneurial culture.

Nevertheless, such a scenario produces a static enterprise coalition always based on the same members that often have not the competences and leadership, e.g., in terms of quality, on specific product and service orders. Furthermore, such coalitions are generally leader-centered, that is a coalition's member (the biggest or the leader one) establishes and imposes its standards to the other members.

Actually, several research efforts have been fulfilled in the prospective of endowing small and medium enterprises with new forms and models of aggregation and collaboration suitable to take advantage of current inter-networking information technology (Franke, 2002; Huhns and Stephens, 2002; Jennings et al., 2000; Pathak et al., 2000; Petersen et al., 2000).

The scenario introduced above can naturally be modelled by means of the virtual-enterprise paradigm (Franke, 2002; Petersen et al., 2000). Into a virtual-enterprise, each member maintains its autonomy and independence related to its internal business processes. Nevertheless, such a member has to collaborate in a synergic way according to the coalition goal, e.g., issuing a (new) service and manufacturing components for a (new) product. This paradigm establishes a network of small and medium enterprises characterized by a variety of value adding products/services (e.g., in a supply chain), alive only for a specific period, for a specific business objective, and disband when the goal is achieved (Franke, 2002).

This paradigm views a distributed system as an open, dynamic network of peers. Each peer is acquainted with a small number of other peers with whom it can exchange information and services. Acquaintances change constantly, there is no central control/registry, and peers remain autonomous throughout their participation in a peer-to-peer (P2P) network (Bernstain et al., 2002). Notice that, current P2P tool capabilities are principally based on file sharing mechanisms; hence, some efforts have been done in the direction of improving/enhancing the data management skills, e.g., (Bernstain et al., 2002; Penserini et al., 2003). For example, in (Bernstain et al., 2002) the authors proposes an extended relational model for P2P databases that supports

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distributed query processing and constraint enforcement.

This paper proposes and describes a prototype of a P2P framework based on collaborative agents in order to support and improve the horizontal and vertical supply chain management network typologies. Indeed, supply chain management is considered a strategic and critical aspect for enterprises and especially for a virtual-enterprise, e.g., (Huhns and Stephens, 2002; Pathak et al., 2000; Petersen et al., 2000). In particular, we describe the ability of the system that can play several roles to effectively encompass all the supply chain's activities, e.g., procurement, production, order processing, transportation, and customer service.

2 MOTIVATING SCENARIO

The supply chain management is a strategic component of an enterprise because such an aspect involves all the activities associated with the value chain, that is, it copes with the required processes to transform raw materials to end user products. Moreover, supply chain management deals with providing products and services to customer faster, cheaper, and of better quality, e.g., (Huhns and Stephens, 2002) and (Petersen et al., 2000).

As an example, it is interesting to observe one of the main advantages, in terms of costs, in applying a collaborative model at the chain storehouse[1] level. Indeed, generally, the *stock holding costs* increase when the product availability increases (i.e., tends to 100%), while the *potential lost sale costs* increases when the product availability decreases. Therefore, the *optimal service* falls near 85% that is the minimum of the *total cost* trend. On the contrary, as experimented and described in (Netsourcing, 2003), applying a *virtual storehouse* collaborative approach the optimal service moves towards a less percentage availability, that is less stock investments at the same customer satisfaction.

For the sake of simplicity, we assume that every time an order occurs the related enterprise can satisfy it in three principal ways: **a)** *using its internal stock*, **b)** *negotiating the quantity/lot required with the known partners*, and **c)** *trying to seek for new partners*. Scenario (a), the more traditional one, means that the firm has to internally produce the goods required and/or it has to hold a high lot size in its storehouse in order to satisfy every order. As a consequence, such an approach risks increasing both the lost sale and stockholding costs. Those costs are decreased using scenario (b). That is the known partners at the same level in the value chain (peer) contribute to satisfy an (retailer) order. For example, as depicted in Figure 1, each time a *Retailer* issues a sourcing order to *Firm*$_1$, this latter distributes the order over the known partners, i.e., *Firm*$_1$ relies on *Firm*$_2$ storehouse. In particular, each firm autonomously makes their own decisions about how to bid, e.g., a negotiation phase based on the prices and their own utilities of the goods[2]. As a consequence, such a kind of coalition suffers of some limitations due to little flexibility to dynamically reconfigure the enterprise network, and the (predefined) members have not always the competence and leadership on specific products or product's components. Therefore, such kinds of alliances tend to adopt common standards that do not allow other partners to easily come in. Besides, often in such a setting a central authority (the leader) constitutes a bottleneck and may break down the system efficiency completely.

Therefore, in such a context, preliminary requirements analysis results conduct to small and medium enterprises that are characterized by weak technological infrastructure and know-how, e.g., they rely upon simple and sporadic Internet connections; hence, each member can both autonomously continue to participate inside a specific market and occasionally exploit collaboration to increase its buyers' market. This latter approach requires being able to know new partners (scenario (c)). Specifically, this domain can

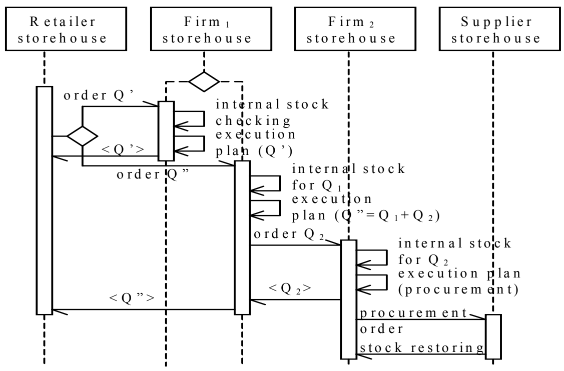

Figure 1: Simplified scenario of virtual storehouse collaboration

[1] Hereafter, by 'storehouse' word, we implicitly refer to the all firm information systems where data/information are effectively managed and organized.

[2] This paper does not investigate the alternative ways to fulfill a negotiation.

be accommodated in a natural way by means of a P2P network. Thus, this style of computing is very suitable for collaborative actor groups, e.g., virtual-enterprise's members that work under conditions of autonomy, coordination, and not permanent connections. In this paper, we aim to extend and improve the scenario (b) and (c) endowing each coalition member with an agent based peer-to-peer (P2P) framework.

3 APPROACH

The proposed multi-agent system[3] aims to characterize the principal agent roles and their relationships required to support and enhance information coordination in a virtual-enterprise's supply chain scenario. Namely, the proposed system does not aim to substitute the internal enterprise behaviour and features, e.g., logistics, supply chain management system, and information systems. On the contrary, it allows enterprises for supporting a more dynamic P2P based computing approach to model the collaborative interactions among partners.

In particular, we dedicate more focus on virtual-enterprise composed of autonomous members (peers) with fragmentary information about the environment in which they live, e.g., incomplete information on both partners and business processes; hence, they exploit coordination each other in order to achieve common goals. For such reasons, our multi-agent system (the peer's agent platform) supports the peer-to-peer computing model. Moreover, we assume that each peer node includes a peer (the enterprise) and a (software) peer's agent platform, which assists the peer (see Figure 2).

As indicated in Figure 2, each agent platform deploys one or more of the following capabilities to support the needs of its human/organizational peer:

Facilitator (searching and registration). In the scenario (b) and (c) described in Section 2, each peer (i.e., an enterprise) needs of looking for partners capable to satisfy a given request. That is, a virtual-enterprise can be seen as a decentralized agent setting, in which each peer (a virtual-enterprise's member) does not know a priori what partners to communicate with. Therefore, the facilitator role allows the peer's agent platform for the searching and registration capabilities in order to get to know other peer's agent platforms with useful skills, establishing new acquaintances. For example, in our approach this ability is based on a yellow page directory service, where agents can advertise themselves and their functionalities. Yellow pages also provide information about the state (e.g., active, disconnected) of other agents and platforms, e.g., see (Penserini et al., 2002; Fipa, 2000). Moreover, as depicted in Figure 2, each time a request cannot be internally satisfied, both the *supply chain manager* and the *information source manager* could interact with the *facilitator* role to get new acquaintances, that is the scenario (b). Notice that, in the case of a new peer's request, the *facilitator* can also autonomously propagate the request over the peer network without overloading the *supply chain manager*, e.g., interacting with other platforms' *facilitators*, that is the scenario (c). In our prototype, we adopt the 'Facilitator' name, because such an agent has been originally developed according to the Fipa'97 reference model (Fipa, 2000), but its further functionality improvements now make it similar to a matchmaker agent role.

Information System Manager (reformulation and integration). When a given peer (enterprise) operates in the scenarios (b) and (c) of Section 2, it needs to interact with the information systems of other peers; this is a sort of virtual storehouse. In other words, we are in the presence of a distributed and heterogeneous information systems. In particular, each peer's agent platform relies on this role to perform and coordinate queries targeted to information sources of the same peer or other peers. Therefore, there exists a well-known data integration problem in distributed, heterogeneous, and dynamic systems. Hence, to cope with integration issues, the peer's agent platform can adopt a mediator architecture to access the information sources, e.g., in our prototype, this architecture is composed of mediator and wrapper agents. For example, it can use one of the several algorithms for answering queries using views, e.g., see (Panti et al., 2001). Therefore, the *information system manager* (*is*

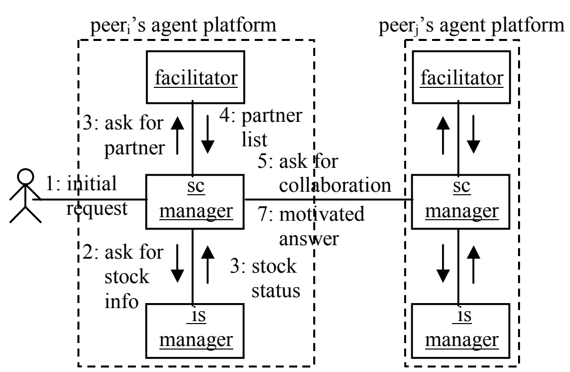

Figure 2: Principal roles played by a peer's agent platform

[3] It is partially based on a MAS prototype, named JEAP. Available at: http://jeap.inform.unian.it/.

manager) provides a platform with reformulation and integration capabilities. Using these, a platform can reformulate the original problem (initial request) in terms of data management operations each targeted at selected sources, in agreement with some soft inter-database constraints, i.e., coordination rules as described in (Bernstain et al., 2002).

Supply Chain Manager (strategy generation). The *supply chain manager* (*sc manager*) role is required to correctly coordinate collaboration activities among decentralized peers, i.e., virtual-enterprise members. For instance, when a failure results from the peer's agent platform inability to satisfy a request locally, the *supply chain manager* can help to build up a cooperation strategy in order to overcome the underling failure. In particular, our system prototype's *supply chain manager* currently deals with the principal failures that affect *virtual storehouse* scenario, such as: product stock unavailability and procurement criteria, partners' unavailability and looking for new partners. Specifically, the *supply chain manager* manages plans (workflows) composed of actions in order to fulfil negotiations, to query information sources, to make bids, etc. Indeed, in our preliminary tests as shown in Figure 2, we have assumed that the pivot role is played by the *supply chain manager* role; that interprets and manages every initial request to choose the more convenient plan. To this end, such a role can rely on the well-known BDI (Belief-Desire-Intention) architecture. According to this architecture, the *supply chain manager* represents the environment status in terms of facts (the beliefs) and the received requests in terms of goals (the desires). Moreover, it chooses the more convenient behaviour (the intentions), among a set of plans, to achieve the current goal. Finally, each *supply chain manager* has the responsibility of coordinating the internal activity required to keep update all the enterprise's repositories. The *supply chain manager* relies on the agent platform's *information system manager* in order to inquire the peer's internal information sources (required to update its beliefs), e.g., repositories to get stock status about specific products.

```
(request
:sender retailer
:receiver PA_F1(sc)
:language XML
:ontology planner-strategy
:protocol fipa-request
:content
 <xmlcontent>
  <action> PA_F1(sc) </action>
   <availability>
    <ID_product> Acer_LCD17_01 </ID_product>
    <quantity> 10 </quantity>
   </availability>
 <xmlcontent>
:conversation-id #)
```

Table 1: An example of 'request' message.

4 INTERACTION EXAMPLES

Let us assume that the entities shown in Figure 1, i.e., *Retailer* (R), *Firm$_1$* (F_1), *Firm$_2$* (F_2), and *Supplier* (S) are respectively interfaced by their platforms (peer's agent platform), i.e., PA_R, PA_{F1}, PA_{F2}, and PA_S.

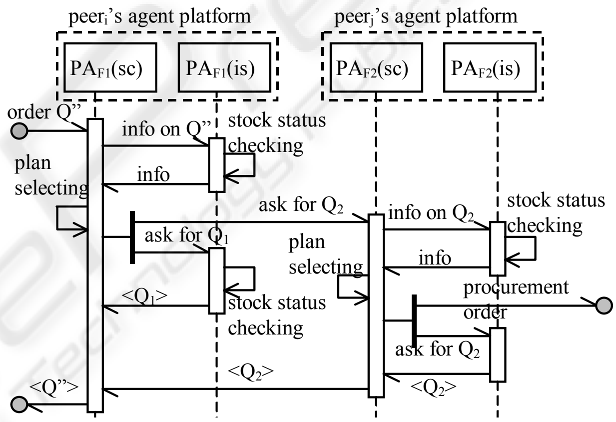

Figure 3: Cooperation plan to cope with the scenario (b) depicted in Figure 1

Specifically, our prototype support an *agent communication language* (ACL), based on the FIPA specification (Fipa, 2000), in order to standardize and define the format of the exchanged messages. ACL is fundamental in order to allow agents to understand their intentions. Besides, performatives, e.g., List 1 shows the 'request', are constrained to follow an exact path of the discourse, required to the agents to recognize if a conversation is terminated (and for what reason) or if it is still in progress, in which point it is (say communication protocol).

To make clearer the roles played by each platform, let us assume to fulfil the *order Q"* indicated in Figure 1.

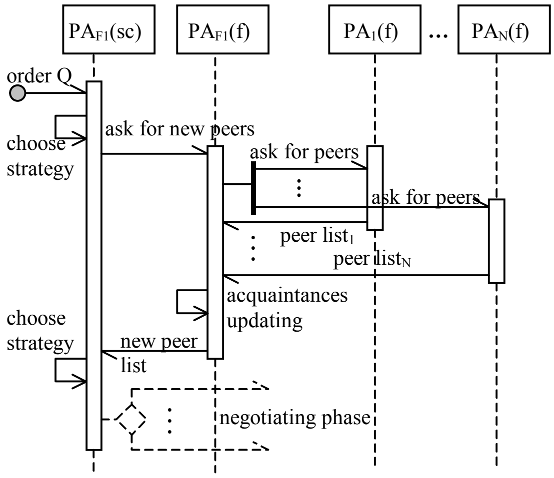

Figure 4: A fragment of the cooperation strategy to cope with scenario (b)

Example 1. According to Figure 3, the *order Q”* is submitted to the *supply chain manager* role of $Firm_1$ (PA_{F1}(sc)) by means of a ‘request’ message, i.e., indicating the product ID and the requested quantity (*Q”*) as shown in List 1. Consequently, PA_{F1}(sc) needs to extract all the product information to effectively deal with the choice of the more convenient execution plan; hence, it relies on the *information system manager* role (PA_{F1}(is)). As already said, PA_{F1}(is) is able both to reformulate the *supply chain manager*'s request into information source requests, and, vice versa, to integrate the source's answers into a single and coherent answer to the *supply chain manager*. For instance, in List 2 is shown the ‘inform’ message content that PA_{F1}(is) provides to PA_{F1}(sc), that is the ‘info’ message line of Figure 3. Therefore, when PA_{F1}(sc) receives the product info, e.g., stock status, procurement criteria (as the Pareto's law), etc.; it has the main components to select the more convenient execution plan. As already said, in this preliminary tests, our prototype's *supply chain manager* aims to avoid internal procurement order collaborating with other partners in the same level of the value chain. To this end, according to the ‘inform’ message of List 2, PA_{F1}(sc) splits the *order Q”* in two sub-orders: the first one (with quantity Q_1) satisfied by the *$Firm_1$* storehouse and the second one (with quantity Q_2) delegated to *$Firm_2$* storehouse. Notice that, *$Firm_2$* is also involved in a stock restoring phase, i.e., *procurement order*.

```
….
:content
 <xmlcontent>
  <session> SUCCESSFUL </session>
  <selectresults> <SELECT1>
    <Element>
      <ID_product> Acer_LCD17_01 </ID_product>
      <quantity> 28 </quantity>
      <class> AA </class>
      <safety-level> 20 </safety-level>
      <flag_availability> on </flag_availability>
      <ID_warehouse>                    Firm1_warehouse3
</ID_warehouse>
    </Element>
   </SELECT1> </selectresults>
 </xmlcontent>
….
```

Table 2: Fragment of an ‘inform’ message generated by an *information system manager* role

Example 2. Let us complicate a bit the scenario described in Figure 3. Namely, the *order Q”* consist of a new product request (quantity *Q”*) and *$Firm_1$* does not know partners, among its current acquaintances, able to collaborate on such a request. Consequently, *$Firm_1$* is forced to seek for new partners (peers) in order to avoid the *lost sale costs* increasing. Notice that, such a case coincides with the scenario (c) introduced in Section 2.

Figure 4 depicts the scenario (c) in terms of the main involved interactions among peers' agent platforms and their roles. When PA_{F1}(sc) realizes that it cannot satisfy the order alone, it relies on the *facilitator* role (PA_{F1}(f)) to find new partners. The alternative ways to fulfil collaboration (cooperation plan) drive us to the notion of cooperation strategies[4]. Therefore, Figure 4 indicates such a process by the ‘choose strategy’ label. In order to satisfy the request ‘ask for new peers’, PA_{F1}(f) performs a broadcast request over its local acquaintances (peers). In particular, by the facilitator role, peer agent's local acquaintances enable access to global information; namely, each peer's global behaviour emerges from local interactions, e.g., see (Penserini et al., 2003; Penserini, 2002).

In our simple tests, for the strategy component ‘ask for new peers’, we decided to select only the active *supply chain managers* of each peer's agent platform. Moreover, the PA_{F1}(sc) has to establish a collaborative criteria (*negotiating phase*) in order to effectively fulfil the *order Q*. For the sake of simplicity, such a *supply chain manager* organizes its partners on a product availability basis, that is, it

[4] Despite of a cooperation strategy is composed of several components (Panti et al., 2001; Penserini et al., 2003), in such an example, we only describe the way to fulfil the ‘ask for new peers’ component.

fairly distributes the requested quantities trying to avoid to each partner a procurement phase. Each *supply chain manager* adopts the well known *crossed matrix* (or ABC) criteria based on the Pareto's law in order to decide the optimal procurement point, e.g., List 2 shows that the Acer LCD display belongs to the class AA of the crossed-matrix.

5 RELATED WORK AND CONCLUSIONS

Recent contributions to the VE's supply chain modelling come from the promising area of multi-agent systems, e.g., (Jennings et al., 2000; Pathak et al., 2000; Petersen et al., 2000).

In (Pathak et al., 2000) the authors describe how to model a supply chain scenario exploiting both the ZEUS Agent Building toolkit and the Generic Modeling Environment (GME). Such tools are able to deal with the problem analysis, the problem design, and the application realization phases. Moreover, they explain how to use the tools to define the agent properties (e.g., ontology, tasks, communication protocols) focusing more on agent modelling issues rather than on the agent coordination. Despite of they recognize the remarkable aspect that agents are often not perfectly rational and fully informed about the world in which they work; they do not characterize any agent roles to overcome such limitations. The AGORA multi agent architecture, described in (Petersen et al., 2000), aims to model functional aspects and the life-cycle of a virtual enterprise. The authors consider a homogeneous environment composed of enterprises, which use the same AGORA system, able to form temporary coalitions (VEs). That is, they do not deal with enterprise information systems heterogeneity. Furthermore, such a system can not model a peer-to-peer scenario characterized by autonomous entities (peers) free to interact each other without to a priori build up a central authority, i.e., an AGORA's instance, that control their communications. Probably one of the most complete and flexible agent-based approaches to model and build process management systems has been realized inside the ADEPT project (Jennings et al., 2000). For instance, ADEPT allows designers for dynamic, distributed, and unpredictable processes, besides, it is able to manage multiple (even though decentralized) organizations that concurrently participate to a given process. The authors detail their system architecture and functionalities, but no examples are given about how to configure each agent's role into a real world scenario, e.g., VE's supply chain scenario.

Thus, our paper presents and describes an agent-based framework prototype, required to cope as automatically as possible with virtual enterprise's supply chain management coordination issues. That is, each peer (person/organization) has an (software) agent platform that manages the peer's participation in the P2P coalition (virtual-enterprise). As far as we know, the results of the architectural design analysis in terms of agents' roles, needed to effectively deal with the inherently interaction relationships of a supply chain scenario, is quite original.

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