Multi-agent Middleware for the Integration of Mobile Supply Chain

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Abstract—With the development of mobile network and communication technology, traditional supply chain management is gradually updating to mobile supply chain management, and multi-agent technology has been considered as a very efficient method for supply chain management in mobile environment. After considering the characteristics and limitations of mobile supply chain, and according to the requirements in the manufacturing domain, this paper designs a multi-agent middleware for mobile supply chain management, aiming to solve integration problems and shield off network and terminal heterogeneity in mobile environment, which can achieve mobile supply chain dynamic integration and then improve the efficiency of supply chain management. Its feasibility and efficiency was demonstrated by experiments.

Index Terms—multi-agent middleware, mobile supply chain, intelligent agent, heterogeneity, ontology library

I. INTRODUCTION

In today’s global and dynamic business environment, competition among enterprises have transformed from company versus company to supply chain management versus supply chain management [1], and with the development of knowledge-based society, most of customers want to acquire the exact products and customized services with less cost, so a favorable supply chain management should ensure the objective to deliver the right product, at the appropriate time, at the competitive cost, and with customer satisfaction for keeping the competitive advantages [2]. Nowadays, supply chain involves managing a wide range of business partners and passing information from partners to partners in a sequential fashion is not good enough. With the development of communication technology and communication network, supply chain management in mobile environment has become more and more prevalent and necessary. Many enterprises are focusing on replacing traditional linear supply chains with more flexible and adaptive management method. Under this demand, mobile supply chain management is proposed, which can help firms to gain cost reduction, supply chain responsiveness and competitive advantages by using mobile devices to aid the conduct of supply chain activities [3]. Compared with traditional supply chain management, there are some limitations existing in mobile environment, for example, storage ability and processing ability of mobile terminals are so restricted and communication networks maybe are heterogeneous, traditional information integration technology for supply chain coordination, such as Electronic Data Interchange, e-hubs and so on, cannot meet the needs of supply chain management in the mobile environment well [4, 5]. At the same time, multi-agent technology is applied in more and more fields and has achieved many remarkable results, because of its advanced mentality and adaptive ability, multi-agent technology has been regarded as a very effective method for mobile supply chain management. The adaptability, self-government and sociality characteristic can help agents work well in dynamic, unstructured and complex environment and finally achieve real-time communication and favorable decision establishment [6]. In our paper, based on multi-agent middleware technology, we propose an agile supply chain management method in mobile environment which faces mobile customers according to the transforming orientation of supply chain management in manufacturing domain, aiming to achieve data synchronization, message transferring, services management and application integration. The multi-agent middleware for mobile supply chain management designed in this paper can work well in mobile environment, shielding off network and mobile terminal heterogeneity and offering lots of flexible interfaces for external applications by integrating some static or mobile agents.

The rest of the paper is organized as follows: research background related to multi-agent technology and mobile supply chain management is first introduced in section 2.
In section 3, we briefly describe the structure of the multi-agent middleware designed in our paper and analyze its characteristics. And then we discuss how to design the multi-agent middleware in section 4. Technology implementation and advantages of the multi-agent middleware is analyzed in section 5. Finally, we conclude the paper with future work.

II. RESEARCH BACKGROUND

With the advancement of communication network technology, traditional supply chain has been upgrading to mobile supply chain [7]. agile supply chain management is becoming more and more crucial. Certainly, research on the questions of supply chain management in mobile environment has become very important. In recent years, how to design a flexible and agile supply chain management solution in mobile environment has received considerable attention from both academia and practitioners [8]. Mobile supply chain management, which was proposed in the end of the last century, is based on the supply chain management platform and integrated with mobile terminal devices, advanced mobile technology and communication network [9]. As a characteristic supply chain, the mobile supply chain management should ensure that anyone can take necessary activities or utilize existing services at any time and at any place [9]. That means business activities are executed by entities and services are provided for customers regardless of time and location. The entities in the supply chain can transfer resources and services in mobile environment conveniently and efficiently, regardless of heterogeneity of mobile terminals and communication networks. The goal of mobile supply chain management is to improve channel efficiency and ensure mutual profits among partners, which should be supported by targeted and customized management methods and tools.

Compared with traditional supply chain management, mobile supply chain management has many obvious advantages. For instance, mobile supply chain management is very appropriate for capturing and managing continuously changing information and resources, and mobile supply chain can reduce the limitations of information interactivity and offer real-time services through providing some convenient, time-saving, and accurate means for the communications among supply chain entities [9]. Besides, high automation, simplification, standardization, and modularization also can improve the efficiency of processing critical information and reduce the uncertainty of supply chain management [10]. Its flexibility and extensibility are also better than traditional supply chain management method.

Undoubtedly, there are also some limitations in mobile supply chain management. First, the heterogeneities of mobile terminals and communication networks are inevitable, which have been regarded as the key problem in mobile distributed computing. Besides, the limiting bandwidth of mobile networks and restricted processing ability of mobile terminals also can affect the efficiency and speed of information transferring in mobile supply chain [11]. Therefore, in addition to the management problems in routine supply chain management, how to overcome the limitations and then achieve mobile management should be considered carefully. Because of these above particularities, the data or information integration methods in mobile supply chain should be different from conventional supply chain and the management mode should be flexible and distinctive.

Many scholars have found that previous integration technologies, such as Electronic Data Interchange, E-Hubs, can not be very helpful for solving the limitations because small and medium enterprises are difficult to bear the expense of Electronic Data Interchange and there are some value-gap and limitations in E-Hubs. At the same time, multi-agent technology is regarded as an efficient method for supply chain management because of its advanced mentality, autonomy, adaptability, and sociality [12]. As an important branch in artificial intelligence domain, agent technology has been applied in more and more domains and offered many advantages for substantial practical applications. According to its development momentum, we can speculate that its application will be more and more extensive. In the mobile supply chain management system, multi-agent can be designed as a layer between the mobile system layer and the mobile application layer, offering a favorable communication bridge for mobile terminals and application servers, and supporting dynamic interaction between supply chain entities in order to create the optimal supply chain organization structure and improve management efficiency [13].

III. THE STRUCTURE OF MULTI-AGENT INTEGRATION MIDDLEWARE

As an independent system, middleware is used to share information and resources between different platforms, and shield off the differences among network hardware platforms, heterogeneities of operating systems and network communication protocols, providing transparent and efficient services. As a representative application of middleware, multi-agent integration middleware is to achieve some specific functions of middleware by using multi-agent technology, which can well serve for mobile supply chain management by inter-operation across mobile network nodes at the abstractive level conveniently and availably with its great potential in supporting management in mobile environment [10].

In general, multi-agent integration middleware can manage many different function agents or resource agents uniformly and offer a flexible and favorable communication media between mobile terminals and external applications. In this way, multi-agent middleware should have the ability of effectual communication mode and management strategy, so the major challenges in designing the multi-agent integration middleware are to consider the behaviors and functions of individual agent, managing their resources and status efficiently, and implementing effective interaction for sharing goals through real-time communication. Of course, shielding off heterogeneity and offering uniform
and flexible interfaces for external applications should be considered carefully too [14].

In the multi-agent middleware, each agent takes charge of its own functions. In different situations, mobility of agents and interaction between them are distinct. For instance, in unstable environment, asynchronous transfer mode and clone-migration are reasonable. According to the actual requirements of mobile supply chain management in the manufacturing domain, we divide the whole structure of mobile supply chain as three layers: distribution service layer, operation function layer and enterprise resource layer as Fig. 1 shows.

![Figure 1. Structure of mobile supply chain](image)

In this hierarchical framework, every layer is controlled by lots of corresponding agents. Every agent, whether mobile or static, provides some corresponding services and functions. For example, agents in the distribution service layer are responsible for receiving orders and then distribute special information or services for customers, while agents in the enterprise resource layer take charge of managing resources. The multi-agent integration middleware integrates the functions of these different agents and furnish right communication strategies for different agents’ interactions, offering many kinds of personalized services to external applications with uniform interfaces. The most important is that it can offer available data integration and synchronization measure in order to adapt to mobile environment. The ultimate goal of multi-agent middleware is to optimize supply chain organization scheme, and then implement personalized and efficient mobile supply chain management.

Based on the theoretical foundation of system software and multi agent technology, we refer to Agilla [6] to design a multi-agent middleware and make some modifications according the actual requirement. The system architecture is shown in Fig. 2. It is also divided into three layers:

1. The top layer is called the agent-layer, which contains many static or mobile agents, being responsible for creating independent agents in accordance with specific business processes and offering a comfortable working environment for them. In this layer, every agent has its function and is able to execute activities independently. For example, order agent can receive the order via mobile terminals by customers and then send it to specific agents, communicating with other agents and waiting for the response.

2. The second layer contains the core components for managing agents, being responsible for establishing interaction rules between agents and providing some

![Figure 2. Framework of the multi-agent middleware](image)

A. Agent Layer

In general, the agents in this middleware, integrating code, data, behavior, status and some other components together, can autonomously execute activities and fulfill their functions on behalf of mobile supply chain entities. As mentioned above, the core function of this layer is to create different agents according to business requirements and determine their behaviors. In order to implement mobility, two different schemes for agent migration are designed: direct transition and clone migration. As to the former, both the code and state of agents transfer to the destination node and then resume their execution at the proper time, but the agent no longer exists on the original node. On the other hand, clone migration means that a copy of the original agent arrives at the destination node and then resume their execution at the proper time when they finish their jobs [15].

B. Management Layer

In the management layer, there are several key components for managing agents and their communications. Among them, the most important parts are agent manager, communication manager, facilitator manager, interface manager and ontology library. The agent manager is responsible for managing agent
registration and allocating necessary memory and unique ID for these agents. In the communication manager module, the communication rules and interaction strategies are maintained between different agents. In our multi-agent middleware, an agent always interacts with other agents using the agent communication language and protocols integrated in the agent development platform. When an agent has registered in the agent manager component, the facilitator manager provides necessary explanation for it and offer yellow-page service, in order to ensure other agents can search and transfer corresponding services conveniently. For improving the flexibility and extendibility of the multi-agent middleware and shielding off the heterogeneity of mobile terminals and communication network, uniform interfaces are designed to integrate with external applications, such as web application interface, mobile application interface and so on. In mobile supply chain management, some data or information can come from different information sources, which results in semantic heterogeneity. Ontology library can be built for solving the problem.

C. Operating System Layer

The bottom layer of the multi-agent middleware is operating-system layer. Nowadays, there are many different mobile terminal operating systems, such as Symbian, Windows Mobile and Linux. How to shield off the heterogeneity among these systems and provide uniform interfaces and services for them is the core task of this layer. In doing so, the multi-agent middleware offers two invoking measures for mobile terminals. They can call middleware services by K-Java applications and interview the agent middleware through WAP browsers. In order to overcome the limitations produced by communication network, the operating-system layer offers some services to maintain the reliability and stability of mobile network nodes, such as asynchronous communication. In this communication mode, senders can temporarily disconnect to network after sending requests. Considering the bandwidth limitation of mobile network, we make each agent divided into tiny packets to minimize the bad impact of message loss which is quite common in mobile network [16].

IV. MULTI-AGENT MIDDLEWARE DESIGN FOR MOBILE SUPPLY CHAIN MANAGEMENT

In this paper, the multi-agent middleware is used to achieve mobile supply chain management, whose framework is shown in Fig. 3 aiming to realize service integration and data synchronization.

First, we designed a lot of agents, which are divided into two types: mobile agents and static service agents. Static service agents only execute their activities in fixed computing nodes, which are responsible for dealing with requests and then offering required services. While mobile agents can move freely across mobile network nodes and communicate with static service agents, adhering to interaction strategy and communication protocols. Every agent needs to register in the agent management module and update their newest information and services when some changes happen in order to ensure other agents can capture the latest information.

Figure 3. Mobile supply chain management framework based multi-agent integration middleware

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The dispatch agent, supply agent, resource agent, delivering agent and inventory agent are designed as static service agents in our multi-agent system. Each of them has distinct responsibilities. Details are as following:

1. The dispatch agent is responsible for searching for suitable supplier according to customer orders and returning results to the order agent.
2. The supply agent is responsible for describing the resources and services provided by suppliers.
3. The resource agent devotes to managing resources of mobile network dynamically and helping other agents obtain data.
4. The deliver agent takes charge of producing delivering statements in order to achieve resource mobility in mobile network.
5. The inventory agent is responsible for checking the inventory status of suppliers or manufacturers. At the same time, the order agent is designed as a mobile agent. It can move between different network nodes and communicate with other agents to obtain corresponding services.
6. The order agent is responsible for transferring order request to corresponding nodes in mobile supply chain and makes contracts with other agents, carrying with order information from customers. Finally, the order agent sends the result to customers.

Well-behaved communication between different agents is obligatory. In the middleware, agents communicate with each other using agent communication language messages, which are integrated in our development platform and offering convenient interaction tools for agents. Considering that asynchronous transmitting mode is more suitable for data transferring in mobile environment, communications between agents are designed by using asynchronous message transmitting. For example, when a customer places an order through a mobile telephone or other mobile network equipments, the order agent receives the order, and then move in mobile network so as to find required agents to transfer information. Then, the order agent submits the order to them and waits for response. In the end, the customer may receive the expected result.

Considering the particularities of mobile network, we choose asynchronous transferring method as communication mode to avoid communication failure because of network instability. In this way, mobile terminals can disconnect with network temporarily and reconnect network after a period of time, without worrying about information losing. By means of the interaction between dispatch agents, supply agents, resource agents and other agents, an optimized mobile supply chain organization structure can be created and customers can obtain efficient and personalized services.

The multi-agent middleware offers some flexible and convenient methods for the interactions among supply chain entities by managing a uniform information library. In the middleware, all agents have registered their information and services in the management module, information sharing and communication are very convenient. In this way, every supply chain entity can get timely information of other entities very easily, so bullwhip effect existing in traditional supply chain management can be released to a certain extent. The most important is that this multi-agent middleware can improve the efficiency of mobile supply chain management and provide better services for customers.

V. THE MULTI-AGENT MIDDLEWARE IMPLEMENTATION

In order to implement the multi-agent middleware and then apply it to mobile supply chain management, we deploy the multi-agent middleware in one host server, whose computing ability is far more than mobile terminals, providing middleware services for mobile terminals and parsing for upper level applications. Mobile terminals can utilize K-Java applications or through lightweight browsers to call the services of this middleware. After considering the requirements of cross-platform and comparing some typical multi-agent system development platforms, we choose JADE (Java Agent Development Framework) to develop the multi-agent middleware, because it has integrated communication strategy and interaction protocols, which can guarantee communication and mobility achievement more easily. With the aid of the agent development platform, we design multi-agent integration and agent management well without worrying about the problems brought by system or terminal heterogeneity. Moreover, the communications between agent middleware and mobile network are concealed from terminal users, users can transfer the service provided by the multi-agent middleware conveniently and efficiently.

The multi-agent middleware consists of basic functions, including agent information management, agent mobility management, directory service, mobile terminal user management, security management and so on. First, we design the agents, including the order agent, dispatch agent, supply agent, resource agent, deliver agent, inventory agent and achieve reasonable management measures for them. Herein, only the order agent is a mobile agent. Furthermore, every agent obtains one valid AID (directory of agent identifiers) after registering with the agent management module, which can offer yellow-page service and life cycle management. Mobility and communication strategy also are well ensured with protocols supported in the JADE platform.

In order to implement mobile terminal user management, we design a user profile in the middleware to store user information, including basic registering information and some personalized information. With the information, the middleware can provide personalized services for different customers. Through directory service, authorized supply chain entities can search agent services in mobile network. As for resource management achievement, we first assign resource management object for every agent, maintaining and managing data, files, threads and so on. Besides, standard security interface is
used to support data encryption, digital signature and other security measures in order to ensure the safety of the multi-agent middleware. The main problems of the multi-agent middleware are discussed as followings:

A. Agents Design

In the process of designing agents, the concept of ‘contain’ is introduced, which can hold up many different agents and provide the working environment for them. First, we design and implement these required agents with the agent classes integrated in the JADE platform, and design their functions. As for the order agent, we also actualize its mobility and transferring conditions. The registration and resource allocation for agents are easily implemented by the agent manager module. After agent registration is finished, agent status management and yellow-page service are also be achieved by the agent manage module. Certainly, as independent software objects, these agents have internal structures, containing input, output, knowledge base, communication and reasoning modules.

B. Communication Mechanism

In this middleware, different agents communicate with agent communication language messages, which can be described by agent communication language message classes with the API provided by the agent development platform, and message interactive model is asynchronous. Before sending messages, agents create one new agent communication language message object, and then attribute values are set, such as receiver, content and so on. Moreover, agent communication language message also determines the behavior mode, which will affect response of other agents. With this uniform description measures, communications among different agents become easy and convenient.

C. Uniform Data Description

For achieving uniform data description and resources in mobile environment, we use XML and RDF (Resource Description Framework) to dispose data with different structures. First, we execute meta-data abstraction, and then deal with these meta-data to describe resources of different network nodes as a flexible and uniform style. In our multi-agent middleware, the data from different supply chain entities can be transformed to uniform format through this method.

D. Ontology Library

In order to solve semantic heterogeneity and message parsing problem, an ontology library was designed and achieved. In this ontology library, many terminologies and concepts relating to the multi-agent system are used to describe the multi-agent integration middleware. As a public vocabulary, ontology library can achieve knowledge sharing and reusing. Herein, knowledge contains ordinary agent models and basic communication messages between agents. And it is also useful for the communications and inter-operability among agents in the middleware.

E. Interfaces

According to the requirements, we have realized some interfaces in this middleware, such as web application interfaces, mobile application interfaces, security management interfaces and so on. In order to ensure that external applications can call the functions and services provided by the middleware. We complete and design the member variable as private in every interface. In this way, destroying encapsulation can be prevented.

F. Mobile Terminals

We choose J2ME to develop some applications, which can well coordinate with the middleware by means of platform independence of the Java language. Using legitimate account, mobile terminal users can join in mobile supply chain management. After customers place orders via some mobile communication devices, the order agent is aroused and moves into the multi-agent middleware for finding corresponding agents and communicates with them. Under the help of other agents, the order agent returns the result to customers.

VI. SIMULATION EXPERIMENT

After theoretical analysis about the multi-agent middleware, we apply it in a small case study to validate the practicability and reliability of the multi-agent middleware. The process is as following:

1) A customer submits an order for buying flowers from terminals in mobile network.
2) After the order is submitted, the order agent starts and moves into the multi-agent middleware to find required agents and prepares for submitting the order to them.
3) The corresponding agents in the middleware execute their activities and communicate with other agents.
4) The middleware returns the result to the customer.

Fig. 4 and Fig. 5 show a successful operation. Herein, Fig. 4 shows the process of starting the order agent, and Fig. 5 shows the service provided by the supplier agent and related information.

Figure 4. Order agent
Through some simulation experiments, we find the multi-agent middleware really can improve the efficiency of mobile supply chain management. Furthermore, some problems existing in traditional supply chain management, such as bullwhip effect and coordination tardiness also have been relieved. So the method based on multi-agents can offer a new and functional way for supply chain management.

Compared with traditional middleware, there are some advantages. First, the network bandwidth demand is lower because it has utilized agent mobility well. Second, the asynchronous transmission mode ensures the middleware to support off-line computing, which allow mobile terminals to disconnect network provisionally. Its mobility and portability are also favorable. Furthermore, in the mobile environment, supply chain management based on the multi-agent middleware is also more adaptive than other service calling methods. Certainly, its cross-platform, flexibility, expansibility are all favorable.

Table 1 shows some advantages of the multi-agent middleware than traditional C/S processing mode.

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<th>C/S mode</th>
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<td>Flexibility</td>
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VII. CONCLUSIONS

By combining the middleware and mobile agent technology, this paper presents a mobile agent middleware specifically designed for agile mobile supply chain management. After considering the characteristics and limitations of mobile network and comparing mobile supply chain management with traditional supply chain management, we give a brief design of a multi-agent middleware, analyzing its framework and main functions in every layer. Furthermore, we discuss how to implement it using existing technologies and analyze its advantages.

As discussed above, mobile supply chain management based on the multi-agent middleware model really can improve the flexibility and expansibility of the whole supply chain management. Furthermore, it can solve the data integration among different mobile equipments and achieve distributing storage. Asynchronous transmission mode insures the applicability in mobile environment. The further research is to integrate the multi-agent middleware with some existing applications in the manufacturing domain and take more measures to improve the efficiency and reliability of the whole supply chain management system.

APPENDIX ORDER MANAGEMENT PROCESS IN SUPPLY CHAIN

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