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Mobile Computing and Auto ID Technologies in Supply Chain Event Management - An Agent Based Approach

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MOBILE COMPUTING AND AUTO-ID TECHNOLOGIES IN SUPPLY CHAIN EVENT MANAGEMENT – AN AGENT-BASED APPROACH

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Abstract

*This paper presents the architecture of an agent-based system for Supply Chain Event Management. Auto-ID (= Automatic Identification), mobile and agent technologies are combined within this agent-based system called CoS.MA (**Co**operative and Ubiquitous **S**upply-Network **M**onitoring **A**gents) in order to realize permanent tracking & tracing of resources (e.g. products, vehicles) in supply networks and to visualize resource-related key performance measures. Potentials and challenges in realizing supply networks by means of such technologies are discussed. CoS.MA is based on a peer-to-peer network architecture. Each member (node) of a supply network will be represented by one CoS.MA agent platform. Mobile agents may migrate between those agent platforms to integrate and to visualize distributed data. An overview of existing agent-based prototypes in Supply Chain Event Management is given to show the state-of-the-art in this emerging research area.*

Keywords: Supply Chain Event Management, Software Agents, Auto-ID, Mobile Computing

1 INTRODUCTION

Today's supply networks are characterized by high complexity and are organized in distributed global supply networks consisting of several enterprises with overlapping supply chains. Information about products, unfinished goods and raw materials along such supply networks are hard to acquire and to manage with conventional methods based on local ERP (Enterprise Resource Planning) systems. In this paper the concept of Supply Chain Event Management (SCEM) supported by Mobile Computing and Auto-ID Technology in conjunction with (mobile) software agents for tracking, monitoring, and decision support is introduced. The remainder of the paper is organized as follows. Section 2 discusses the concepts of SCEM and Supply Chain Visibility. Section 3 gives a short overview of supporting technologies – Mobile Computing, Auto-ID and Agent Technology – for SCEM. Potentials and challenges of realizing supply networks by means of such technologies are discussed. In section 4, the architecture of the agent-based SCEM system *CoS.MA* (***Co***operative and Ubiquitous ***S***upply-Network ***M***onitoring ***A***gents) is described. The long-term goals are to accelerate and improve existing business processes in supply networks and to visualize the whole supply network by means of the technologies integrated in *CoS.MA*, so that all members can react in time to unforeseen exceptions or even can anticipate such exceptions. Section 5 gives an overview of related work to show important research directions. Section 6 summarizes some conclusions and identifies future work.

2 SUPPLY CHAIN EVENT MANAGEMENT AND SUPPLY CHAIN VISIBILITY

At present, no standard definition exists for Supply Chain Event Management (SCEM). ARC Advisory Group (2002) defines SCEM as one part of Supply Chain Process Management to identify and to monitor events in the supply chain, which is also called *tracking*. The counterpart is Supply Chain Performance Management that identifies problems in supply chains from observed data over a certain time period, which is also called *tracing*. In this paper, the following definition is preferred: SCEM is a concept of tracking, monitoring and measuring events in supply networks (Nissen 2002), where disruptions will be identified and solved. Existing problems concerning today's tracking and tracing systems are their reliance upon stale data, their missing control capabilities, and their passivity, which forces the process owners themselves to search for the information they need. Furthermore, they are not monitoring the whole supply network (Bretzke et al. 2002, p. 2).

Supply Chain Visibility (SCV) is one precondition that all members of a supply network can react in time to unforeseen exceptions. Through SCV, for example, the so-called "bullwhip effect" can be significantly reduced (Simchi-Levi, D. and Simchi-Levi, E. 2002, p. 17). Permanent tracking of all products and machine data is one crucial requirement for SCV. Therefore, a visualization and summary of facility and product-related key performance measures (e.g. order fulfillment or supplier effectiveness) should be given. Furthermore, process owners should be alerted when performance measures violate predefined thresholds (Simchi-Levi, D. and Simchi-Levi, E. 2002, p. 17). In the following section, we introduce important technologies – Mobile Computing, Auto-ID and Agent Technology – for realizing SCEM and SCV in supply networks.

3 SUPPORTING TECHNOLOGIES FOR SUPPLY CHAIN EVENT MANAGEMENT AND SUPPLY CHAIN VISIBILITY

3.1 Agent Technology

AgentLink, the European Co-ordination Action for Agent Based Computing, defines agents as "autonomous, problem-solving computational entities capable of effective operation in dynamic and

open environments" (Luck et al. 2003, p. 10). Platforms that support several autonomous agents and their interactions are called Multi-Agent-Systems (MAS). The characteristics of agents (e.g. autonomy, pro-activity or adaptivity) lend themselves to model, simulate and realize distributed supply networks. Thus, agents have been successfully applied to a variety of supply network processes such as production planning, scheduling and transportation (Fox et al. 2000).

3.2 Mobile Computing Technology

Through third-generation mobile networks (e.g. UMTS) data transfer rates are now available theoretically up to 2 MBit/s. Nevertheless, in today's enterprises the use of mobile devices such as mobile phones or smart phones is often limited to make calls and to use the short message service (Van Akkeren and Harker 2003, p. 223), although today's mobile phones still support Java- or WAP-based applications. Beyond data transfer rates enterprises are often concerned about security, service continuity and cost (Marshall et al. 2004, p. 8). With *Mobile IPv6*, for example, the implementation of strong authentication and encryption features (IP Security) will improve security in mobile networks (Nokia 2001, p. 4). Furthermore, a unique static IP address can be assigned to the mobile device, so ubiquity and seamless roaming will be possible within supply networks.

3.3 Auto-ID Technology

For tracking & tracing resources along supply networks Auto-ID technology plays an important role. The Auto-ID technology developed by the Auto-ID Center (a non-profit organisation) consists of the following components combined in the EPC network (Floerkemeier 2004, pp. 2-10):

- Radio Frequency Identification (RFID) tags and readers: A tag is only a few square millimeters in size and is made up of a chip and an antenna. It can be scanned by special readers from a distance up to some meters dependent on the technology used.
- Electronic Product Code (EPC): EPC as the core of the EPC network is used for identification of physical objects in the real world. The Auto-ID Center released several different versions. The most common one is a 96-bit version with two different formats (General-Identifier and Serialized-General-Trade-Item-Number).
- Object Naming Service (ONS): ONS is a look-up service that delivers one or several IP addresses to the identified EPC.
- Savant: Savant acts as middleware that integrates the other components. The main functions are transmitting, filtering and bundling incoming data streams from readers to other services like ONS or existing enterprise applications.
- Physical Markup Language (PML): PML is a XML-based markup language to describe physical objects for standardized data exchange between the components of the EPC network.
- EPC Information Service: This service delivers product-related data of the observed objects.

An extended overview of this technology can be found in Floerkemeier (2004). Organizations like EPCglobal (formerly Auto-ID center) or EICAR RFID Task Force are strong forces behind the global diffusion of RFID-technology. Nevertheless, cost and security issues are still to be solved.

3.4 Potentials and Challenges

Integration of mobile networks and Auto-ID technology in conjunction with agent technology seems to be a promising approach. The information about the status of delivery or manufacturing processes is thus available at any time through permanent tracking. Mobile devices are needed for transmitting this information into the Tracking or SCEM system in the enterprises and to inform mobile workers directly. An agent platform can act as a middleware for the integration of pertinent data in distributed information systems along the supply network with mobile agents as information gathering entities.

Nevertheless, these technologies today are not mature enough for trouble-free execution of the given tasks. Challenges to be solved are:

- Security: Security issues concerning mobile agents and mobile devices remain unsolved (Luck et al. 2003, p. 13). Mobile Agents with Public Key Cryptography, for example, should be implemented for inter-organizational collaboration.
- Trust and Privacy: Beyond security, trust issues concerning autonomous mobile agents (Luck et al. 2003, p. 51) and privacy issues concerning Auto-ID have to be solved (Günther and Spiekermann 2004, pp. 245-246).
- Available resources: Krishnamurthy and Zeid (2004, p. 177) note that mobile agents require significant resources to execute. Smart phones and PDAs have limited resources, so resource-intensive tasks should be executed by stationary agents, which are not located on mobile devices
- Information overflow: The mass of products and machine data that have to be scanned can yield problems in time-critical processes due to constraints in available bandwidth and computing power (Palmer 2004).

4 CoS.MA – AN AGENT-BASED ARCHITECTURE FOR SCEM

4.1 Goals of the Architecture

In this section, we propose the agent-based architecture *CoS.MA* to make use of existing potentials in supporting business processes in SCEM. CoS.MA's mobile agents are not limited to information gathering from legacy or ERP systems for the field staff. Besides that, agent-based decision support for mobile workers and autonomous agent-based negotiation between all members of a supply network will be possible in order to realize more effective processes. The challenge here is to integrate the distributed information of all members of a supply network so that transparency will be achieved.

In summary, the following points are addressed in the CoS.MA architecture:

- Event notification: Through tracking with RFID and mobile technology, resources (e.g. commodities, products, and vehicles) can be monitored along the whole supply chain.
- Exception management: When disruptions occur agents may negotiate with each other to find a new solution to fulfill the disrupted process or at least provide advice to human users in the form of decision support.
- Tracing: The analysis of historical data for disruptions, irregularities and other problems should be realized, so that future planning processes can be more effective.
- Supply Chain Visibility: All partners of the supply network can access actual data like available stock, delivery status, actual lead times, and costs via web interfaces and mobile devices.
- Personalization: Users can initialize agents to provide only the information that are necessary.
- Extensibility: The architecture is extendable to fulfill new tasks. New agent platforms can be added when new members become partners of a supply network.
- Peer-to-peer based architecture: According to the structure of supply networks, it seems feasible to implement a decentralized, peer-to-peer based system. This preserves the necessary independence of the enterprises within the supply network and provides a flexible mechanism for adapting to changes in the supply network structure (e.g. adding new network partners).

4.2 CoS.MA

The CoS.MA architecture consists of three layers: the user interface, the agent platform, and external applications (see figure 1). The user interface is characterized as the communication layer which is

represented by user agents interacting with users via web and mobile devices when information on resources (e.g. orders) are gathered (pull mode) and when important status information are proactively distributed or unforeseen events occur in the supply network (push mode).

The agent platform (layer 2) hosts supporting services (e.g. ontologies and negotiation protocols) for the agents. For each monitored resource (e.g. a product, an order, a vehicle, etc.) a monitor agent is triggered via a user agent. Monitoring agents search for desired status information in external applications (e.g. in ERP systems), databases or Tracking & Tracing systems (layer 3) by means of wrapper agents which collect the corresponding status information (e.g. using Web Services). The content converter (see figure 1) transforms XML based content by means of XSLT into formats (e.g. HTML, WML) for different devices (e.g. web and mobile phone browsers).

Resource agents are mobile agents which have the capability to negotiate with the resource agents on other CoS.MA agent platforms about prices, quantities, availability of resources, etc. Mobile Computing and Auto-ID technologies (e.g RFID) are the cornerstones of the CoS.MA architecture. Ontologies used by the resource agents will be based on existing standards (e.g. RosettaNet).

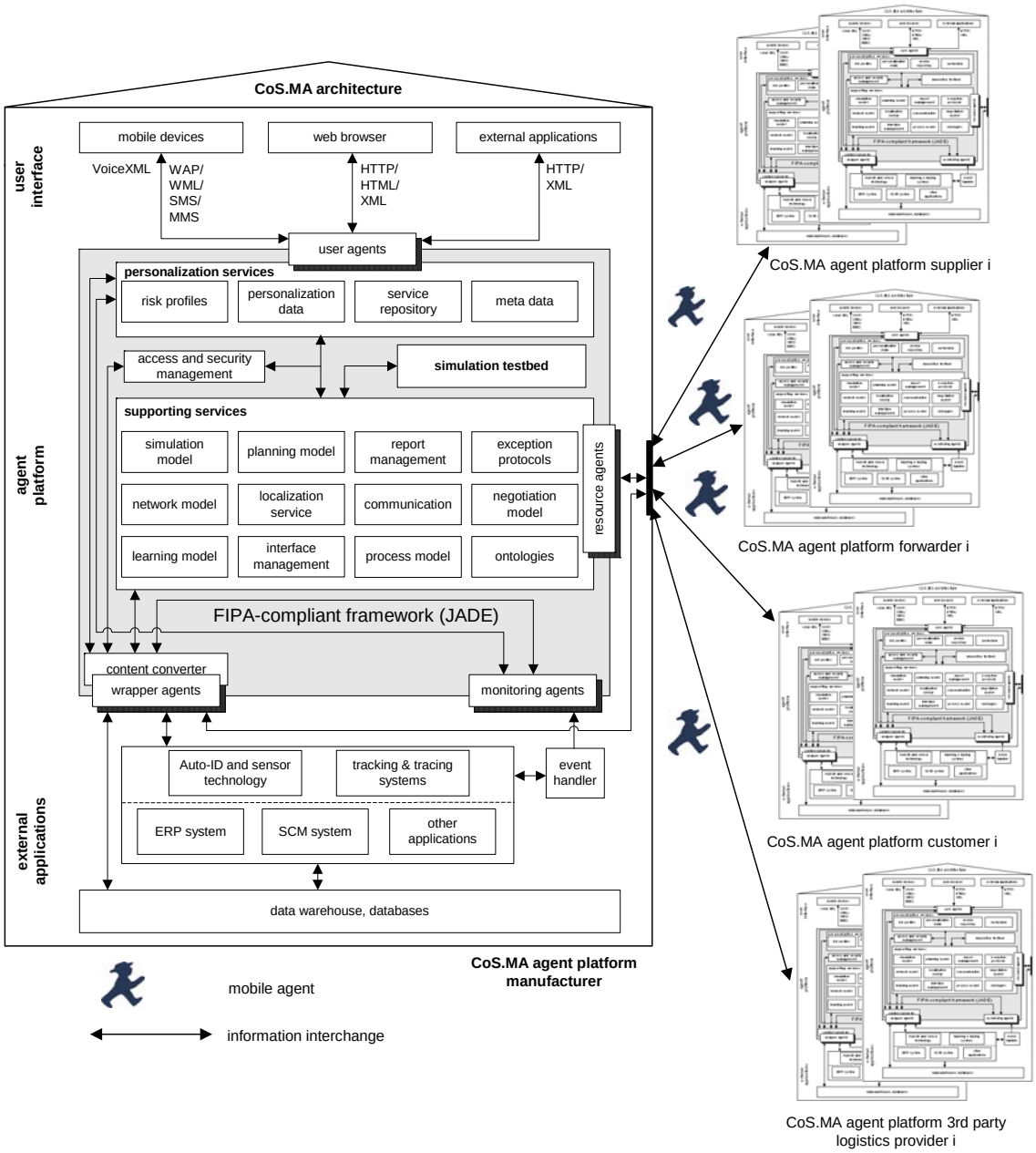

Figure 1. CoS.MA architecture

5 RELATED AGENT-BASED APPROACHES IN SCEM

This section summarizes related projects in SCEM. Existing agent-based prototypes that address SCEM tasks are presented in table 1.

Multi-Agent-System		**ECTL-Monitor**	**PAMAS**	**DIALOG**	**PROVE**	**CoagenS**
Authors and Year of Publication		Hofmann et al. (1999)	Zimmermann and Paschke (2003)	Kärkkäinen et al. (2003)	Szirbik et al. (2000)	Dangelmeier et al. (2004)
SCEM	area of scope	tracking and tracing	tracking and tracing	tracking of products by means of RFID	monitoring of products in VEs	monitoring capabilities in the whole supply network
	supply network architecture	peer-to-peer	peer-to-peer	peer-to-peer	not fixed	peer-to-peer
	use of RFID	no	intended	yes	no	no
MAS architecture	agent roles	user, retrieval and service provider agents	order gathering, coordination, surveillance and wrapper agents	agents are assigned to the tagged product	mobile monitoring agents, mediator agent	work agents
	agent coordination	co-operative	co-operative	co-operative	co-operative	co-operative
	agent communication	self-developed language	FIPA-ACL	XML-based for future versions	XML-based language	XML-based language
	agent negotiation	not supported	not supported	not supported	bilateral	multilateral
	framework	self-developed framework	FIPA-OS	self-developed framework	self-developed framework	in conformity with FIPA
	programming language	Java	Java	Java	Java	Java
	ontology	no explicit ontology	no explicit ontology	no explicit ontology	XML-based ontology	XML-based ontology
	planning algorithms	not supported	not supported	not supported	agent mediated negotiation	based on rules, agent mediated negotiation
	system access	Web interface	Java GUI	mobile devices, Web interface	Java GUI	Web interface, Lotus Notes GUI
	extensibility	no	yes	yes	yes	yes
Agents' characteristics	adaptivity	no	no	no	intended	yes
	autonomy	yes	yes	yes	yes	yes
	reactivity	yes	yes	yes	yes	yes
	pro-activity	no	yes	yes	yes	yes
	mobility	no	no	no	yes	no
	social ability	yes	yes	yes	yes	yes

development status	prototype realized	prototype realized	prototype applied by industrial project partners	prototype realized	CoagenS is released by PAVONE AG

Table 1. Existing Prototypes of MAS in Supply Chain Event Management

The MAS ECTL-Monitor and PAMAS are two research prototypes, which address the basic concepts of tracking and tracing in supply networks. In contrast to these prototypes, DIALOG is an advanced tracking system that supports several sensor and Auto-ID technologies such as RFID. It is the only agent-based prototype in SCEM that enables user access to the system via mobile devices. It is released under the Lesser General Public License (LGPL). A further, but extended research prototype exists with PROVE, which solves problems in supply networks through agent-based negotiation. CoagenS is a complex MAS addressing several issues in SCEM such as disposition, monitoring and resource management applying heuristics and agent-based negotiation for problem solving (Dangelmeier et al. 2004).

In the joint project Agent.Enterprise (Frey et al. 2003) different supply chain management tasks such as production planning, distribution or Tracking & Tracing are addressed by means of several MAS (e.g. IntaPS, KRASH and FABMAS for production planning, ATT/SCC for T & T and DISPOWEB for supply chain planning) which are integrated into one architecture. The ATT/SCC project seems an interesting approach in SCEM, but no prototype is presented yet.

An interesting work is also presented by Krishnamurthy and Zeid (2004). They describe an agent-based architecture for information access to existing ERP or legacy systems by means of mobile devices. The architecture is based on Java technology. XML is used for inter-agent communication. They are only considering the intra-enterprise level, not the whole supply chain or network.

6 CONCLUSIONS AND FUTURE WORK

Product tracking and tracing in SCEM is today mostly limited to single supply chain members. The presented peer-to-peer based architecture CoS.MA is aimed to integrate data from single members, so that all members have a visualization of pertinent data. Furthermore, with support from Auto-ID and mobile technologies permanent tracking and tracing of products in the whole supply network will be possible. Currently, the implementation of a prototype system based on the CoS.MA architecture and specified in UML (Unified Modeling Language) notation is in work. A critical factor for adopting CoS.MA and guaranteeing easier acceptance in real business environments will be the implementation of solutions for security and privacy issues. A future step will be the migration of mobile agents to other agent platforms on mobile devices in order to realize better personalization in information delivery. It is intended to simulate typical business processes in supply networks based on real-world data from business partners.

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