Agent-Based Integrated Services for Timber Production and Sales

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I-commerce extends e-commerce by getting customers more involved so that contractors can more efficiently fulfill orders. The Casa project focuses on developing an agent-based information and trading network to help establish integrated services in forestry and agriculture.

The ability to access and send information from just about anywhere—one of the prime advantages of pervasive computing—is transforming the way we live and work. Pervasive computing's advantages have strengthened countless industries, and now there is a palpable need to enhance just-in-time production and trading in agriculture and forestry. To solve some of the problems in forestry and agriculture, the German Research Center for Artificial Intelligence and the Saarland Ministry of Economics founded the Cooperative Agents and Integrated Services for Logistic and Electronic Trading in Forestry and Agriculture (Casa) project.

The Casa project focuses on developing an agent-based information and trading network (ITN). In particular, the project seeks to establish mobile, integrated services in selected application scenarios within forestry and agriculture. Casa ITN supports the main business processes that users perform in customer-oriented dynamic timber production, mobile timber trading, and electronic cereal trading.

The paradigm that informs the Casa ITN project is *integrated commerce*, an operational extension of traditional e-commerce that entails getting customers more involved in ordering activities so that contractors can more efficiently fulfill orders. I-commerce also entails more effective practical integration of supply-chain processes. In this light, Casa ITN offers its users several i-commerce techniques for negotiating, communicating, and exchanging information more effectively. We anticipate that these techniques will lead to more effective integration of production, logistics, and trading processes in other industries as well.

Holonic agents and services

The Casa ITN system differentiates between the following participant groups: producers, buyers, retailers, and logistics companies. Casa ITN represents each member of these groups with an appropriate kind of software agent called a *holonic agent*.[1-3] Holonic agents accomplish complex (mostly hierarchically decomposed) tasks and resource allocations in the selected application scenarios. They also coordinate and control the activities and information flows of their subagents. In a holonic multiagent system, autonomous agents can join other agents to form, reconfigure, or leave a holon.

This holonic agent technique lets personal assistants that represent human users act on behalf of their users even if those users are offline. Personal assistants operate as the coordinating heads over a set of other specialized agents designed for enhancing individual negotiation, auction participation, information location, and strategic trading.

In addition to representing users with agents, Casa ITN represents each corporation with a special holonic agent system according to each corporation's task-oriented classification. These subdivisions treat corporations from the perspective of information management, logistics, and production planning. Information management services provide information either on certain products and related production processes or on current market situations and potential competitors. Logistics services support coordinating machines for production and transport, human resources, and storage capacities. Finally, production planning services support short-, middle-, and long-term product planning cycles.

A corporation holon consists of several holonic agents, each of which represents a special department and its corresponding tasks and services. Because Casa ITN can use the roles of buyer and retailer and seller and producer interchangeably, we model both

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with similar holonic agent structures, and we distinguish between buyers that either have or do not have logistics departments.

We developed agent-based services for a distributed virtual marketplace to facilitate different kinds of trading between the participants within Casa ITN. These trading types can include multiple online auctions or sales through fixed or negotiable prices in bilateral negotiations. Each registered user in Casa ITN might, for example, initiate and perform one or multiple auctions of its own goods and products at any time, anywhere.

The aggregate of Casa ITN agents provides several services to its users:

- *Auction mechanisms*. Agents facilitate several auction types, including Dutch, English, Vickrey, and First-Price-Sealed-Bid auctions. At first-price, open-cry, so-called English auctions, bidders win with and have to pay the amount of the highest bid. In descending price, open-cry, so-called Dutch auctions, the auctioneer sells a single item at the first incoming bid. At first-price, sealed-bid auctions, each bidder submits one bid unaware of all other bids; the highest bidder wins and pays the amount of the bid. Similarly, at second-price, sealed-bid, so-called Vickrey auctions, the winning bidder pays the price of only the second highest bid.
- *Integrated services for dynamic pricing*. Agents collect information on transportation costs and other constraints to meet as a decision-support service for its users.
- *Logistics services*. Agents provide dynamic transportation scheduling and planning. We use an extended version of the Contract Net protocol, which relies on simulated trading to optimize transportation planning and scheduling.[4,5]
- *Information management*. Agents gather relevant information on behalf of their users in different trading and production settings.
- *Mobile services*. Agents enable the mobile services that let users access most of the Casa ITN on WAP-enabled mobile devices.

Together, these services form the basis for establishing an ITN for forestry and agriculture. The forestry and agriculture industries are so dynamic that if an information system is to be truly useful, it must offer just-in-time services.

Casa ITN's application scenarios include customer-oriented dynamic timber production, mobile timber sales, and electronic cereal trading. In the Casa ITN system, foresters and timber harvesters cooperate with the service-providing agents to satisfy an individual customer's order and to deliver a certain quantity of timber at a given time. Registered users can set up and participate in multiple timber auctions through WAP-enabled mobile devices. These registered users can also trade grains through auctions or multilateral negotiations with interested parties.

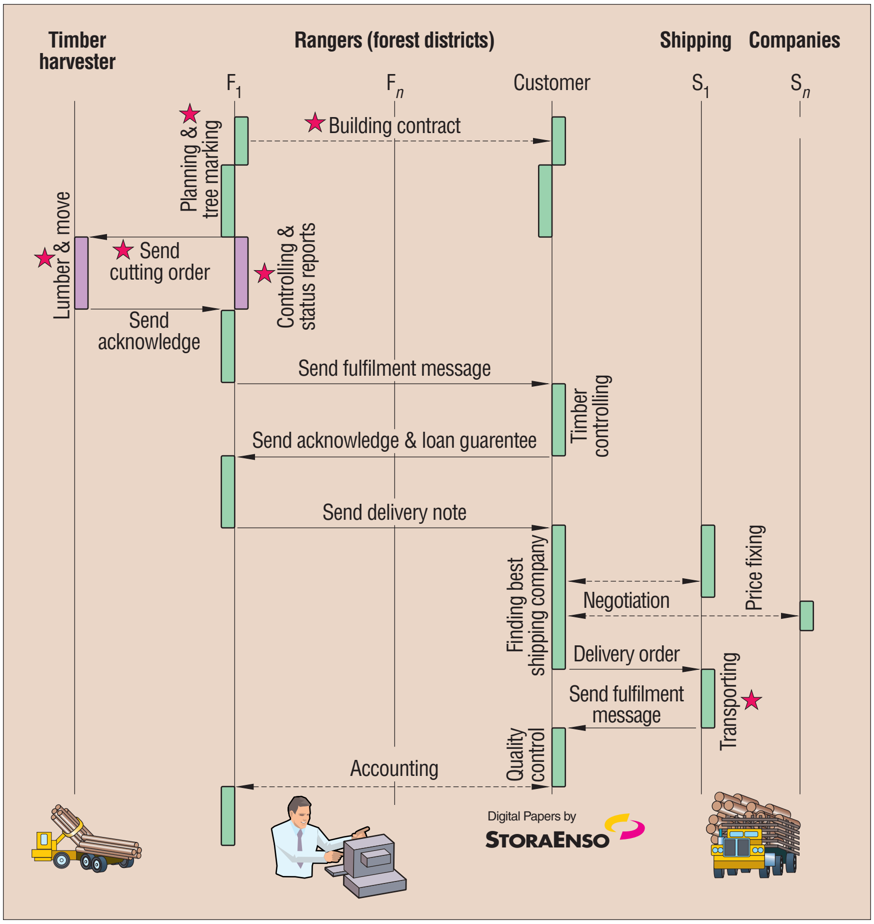

Figure 1. Interaction of the abstract user groups in the dynamic timber-production scenario.

Dynamic timber production

In the first phase of the Casa ITN project, we concentrated on organizing logistics tasks. The logistics process consists of several elements. The customer initiates tasks for delivering a certain quantity of trees with a predefined quality at a prenegotiated price. Then the forester receives the customer's request and initiates the tree-cutting schedules to meet the demand. The timber harvester is a company that specializes in efficient tree cutting using special machines. Foresters book the timber harvesters, which in turn generate plans and schedules for their own fleets and human resources. Finally, the shipping companies schedule the incoming tasks and transport the cut trees.

To understand the behavior and the functionality of these user groups, it is important to understand the flow of information beginning with the first negotiation between the customer and the forester (see Figure 1). This negotiation becomes a contract that contains all required conditions, such as quantity, quality, and date. The contract's depth is not necessarily fixed; the participants might revise it in later phases, especially since the costs depend the actual quality of the goods.

Once the parties negotiate the contract, the forester builds a plan and marks the trees that have to be cut. This planning process might be continuous because a forester has many customers that make calls at any time. After the forester finishes marking the trees for one contract, that forester sends a cutting order to the timber harvester. This order contains all relevant data, such as the location of the trees, their quality, and when they have to be cut. The harvester company collects all orders, builds the cutting schedule, and allocates the appropriate machines.

Because heavy machines cannot enter a

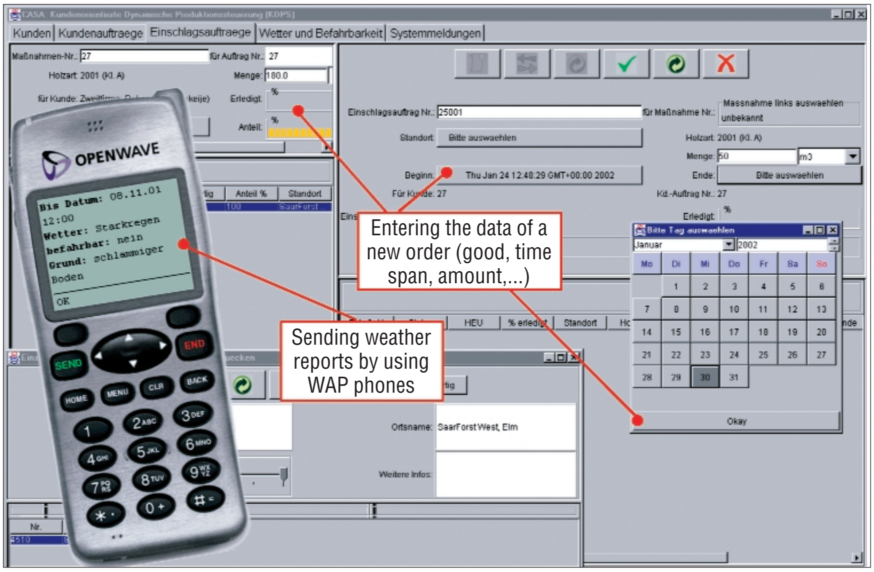

Figure 2. On the Casa ITN, you can send a weather report with a WAP phone and organize the resources and orders in a forestry district.

region when the ground is too wet (the ground might be damaged), the foresters must provide continuous reports on the ground's appearance. On the basis of this information, the harvesters must dynamically plan and schedule the cutting sequence. During the cutting process it is essential that the forester and harvester efficiently exchange data about the weather and ground conditions. In this context, Casa ITN helps with the use of mobile services. These services let the forester send information to the harvester's server, where a planning and scheduling program can automatically process this information.

During the cutting process, the harvester sends regular status messages to the forester with information about where all the cut trees are lying and how much of the task is complete. Because of these updates, the forester gets a better view of overall progress. When the harvester completes a task, the forester receives a report. Then the forester and the customer exchange information about the trees and the financial guarantees, so that the customer gets permission to carry these trees out of the forest. The customer then has to find a shipping company that can transport the trees.

After the trees arrive at the customer's site, the customer and forester negotiate the real cost of the goods. Figure 1 shows events that are susceptible to problems during the process; these problems can cause scheduling failures. In a supply-chain scenario like the one we've just described, where one event can dynamically influence another, the systems must prevent or minimize the impact of uncertainty.

Agent society

Because of the uncertainties inherent in the timber-production scenario, the system must be flexible enough to reorganize itself quickly. We use a multiagent system because such systems are well suited for dealing with complex tasks that can be divided into a set of subtasks. Multiagent systems exhibit stability and robustness because one agent can often take over the role of another in case the latter is inhibited or suspended for some reason. Agents in a multiagent system can also exchange messages to coordinate their efforts more effectively.

We use complex agent structures—consisting of holonic agents—to represent the abstract groups of participants. We represent the forester (or forest district) with several holonic agents: a personal assistant agent to help the user while using the system; a holonic agent for information management; a planning holonic agent to build production plans and schedules; and a holonic agent to represent the company as a whole and to build an interface to the outer agent society. In addition, four holonic agents represent the harvester company: a company holonic agent to present the company's internal agent society to the outer agent society with a communication interface; an information managing holonic agent; a logistics holonic agent that coordinates and controls the company's resources; and a planning holonic agent to build an execution schedule.

Another group of holonic agents represents the customer's company in the Casa ITN. The agent structure of the customer's company is analogous to the harvester company's agent structure. But the components of the customer's company are not as detailed as the harvester's. Rather, the customer agents must provide an information service that helps the trader obtain knowledge about resources and needs, including required dates and timing information. The involved parties use this information during the trading and negotiating process.

The logistics company—which offers services for transporting trees—has a structure similar to the harvester's. Both companies must coordinate, control, and schedule the resources of the executing companies. The harvester and the logistics companies receive task requests, but they are not involved in any trading process. Instead, they provide services that other companies use.

Implementation details

To use the Casa ITN system, a participant has to be member of the ITN to access the ITN services. Because sensitive information must be exchanged across the network, there is a strong need for security and safety. We built the Casa ITN as a secure extranet. We implemented the Casa ITN services in Java JDK 1.3 and the system prototype on Windows machines using various kinds of modern WAP phones from different producers.

We designed the Casa holonic agents in accordance with the InteRRaP agent architecture and we implemented them using the standard open-source FIPA-compliant agent system development environment FIPA-OS.1 (http://fipa-os.sourceforge.net). We made sure that the implementation of Casa ITN's mobile application services maintained compliance with the WAP 1.1 and WAP 1.2 standards. Users access the Casa ITN services through the secure T-D1 WAP-gateway of the Deutsche Telekom AG. In the prototype, we used Checkpoint's VPN suite for data security.

Figure 2 shows how Casa sends a weather report on the extranet by means of a WAP phone. A PC connected to the Internet can also send weather reports. Such report information can be very important for the harvester company, which might need to adjust its plans to avoid idle times. To handle all the information and planning, the software package must consist of three parts: WAP services, forestry software, and harvester software. The forester gets a software bundle that lets them organize their goods, incoming orders, and the activities of the commissioned harvester companies, including WAP services. The harvester company on the production side gets a system that supports the planning and coordination process of its machines and staff.

The coordination software lets users organize their goods and participate in auctions. Figure 3 shows how an auction can be initiated on a computer. The user has to decide what type of auction to start, how long it will run, and what the initial amount of money for the first bid should be. All the functionality of the coordination software is accessible from a WAP device. Users can initiate auctions and monitor their progress using their WAP devices. Figure 3 shows a WAP deck presenting information on a running auction. The device shows the actual last bid and the possible amount of money left for the user's next bid, minus the transportation costs.

Block hierarchy

To map the process chain to a multiagent system, we had to identify services and specify their interdependencies. The main blocks of the dynamic timber production system include consumer, forestry, logistics, and weather-service blocks (see Figure 4). These blocks form the supply chain. After the customer assigns the forester an order, the forester finds a logistics company capable of fulfilling the order. During the order execution phase, the forester and logistics companies exchange information—in conjunction with the weather service—about the actual ground situation.

To administer information, orders, inventory, and schedules, a forester must have access to a computer system connected to the Internet. The system consists of a single computer (or a network of computers) and at least one server. The server maintains a connection to the ITN at all times. For sending weather reports, the foresters use mobile devices but the lumberjacks themselves do not typically have access to a computer or a mobile device. The server manages the forestry orders and provides a graphical user interface, a database for saving data, and an interface for receiving weather reports sent from mobile devices.

The ITN's logistics service component coordinates with the harvester company, which is able to do the cutting process. The harvester company has several WAP devices for sending weather and status reports and a computer or network of computers for planning and scheduling the orders and resources.

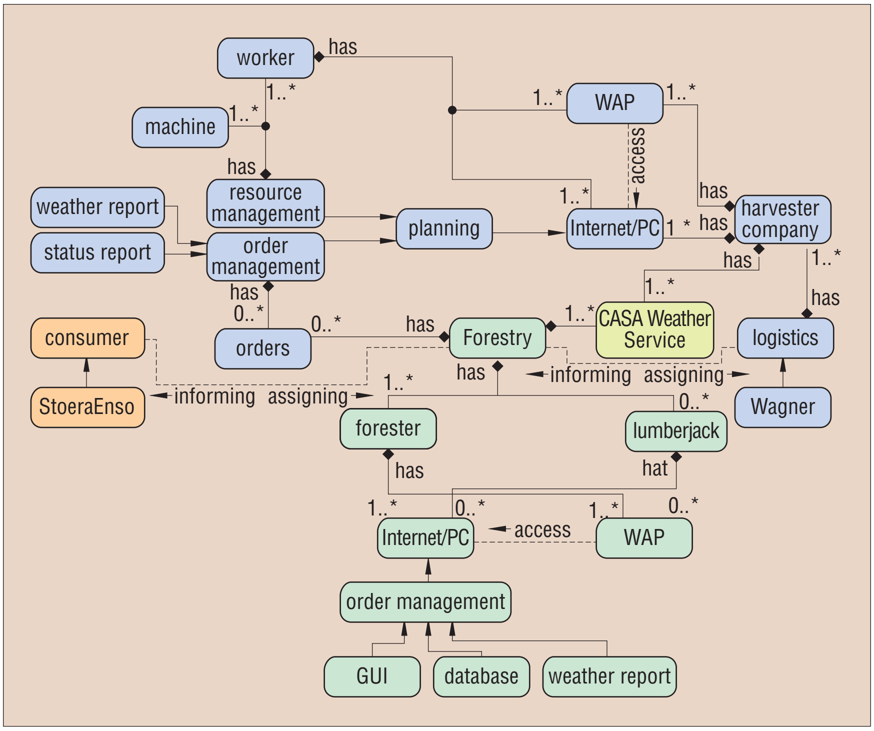

Figure 3. Controlling goods and running an auction from an Internet-connected computer. Additionally, the Casa ITN lets users access auctions with WAP devices.

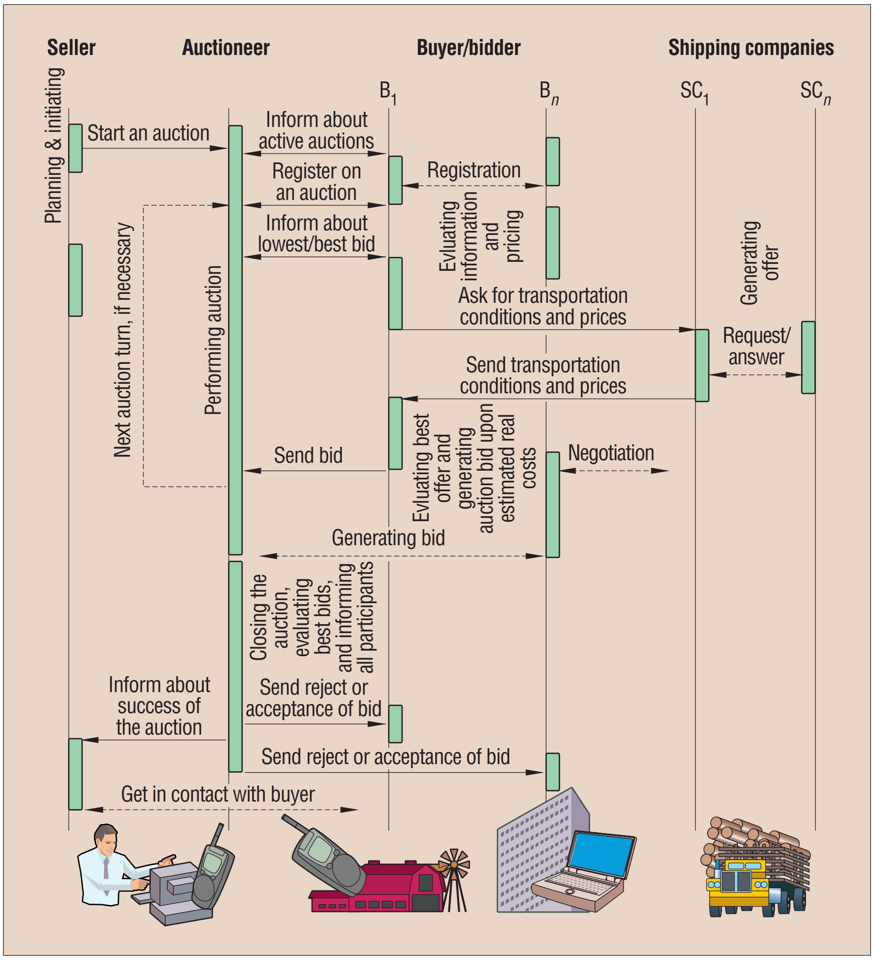

Figure 4. Component hierarchy of the dynamic timber-production network.

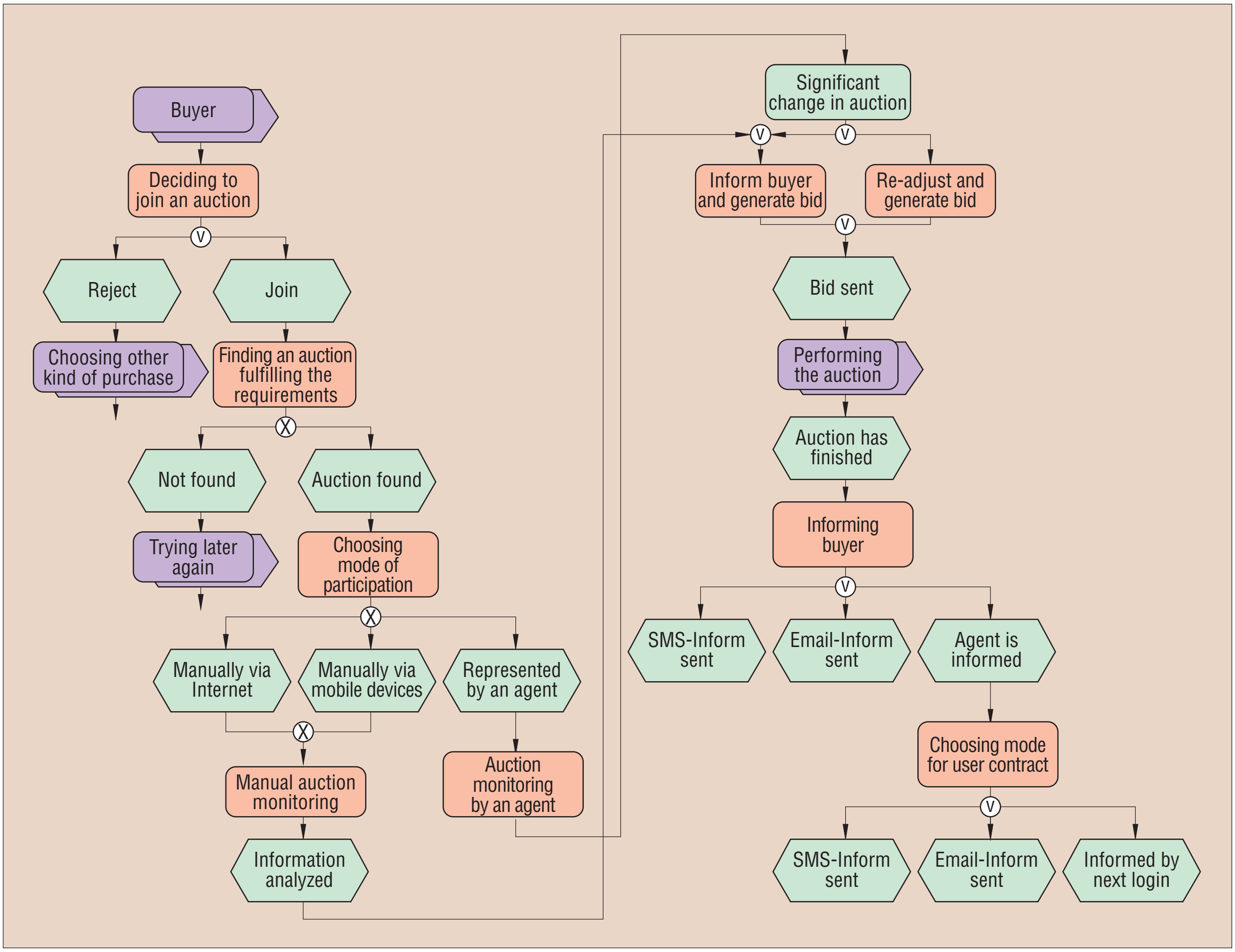

Figure 5. Interaction between participants in a mobile timber auction.

One of these computers acts as a server connected to the ITN. This server consists of a planning component built from a resource and an order management component. The order management unit handles all incoming orders and offers interfaces for receiving weather and status reports sent by mobile devices. The resource management unit schedules all the machines and workers in the company. The workers in turn have access to WAP devices for sending reports directly from their working location and to their company's server.

When the harvester company receives an order, the order builds a connection between forestry and the selected harvester company. The weather service builds a connection between forestry and any harvester company registered to the weather-service component on the ITN. So everyone who subscribes to the weather service gets automatically updated information about the actual weather situation when reports are sent.

Mobile timber sales

When the project is finished, the owner can sell the wood using a fixed-price negotiation, a predefined contract, or an auction. Typically, at least part of the wood production will be sold at auction. But the auctions in the forestry industry are usually performed by hand, which means they are error-prone and require a long time to finalize. On the Casa ITN system, however, each owner can sell timber through different kinds of auctions to other registered users. The main benefits of this agent-based service include concurrent price monitoring in addition to the ability to compute optimal transport costs during bidding. Furthermore, the use of mobile services during an auction enables new possibilities for auction monitoring and participation.

In general, Casa ITN's mobile timber sales services let registered users initiate or participate in one or multiple timber auctions and sell or buy timber at fixed or negotiable prices. As mentioned earlier, Casa ITN support the following types of auctions: Dutch, English, Vickrey, and First-Price-Sealed-Bid. The auction server relies on a general holonic coordination server for supply webs.[6]

Users can invoke integrated services for decision support while participating in one or more auctions. For example, a personal Casa ITN agent might concurrently determine the optimal transportation costs and delivery dates of some auction good for each individual user bid. As a result, the agent can notify its user in real time if estimated optimal transport costs exceed the allowed limit or if some preset deadlines are at risk of being violated.

The holonic agents provide integrated trading services and facilitate participant interactions, namely those between seller and auctioneer, buyer, and shipping company. Figure 5 summarizes the possible interactions at an auction. First, a seller typically initiates an auction on a trusted auction site and informs potential buyers about the offered goods, the auction type, and the related bidding policies. During an auction, the bidders can evaluate their bids, monitor the current auction process, and place bids according to their individual bidding strategies. If users access the auctions through mobile phones or WAP devices, appropriate Casa ITN agents perform the necessary synchronizations. At any point, the users can delegate their participation in any trading process to their personal agents, which then take over the process of negotiating prices or bidding at an auction. These agents notify their users (when needed) either by SMS or email.

Generally, a seller has three different options to begin an auction: manually using a personal computer connected with the Internet, manually using a mobile phone, or charging an agent with that task using a PC or mobile device. The buyer can access the system in a similar manner (see Figure 6). When the buyer has found an auction to participate in, that buyer can join the auction using the same methods as the seller.

The advantages of using an agent combined with mobile services are obvious. Buyers and sellers can join an auction and let their agents participate in the auction unattended. When a significant change in an auction happens, the agent can inform its user immediately, which means that the user—whether buyer or seller—does not have to wait to access a PC at a later point. The users simply send new instructions to the agent over a WAP device. Users can therefore react much more flexibly to any changes in an auction.

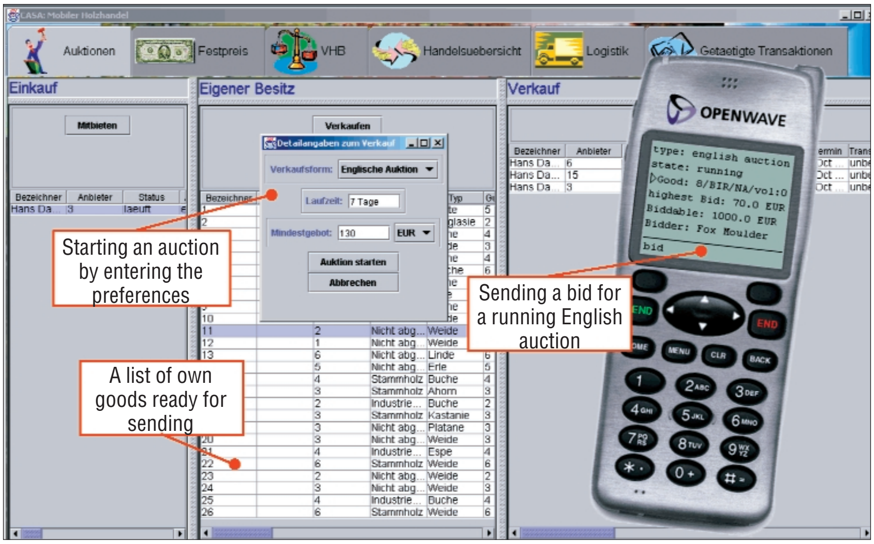

Figure 6. Buyer participation in a running auction.

Related work

The existing projects relating to agriculture and forestry mostly attempt to facilitate and enhance supply-chain management and business issues. For example, the main objective of the Agriflow project (www.agriflow.com) is to help Europe's agricultural industry adopt better e-business practices with a series of dynamic products. Another approach, the Virtual Agricultural Market (VAM) system, helps facilitate business-to-business transactions in agricultural markets. The scalable VAM architecture[7] provides mechanisms for Internet-based trading and distribution of perishable agricultural products.

In addition, there are multiagent forestry management systems. These include the Phoenix project (eksl-www.cs.umass.edu/research/phoenix.html), which helps fight forest fires with a sophisticated computer simulation system based on satellite data. The Phoenix system consists of an instrumented discrete event simulation, an autonomous agent architecture that integrates multiple planning methods, and a hierarchical organization of agents capable of improving their fire-fighting performance by adapting to the simulated environment. The Phoenix agent architecture includes several innovative features that support adaptable planning within real-time constraints, including a least-commitment planning style called lazy skeletal refinement and a combination of reactive and deliberative planning components that can operate at different time scales.

To some extent, these approaches resemble the Casa ITN with respect to the kind of services provided to the user. However, they significantly differ from the Casa ITN project in terms of integration and coordination of services for logistics and trading. In this respect, the Casa ITN system not only offers unique i-commerce services to its users—such as mobile timber auctions with integrated support of optimizing logistics—but also provides the first agent-based framework for e-business in these special application domains.

The Casa ITN system illustrates how agent-based services can help increase the flow of information and help save time in just about any industry. These techniques let buyers, sellers, and all other participants have better control over their products. We plan to extend the Casa ITN system to the agricultural domain using dynamic resource planning through integrated mobile services to enable, for example, flexible and cost-efficient precision farming. Future research and development of the follow-up prototype, called Agricola.net, will include approaches for agent-based dynamic coalition formation, distributed constraint satisfaction, and adaptive replanning in open, real-time environments.

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