Transport scenario for the intelligent container

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Scenario setting

The previous chapters described the application of autonomous cooperation on embedded systems, in sensor networks, transport planning and communication systems. For practical demonstration of the implications of the described studies the prototype of the intelligent container was linked to an agent system for transport coordination including communication gateway and vehicle location. We arranged a demonstration scenario that illustrates the cooperation of these system components by displaying the processes that are related to one selected freight item and one transport vehicle.

The scenario describes the automated supervision and management of a transport of perishable goods like foodstuffs. The location of the freight and the vehicles are traced by two RFID systems. The transport coordination automatically initiates reactions to transport disturbances.

The logistic entities and services that are involved in the transport scenario are represented by software agents. The agent system comprises means of transport, freight items and storage facilities as well as secondary services like traffic information, route planning and service brokerage. For our demonstration setup the agents are pooled in two notebooks. The first one depicts the site of the manufacturer or sender of goods who defines the transport order and receives notifications about the current state of his consignment. The second laptop provides a platform for the transport coordination. The sensory supervision related to specific freight items is executed on the embedded platform inside the means of transport. This quality supervision process is realised as a mobile agent that accompanies the fright item along its way through the supply chain.

The required hardware for the demonstration setting is summarised in **Figure 1**. A map with the related cities, motorways and the current location of our selected transport vehicle together with status information is displayed on a screen. This electronic roadmap is connected with a model truck that drives around in our shop floor. A network of RFID readers that are mounted under the floor represent the cities and motorway crossings. If they detect a passive RFID tag, which is mounted at the model truck, they send the updated position information to the transport coordination. For easier demonstration we use a second immovable model truck or container to explain the supervision of loading processes and the internal sensor network.

Beside the Ultra High Frequency RFID system at 866 MHz for the location of the truck a second RFID system is used for tracking of the freight items and the loading process. The second system operates in the High Frequency range at 13.56 MHz. A passive RFID tag is attached to the freight that is used to control the transfer of the quality assessing agent. Because of the low data transfer rate of HF-tags only few information are stored on the tag like the unique identification number and the network address of the last platform or server that hosted the freight agent. When the freight is loaded to a new platform like a storage room or a transport container, the local processor reads the information from the RFID tag and requests the corresponding supervision agent under the given address as shown in **Figure 2**. After being transferred to the new platform the agent connects itself to the local sensor facilities and continues its supervision task in the same cargo hold as the physical object was loaded to.

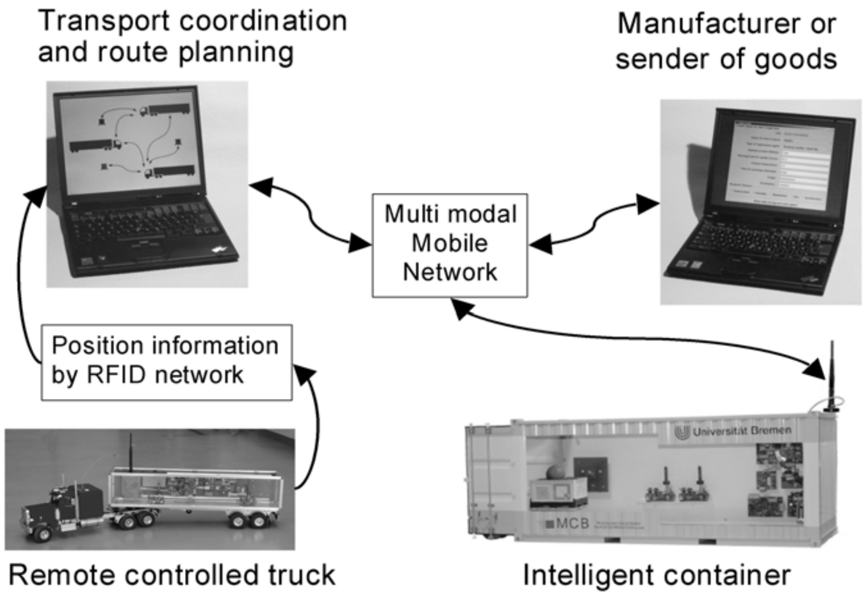

Fig. 1. Hardware setting of the demonstrator. Two computers are used to display the processes of the transport coordination and the monitoring by the freight owner. The model container is linked over multiple mobile networks with the information infrastructure. Temperature and other environmental parameters are provided by a sensor network inside the model container. A second remote controlled model truck drives to points in the demonstration hall that represent cities of Germany. Position data are delivered by a network of RFID readers mounted in the floor.

The effects of deviations from the optimal transport conditions are calculated by the concept of shelf life that predicts the remaining time-span until the quality falls below an acceptance limit. The freight specific models take different dynamic effects of temperature into account like 'chilling injuries' by storage below the recommended temperature and accelerated decay processes by temperature rises. The nonlinear dependency of shelf life from these processes is calculated according to the laws of reaction kinetics.

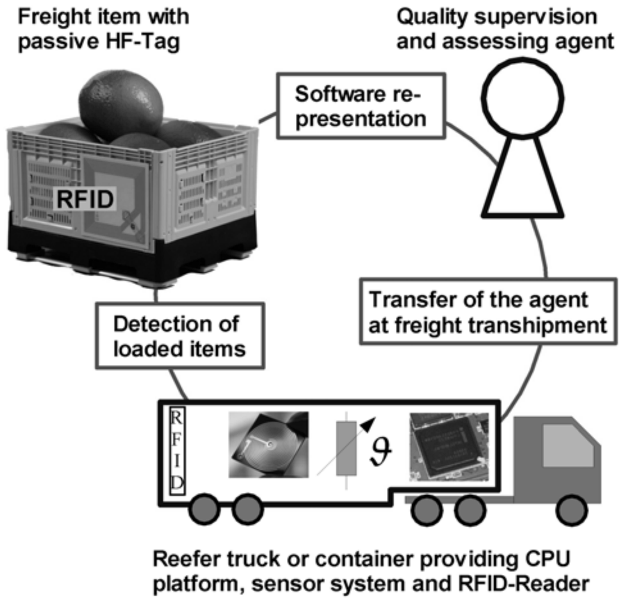

Fig. 2. Control of the transfer of the mobile quality supervision agent by an RFID tag attached to the transport packing. After reading the address information from the RFID tag the new means of transport sends a request for the agent that represents the freight item. On the new platform the agent links itself to the sensor facilities provided by the means of transport.

Steps of the transport demonstration

During the course of our example transport scenario the system has to cope with various disturbances like failure of one mobile communication network, traffic congestions and quality losses due to deviations from the recommended transport temperature. The system recognises these problems and handles them automatically by selection of alternative communication paths and means of transport, dynamic route re-planning, and by putting the freight temporarily into stationary cold storage for transhipment.

The following section describes the steps of the transport demonstration scenario, which show how autonomous cooperating processes could improve the supply chain management. The demonstration starts with the definition and placement of the transport order and ends with arrival at the final destination. As example transport order we selected the shipment of a consignment of fish from Bremerhaven to Frankfurt. This freight requires cold storage at a recommended temperature of 1 °C.

Creation of the transport order

The transport packing or freight object is marked with a standard passive RFID tag. In the first step this ‘empty’ tag has to be linked to the transport order and to a supervision agent. The RFID tag is scanned in the warehouse of the manufacturer or sender of goods. A dialog box (**Figure 3**) supports the sender for definition of the transport order. First he selects the kind of good. A knowledge base proposes supervision parameters for the specific product. The user defines which types of sensors are required for supervison. He can choose between different mathematical or bio-chemical models for prediction of quality changes. Finally he enters the destination and other transport parameters. After closing the dialog box two freight specific agents are created. The first agent is responsible for the local sensor supervision of the environmental parameters and assessing their effects on the freight quality.

This supervision or assessing agent accompanies the freight along its way through the supply chain. The agent is started first at the warehouse of the sender. His computer or IP address is stored on the RFID tag. Different agents that are running on the same platform are discerned by a read-only unique identification number given by the RFID tag.

As the second agent that is related to the freight item, the load attendant is started on the transport coordination platform. He is responsible for transport planning and coordination with different means of transport on behalf of the freight or his sender, respectively. The load attendant could run on different platforms. In our test scenario it stays together with the route planning and information systems on the second laptop.

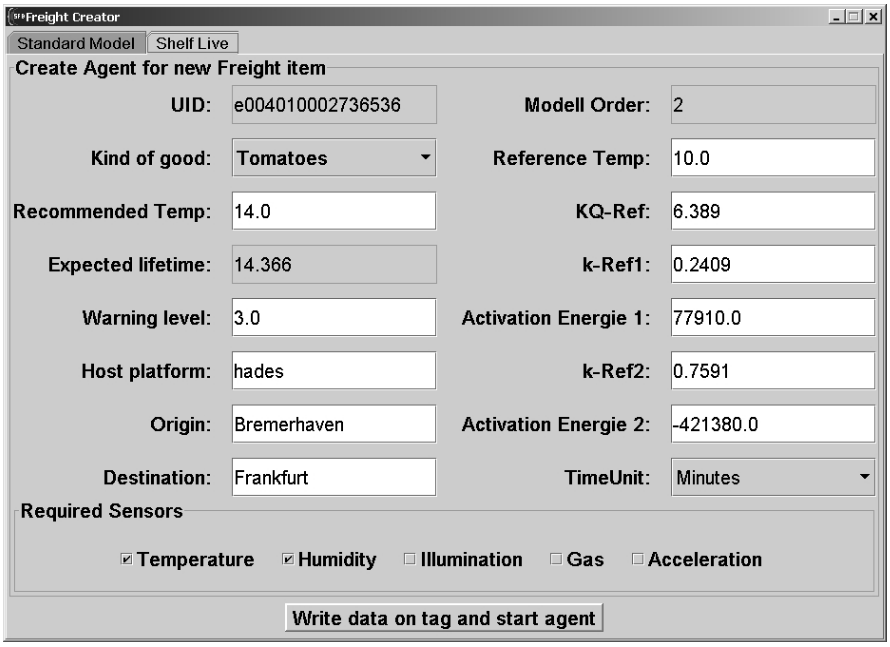

Fig. 3. Dialog box for definition of the transport order. The sender selects the kind of good, type of quality model and transport destination. The product specific model parameters in the right column are retrieved from a knowledge base.

Transport Coordination and Route Planning

As soon as the load attendant agent is started, the agent looks for appropriate means of transport (referred to as *trucks* in the following) to get to his intended destination. The needed transport information is given by an electronic consignment note that is passed to the attendant agent on start-up. Transport information includes, e.g., current location and destination as well as technical properties and requirements. In order to get an appropriate truck the agent consults a logistics services broker agent. This service broker provides a managed virtual marketplace for transport capacities and freight. The load attendant registers at the broker with his location, destination, and technical requirements (**Figure 4**).

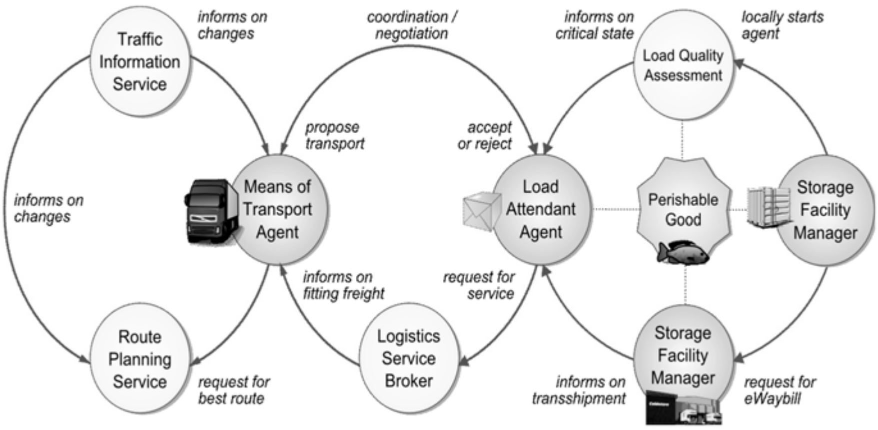

Fig. 4. Software agents (as circles) participating in a autonomous transportation process and selected interactions between them.

Trucks that again are represented by software agents also register at the service broker if they want to be informed on new fitting freight. In order to determine which freight meets a truck's requirements he may inform the broker on his technical features he is willing to disclose. In our scenario, these features are, e.g., the ability of cooling and online sensor monitoring. The scenario includes multiple trucks with only two of them providing the features needed to transport fish. One is located in Osnabrück; the other is located in Frankfurt. The truck in Osnabrück virtually hosts the intelligent container.

Both trucks only transport perishable commodities which require temperature-controlled transportation. When the load attendant agent of the consignment of fish in Bremerhaven registers at the broker both trucks are informed on the new matching load. In the following, both agents deliberate about whether to propose to this load to take over its transport to Frankfurt. The truck in Frankfurt does not make a proposal because he would have to accept too much empty miles to get to Bremerhaven. Though, the truck in Osnabrück with our intelligent container proposes to perform the transport.

Thus, the load agent and the truck agent negotiate the conditions of cooperation including, e.g., shipping costs. This interaction follows standardised protocols defined by the Foundation for Intelligent Physical Agent (FIPA). The load attendant agent finally accepts the truck's proposal and the truck plans its way to Bremerhaven. Route planning is done by consulting a route planning service agent that determines the fastest available route given the current traffic situation. Both, truck agent and the route planning service, are registered at a traffic information service that informs them on changes in flow of traffic as soon as they are noted. For tracking of the truck agent's behaviour the monitoring panel shows his current route on the road map (**Figure 5**).

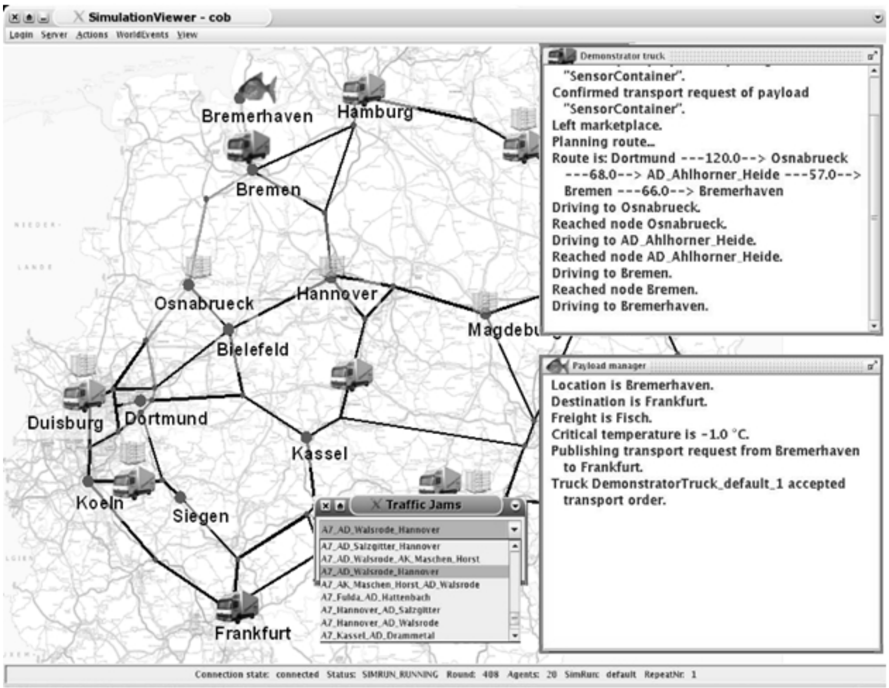

Fig. 5. Scenario monitoring GUI showing the traffic network, trucks and loads with their respective positions as well as status information of selected agents.

Loading and transfer of the supervision agent

After arriving of the truck in Bremerhaven the freight can be loaded. Our palette of fish is detected by an RFID reader mounted at the door of the means of transport. In order to transfer the mobile supervision or assessing agent the manager of the means of transport sends a request to the computer platform that was responsible for the package before the transfer. The necessary address information is retrieved form the RFID tag. After being transferred the supervision agent links itself to the sensor facilities that are provided by the means of transport and continues the quality assessment.

Sensor configuration

The first task of the supervision agent is to test whether all required sensors are available inside the means of transport. In our setting the missing of a requested humidity sensor is detected. The agent sends a warning message to the transport operator who adds an additional sensor node to the container. The self-configuration of the sensor network automatically integrates the new node. After completion of the sensor network a message is send to the transport coordination that the vehicle is ready for departure.

Route Re-planning Based on Flow of Traffic

The truck agent again plans his route now directed to freight destination Frankfurt. The currently fastest available route leads via Hanover following German motorway A7. Shortly after departure in Bremerhaven a traffic congestion from Bremerhaven to Bremen is triggered. The traffic information service is informed on the new congestion and immediately reports it to all registered agents including the truck with the intelligent container and the route planning service. Then, the truck agent detects that this congestion affects his current route and requests for an updated route at the routing agent. Given the new traffic information the routing agent now proposes a route via Dortmund following motorway A1. The truck agent changes his plan correspondingly and informs the truck driver on its PDA.

Communication failure

For external communication the embedded platform of the container is connected with an automated gateway that selects between different mobile networks like UMTS, GPRS and WLAN according to their availability, bandwidth and costs. In practical application WLAN would be selected as long as the truck is inside the range of a hotspot. The loss of the WLAN connection can be simulated during the demonstration by removing the WLAN device form the PCMIA slot of the gateway. The gateway immediately switches to UMTS communication. The embedded processor and the notebooks are connected via VPN tunnels that provide a permanent IP-connection with fixed addresses independent of the currently used mobile network.

Quality supervision

During transport the freight owner only receives notifications about important changes of the freight state like transhipment and crucial quality losses (**Figure 6**). To retrieve the history of an alarm he can request a full sensor protocol that is displayed in an oscilloscope view. During normal transport operation the sensor data are pre-processed by dynamic quality models. These models represent the knowledge that is necessary to assess the effects of sub optimal transport conditions. Instead of sensor raw data only information about predicted quality changes have to be transferred over external mobile networks.

To force a quality loss we press a test button at one of the sensor nodes to simulate a temperature rise. This deviation from the recommended transport parameters leads to an accelerated decay of the loaded good. Only if this disruption is continued for a certain period a crucial quality loss is predicted by the dynamic model. This process can be observed in the oscilloscope view. If the quality drops below a defined warning threshold or if it becomes foreseeable that the quality will fall below an acceptance limit before the freight arrives its destination a warning is send to the transport coordination agent.

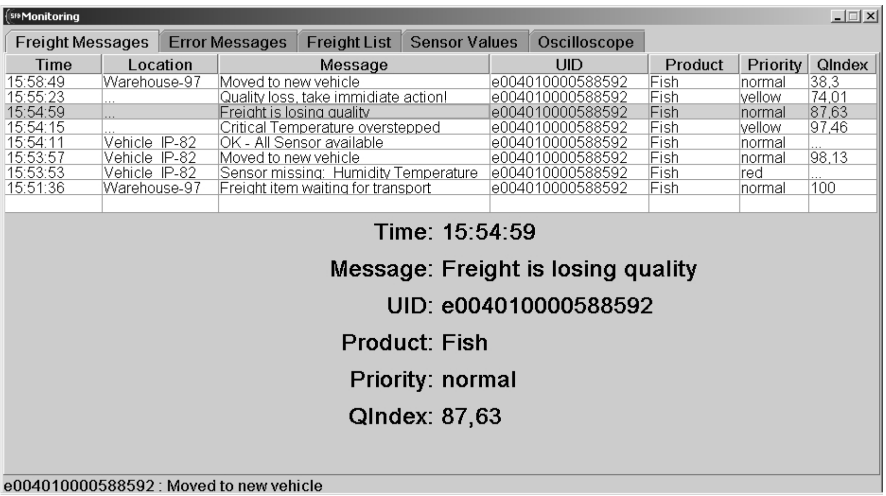

Fig. 6. Log of the messages that are received by the owner of the freight. He is informed on transhipments, state of the sensor system, overstepping of the recommended temperature and changes in quality. The messages contain time stamp (time-lapse mode), current location of the package, an unique identification number of the freight object, the kind of good and an index value for the current quality.

Reactions to quality loss and re-planning

The freight's transport planning and coordination agent assesses the quality warning message by estimating the prospective freight quality when reaching the freight destination, i.e., Frankfurt. In the given scenario the agent receives the warning message with the truck located on German motorway A1 between the cities Osnabrück and Dortmund. The prospected quality in Frankfurt is assessed as too low to continue the transport. Thus, the agent searches for alternatives to reach his goal. As one possibility, the freight could be transhipped to another truck that has a properly working cooling system. Although there is such a truck located in Frankfurt the transhipment must not interrupt the cold chain. Thus the agent searches for refrigerated warehouses. This information is provided by the agent's local knowledge base and the logistics service broker agent. In this case, the agent finds an appropriate refrigerated warehouse near Kassel as the shortest possible detour. Subsequently, the agent coordinates with the truck agent and the agent representing the warehouse to organise transhipment with intermediate storage in Kassel.

The truck again re-plans its route to the Kassel warehouse. The truck driver is notified by his PDA display that destination has changed to Kassel. Furthermore, the freight agent informs the truck agent that rising temperatures were responsible for change of destination. This causes the truck to schedule his maintenance because the cooling system may have been damaged.

When reaching Kassel the freight agent requests for a compensatory truck by consulting the service broker. This time the simulated truck in Frankfurt with cooling abilities proposes to take over the transport from Kassel to Frankfurt. The freight agent accepts this proposal and finally the transport successfully reaches Frankfurt within time and acceptable quality. Despite all disturbances, local control strategies implemented by software agents and supported by communication and sensor technologies managed to perform the process successfully. Therewith, this rather simple transportation scenario demonstrated some of the current possibilities of autonomous logistic processes.

Institutional cooperation

The scenario was developed inside the CRC637 by cooperation of different institutes form the fields of electrical engineering, computer science and applied work science.

- The Institute for Microsensors-, actuators and systems (**IMSAS**) developed the embedded agent platform and the prototype for the 'intelligent container' including software agents for dynamic quality assessment and RFID controlled agent transfer.
- The **TZI** Intelligent Systems division developed the distributed PC-based agent software platform including simulation and visualisation components. Additionally, they contributed agents running on this platform and managing the transport process by autonomous coordination.
- The Institute for Electromagnetic Theory and Microelectronics (**ITEM**) developed the wireless sensor nodes and the software for the self-configuration of the sensor network.
- **ComNets** implemented a self-organized selection of communication networks in a device called Autonomous Communication Gateway. The device has the ability to communicate using three different communication networks, namely *Wireless Local Area Network* (WLAN), *Universal Mobile Telecommunication System* (UMTS) and *General Packet Radio Service* (GPRS).
- The Bremen Institute of Industrial Technology and Applied Work Science at the University of Bremen (**BIBA**) provided the indoor location system and the facilities to 'run' the remote controlled model trucks.

The theoretical background of the demonstrator was discussed in the earlier articles of this volume:

- Article XXX "Intelligent containers and sensor networks" describes the background of the embedded platform, the layout of the sensor network and future perspectives to incorporate autonomous processes into miniaturized devices with limited resources.

9 Jedermann,R.; Gehrke, J.D.; Becker, M.; Behrens, C.; Morales-Kluge, E.; Herzog, O.; Lang, W.: Transport scenario for the intelligent container. In: Hülsmann, M.; Windt, K. (eds.): Understanding Autonomous Cooperation & Control in Logistics – The Impact on Management, Information and Communication and Material Flow. Springer, Berlin, 2007

- Article XXX “Distributed Knowledge Management in Dynamic Environments” discusses the theoretical backgrounds of an agent-based distributed service framework for knowledge exchange in autonomous logistic processes.
- The Article XXX "Self-organized Selection of Communication Networks and Services" in the Chapter "Self-Organization Concepts for the Information- and Communication Layer" describes the communication gateway that is part of the demonstrator.
- The Z2- Demonstrator??? Article XXX gives additional information about the indoor location system that was applied in various demonstration scenarios.

We additionally thank Farideh Ganji who worked on the RFID based location system for the trucks, Martin Lorenz who supported agent development, and our students that were committed to the project, namely Javier Antunez-Congil and Christian Ober-Blöbaum.