A Sensor Middleware and Agent-based Communication Platform for Supply-Chain Management *

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ABSTRACT

We present a supply-chain management system that supports transportation of cargo containers and monitors the quality of control during transport. Our system primarily focuses on the non-trivial challenges related to the interoperability between supply chain actors and their respective WSNs. It was developed by combining an end-to-end WSN middleware with an agent-based communication platform. The overall goal of the system is to offer different actors in the supply chain an easy way of handling services and continuous monitoring traces of containers along their path.

Categories and Subject Descriptors

H.4.m [**Information Systems**]: Applications—*Miscellaneous*; C.2.4 [**Computer systems Organizations**]: Computer Communications Network—*Distributed Systems*

Keywords

Wireless sensor networks, multi-agent systems, logistics

1. INTRODUCTION

Currently there is an undeniable need for coordination between actors in a logistic supply chain. Monitoring the transported products and exchanging that information among the supply-chain partners is a key to handle the dynamics of the supply-chain, shorten delivery times and lower the transportation costs. This means, for example, that the Enterprise Resource Planning systems (ERP) and Transport Management systems of various partners need to be coupled to allow for automatic logistic activities such as order handling. In addition to this integration of supply-chain partners, the quality of control during transport must be increased by equipping cargo containers with wireless sensor nodes that are capable of collecting environmental data like temperature, humidity and light intensity. An integrated communication system can benefit considerably from the data supplied by the WSNs [3]. Initial content checks, for instance, can be handled automatically by inspecting a container's monitored data and thus reducing the traversal time of containers at each storage site.

We present a fully integrated platform for container transport in which (i) all supply chain partners are integrated in a shared environment, (ii) sensor nodes are able to migrate between the WSNs of the various supply-chain partners while guaranteeing continuous monitoring traces, and (iii) supply chain partners are able to exchange the monitored data.

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2. OUR ARCHITECTURE

Our architecture is based on two design decisions.

First, the choice was made to design the communication platform as a multi-agent system (MAS). An agent abstraction is very adaptable to some typical characteristics of the transports sector: distributedness of knowledge, changing population and conflicting concerns. This offers a natural paradigm to represent the different actors of the logistic chain and their personal preferences. Every player in the supply chain is represented by an agent, see Figure 1. Next to these user representatives, there are also agents present for communication with external systems such as databases and back-end servers.

The second design choice was to develop specialized WSN middleware. Integrating resource-constrained WSNs with existing enterprise systems creates large-scale and highly heterogeneous network infrastructures. Even within the WSN-tier, various types of sensors might be used with different data and messaging formats. Such environments require middleware support to enhance application development and network administration.

We consider the case where a consumer, a distributor and a producer are involved in the ordering, tracing and delivering process of goods transported by container traffic as shown in Figure 1. In such a setting, every partner is represented by an agent in the communication platform. Furthermore, each partners' site is equipped with a WSN to monitor the local containers. For simplicity reasons we only use one type of sensor nodes which form a separate sensor network at every supply chain partner, but which store all their data in a central database. A separate database agent, finally, allows each partner's agent to access the monitoring data of the products he is currently handling.

The key contributions of our architecture are:

- **End-to-end interoperability** among the various supply-chain partners and the WSN tiers.
- **User-friendly user access** tailored to every partners role in the supply chain.

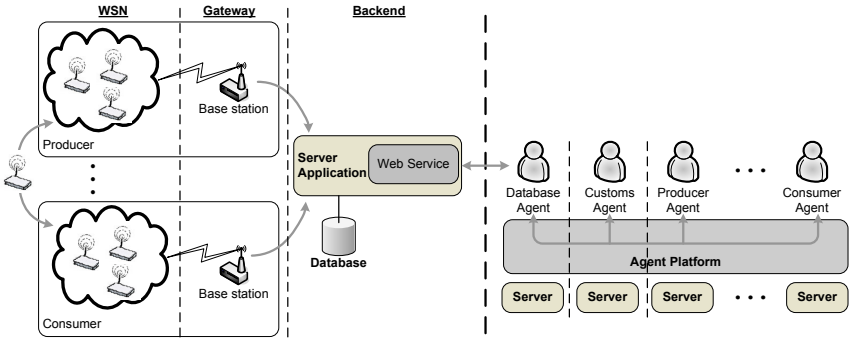

Figure 1: Architecture of the overall communication platform.

- **Data exchange** between WSNs and agents.
- An **open** system which allows new supply chain partners to easily join the system.
- **Local caching** of sensor node data to handle the intermittent network connections of migrating sensor nodes.

Furthermore, scalability is provided by both subsystems. Addition of new partners in the supply-chain is fairly easy and involves creating a new agent and optionally allowing a new WSN to forward data towards the database server. To improve scalability even further, we might move towards an architecture in which every supply-chain partner has its own database server and is thus in greater control of the WSN infrastructure and the collected data at his premises.

3. A USE CASE SCENARIO

The inner workings of our integrated platform will be demonstrated by the following use-case scenario.

Webpages provided by the agent platform allow the consumer to place an order for a crate of bananas at his distributor. This will trigger the corresponding consumer-agent to send an internal message to the distributor agent and thus forwarding the order. Consequentially, the distributor agent checks its current stock and in the case this is inadequate, automatically sends an internal message to the producer agent to place the order in the producers order list.

Preparing the order delivery at the producer's site, involves attaching a sensor node to the crate of bananas which upon activation will integrate itself into the WSN, start collecting temperature readings and forward them to the backend server. Here the data is persisted into the database and administratively coupled to the crate of bananas so that a full monitoring trace of the crate can be requested.

When the order is ready for delivery, a multimodal route from the producer towards the distributor is calculated by a routing agent [1] which outputs a list of coordinates to follow. Furthermore, an invoice is automatically send to the distributor. This transport is visualized in the demo by moving the respective sensor node or crate of bananas from the producer's WSN towards the distributor's WSN. From this point on, both consumer and distributor can track the order via the sensor data. In case the transportation truck has no connectivity provisions, temperature readings are cached on the sensor node until arrival at the distributor's site.

Finally, the distributor delivers the order to the consumer. Again, this is demonstrated by moving the sensor node towards the consumer's WSN where it will integrate itself. The order delivery inherently provides the consumer with the ability to request a temperature monitoring trace of its order over the total supply-chain starting at the producer, via the distributor, all the way to its own premises.

4. OUR IMPLEMENTATION

Our implementation leverages on existing software platforms in both the agent and WSN communities. The distributed agent platform is implemented using the Java Agent Development Framework (JADE) and FIPA compliant standardprotocols [2] for internal communication. The WSN middleware reuses software components provided by TinyOS [5] and the Java Enterprise Edition (Java EE) platform. Communication between the agent platform and the WSN middleware is implemented using the Java API for XML Web Services (JAX-WS).

5. CONCLUSION

We presented our demo of an end-to-end agent-based middleware communication platform for cargo container transport. We integrated an agent-based architecture with a WSN middleware architecture, focusing especially on tracking and tracing containers throughout the supply chain.

6. ACKNOWLEDGMENT

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