Collaborative Smart Items

Christian Decker[1], Clemens van Dinther[2], Jens Müller[2], Marc Schleyer[3], Emilian Peev[1]

[1)] Telecooperation Office (TecO), University of Karlsruhe
[2)] Forschungszentrum Informatik (FZI) Karlsruhe
[3)] Institut für Fördersysteme und Logistik, University of Karlsruhe

Abstract: Business information systems provide computer support for decision making across huge data sets. Smart Items are miniaturized computer and sensing systems embedded into physical goods, items and assets. This paper proposes collaborative Smart Items for pushing business relevant computing as close as possible into the real world. Collaboration is enabled through an auction-based negotiation mechanism running distributed between the Smart Items. This mechanism serves as an abstraction across Smart Items in order to enable a common reasoning on business critical contexts as they may occur in logistics, safety and highly dynamic planning scenarios. In this paper, we investigate auction-based collaboration for Smart Items and present first experimental results. We conclude that auctions facilitate reliable business information processing even under harsh industrial conditions such as information loss or device failure.

1 Introduction

Business information systems support planning and organization of resources and processes. They strongly rely on accurate and contemporary context information. In particular, if physical items, goods and assets are involved, the context is very dynamic due to information like location of mobile items, item bundling and environmental conditions. For instance, during transport of perishable or chemical goods, the temperature information is crucial for the quality management enforcement. Loading and unloading activities in cross-docks may change the bundling of items. Additional checks are then required to enforce the transport safety level of dangerous goods, e.g. hazardous chemicals. The closer the information gap between real world activities and the representation within the information system, the more accurate and flexible can be planned and reacted in dynamic business scenarios. Various technologies have been developed to close this gap. Smart Items aim to handle complex information flows across this gap. Current technology like Radio Frequency Information (RFID) captures identification and in parts location of physical items and assets. As a result, snap-shots of real-world processes are formed. Smart Items are miniaturized computer and sensing systems embedded into physical goods, items and assets. They couple business information systems actively to real-world processes. With actively, we mean that the business process logic is *relocated from the information system down to the item*. As a result, the item itself can continuously capture the complete dynamics of real world processes within the most recent business context. Our focus is on collaboration for processing the information among Smart Items. Collaboration, i.e. the cooperation of Smart Items in order to *achieve a common goal*, is a key concept to build efficient Smart Items systems.

2 Smart Items Analysis

2.1 A Case for Collaborative Smart Items

Within the research project CoBIs (http://www.cobis-online.de), we explored automatic workplace safety enforcements when handling hazardous chemicals in one of BP's plants in the UK. Smart Items based on wireless sensor nodes technology were attached on chemical drums (Figure 1) and collaboratively processed business critical information. They detected hazardous situations like an exceeded storage limit, prohibited storage combinations of materials or placement in an invalid storage area. As a result, alerts were raised both visually on the drums for notification of nearby workers and communicated to an information system.

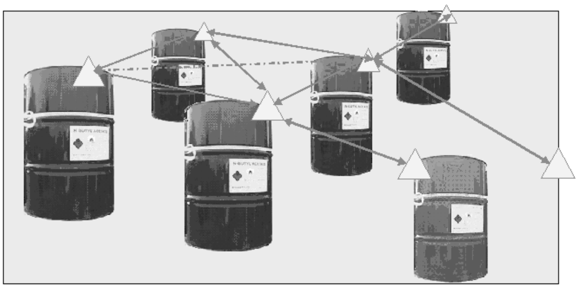


Figure 1. Left: Detecting hazardous situations (Source:BP); Right: Prototype implementation

The advantage of the usage of Smart Items in this scenario is the fast response in dangerous situations. The in-situ detections and alerts shorten long communication paths for notifications. Furthermore, re-located processes do not rely on a permanent connection to a central information system. As a result, business applications can also handle highly mobile items without being dependent on a full monitoring infrastructure.

2.2 Enabling Collaboration

Collaboration reduces load on back-end systems and enables real-time action. The immense amount of information acquired from items and assets may soon become a problem of scalability for centralized information systems. High loads are avoided, when the information is processed collaboratively on the items. Furthermore, long communication roundtrips paths to the back-end are shorten and allow direct responses in real-time.

Collaboration enables efficient business logic processing. Smart Items comprise limited computation and memory resources. Collaboration may compensate those limitations by utilizing two key properties: distributed computation and high locality of information for business logic. Practically, mostly single hop communication between the items is needed to acquire and process the relevant information.

Technologies for enabling collaboration. Processing business information focus on the description and implementation of rule-based business logic. Programming languages for Smart Items platforms [RAD07] are very flexible, but collaboration has to be explicitly programmed as a distributed application. Collaborative information processing requires the Smart Items to achieve a commonly agreed state. This state might be for instance the result of the in-situ reasoning on a hazard like in the case in section 2.1. We demand that collaboration shall always converge to the best common state. We propose an auction-based mechanism, where Smart Items negotiate this state. We believe, that our view on collaboration is intrinsic in this class of algorithms. An auction may serve as a generic interface to implement collaborative information processing among Smart Items.

3 Auction-based Collaboration Mechanism for Smart Items

Auctions are market-based algorithms, where prices are used to achieve a common coordination. An auction comprises an auctioneer responsible for starting and closing an auction and one or more bidders communicating bids to the auctioneer. Smart Items can take on both roles. The decision is application-specific and may change during the operation. Before an auction starts, the Smart Item must select a private value. The private value represents the Smart Item specific importance or costs of an activity in the current business context. It has to be defined by a developer or determined a-priori before the Smart Item can participate in an auction. Novel is, that Smart Items are able to *pro-actively derive the private value* from their surroundings through sensors. For instance, the distance to an event, number of message hops to an event source or the dynamics of a sensor reading can be used as private value or affect a pre-defined one by weighting. As a result, the auction works then as a filter for the level of participation and the effect of each single Smart Item on a common reasoning process. For instance, Smart Items may negotiate the resources on production lines via auctioning. The line with the highest importance is collaboratively selected. In the use case from section 2.1 auctioning may quickly identify the hazardous situation by using auctions as collaborative filters.

In this paper we investigate three types of auctions. In the **open English auction**, i.e. all bids are known, the auctioneer starts with a minimum price and successively increases it until all bidders except one reject the price. The last bidder left has to pay this price. In the open **Dutch Auction** the auctioneer starts with the highest price and successively decreases it until the first bidder accepts it. Finally, the **Sealed-Bid First/Second Price Auction** is a closed auction, i.e. only the auctioneer knows the bids. After the start each bidder has exactly one bid. The first price auction selects the highest bid for the final price; the second price auction (=Vickrey auction) selects the second highest bid. Business relevant Smart Items applications require a fast decision-making. Hence, our goal is to select the auction mechanism with the lowest communication effort for Smart Items.

4 Implementation

4.1 Particle Smart Item Platform

The Particle Computer sensor node platform [DKB05] served as an implementation platform. The node depicted in Figure 2 consists of the Particle Computer communication board. It comprises an 8bit PIC18LF6720 MCU running the auction mechanism. The communication interfaces utilizes a RFM TR1001 transceiver on 868MHz with 125kbit/s. The sensor board in the housing comprises sensors for light, temperature and acceleration. Actuators are two ultra bright LEDs. In the use case presented in section 2.1 the LEDs indicate that immediate action is required to ensure safety. The technology is embedded in a splash water resistant housing.

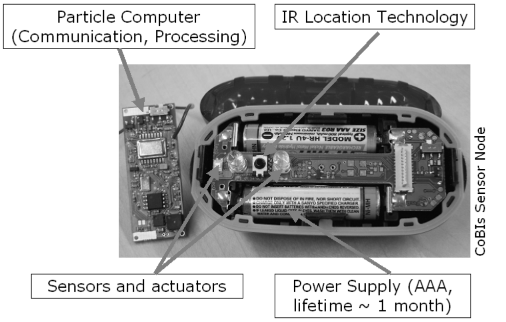

Figure 2. Smart Item based on Particle nodes

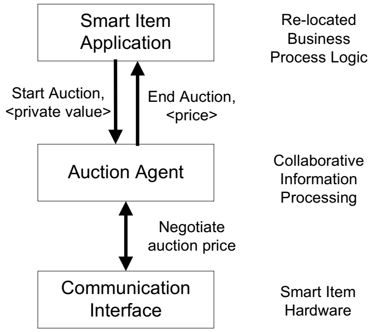

Figure 3. Smart Item architecture

The auctions mechanisms were implemented using the Particle JavaVM [RAD07]. The auction logic runs as an agent on the node. It separates the Smart Item application from the collaborative processing. The Smart Item application implements the re-located part of the business process and delegates the collaborative information processing to the agent operating as auctioneer or bidder (Figure 3). The role depends on whether the application starts the collaboration, e.g. on the detection of a critical event, or receives a collaboration request from an other auctioneer Smart Item. For each auction the agent is initialized with a private value determined by the application. The agents interact by sending messages containing negotiating the current price using accept/reject bids. If the auction is closed the agent returns the agreed price to the application.

4.2 Results and Achievements

We tested the auction agents on three devices of the Particle Smart Item platform for the different auction mechanisms varying the auction parameters: After each complete auction, the auctioneer incremented its price from 2 to 15. Two bidder agents set their private values on 8 and 10. Table 1 lists the spent communication effort from start to the end of the different auctions types. The duration is concluded from the communication parameters of the Particle sensor nodes. The effort of the Sealed-Bid-Vickrey auction is in best- and worst-case the lowest. Dutch and English Auction need more communication steps.

	Best Case		**Worst-Case**	
	# Msg.	**Duration [ms]**	**# Msg.**	**Duration [ms]**
English Auction	24	312	24	312
Dutch Auction	18	234	42	546
Vickrey Auction	3	39	3	39

Table 1. Communication effort of different auctions types

The results from Table 1 are achieved under ideal conditions without message loss. However, wireless communication among Smart Items suffers from loss due to RF shielding, channel noise and disturbances. For the setting with one auctioneer and two bidders we present some simulation results on the expected communication effort and the achieved auction prices under varying message loss probabilities. A message lost message is recognized by a timeout. Under loss the auctioneer may choose one of the following policies: A lost message is interpreted as an accept-bid (accept policy) or interpreted as a reject-bid (reject policy). Both policies do not apply for the Vickrey auction. All auctions repeat the current round, if both bids got lost. The Figure 4 (left) shows the achieved price averaged over 1000 simulation runs for the policies. The Vickrey auction achieves prices with low fluctuations. The other auctions are strongly biased. The reject policy leads to lower prices for Dutch and English auction. If a lost message is a rejected bid, the other bidder wins (English) or issues a later accept (=lower price, Dutch). In case of higher loss rates, the message count increases (Figure 4, right). The Vickrey auction is less affected, because only one bid is required from the bidders. Loss affects this auction only, if both bids got lost.

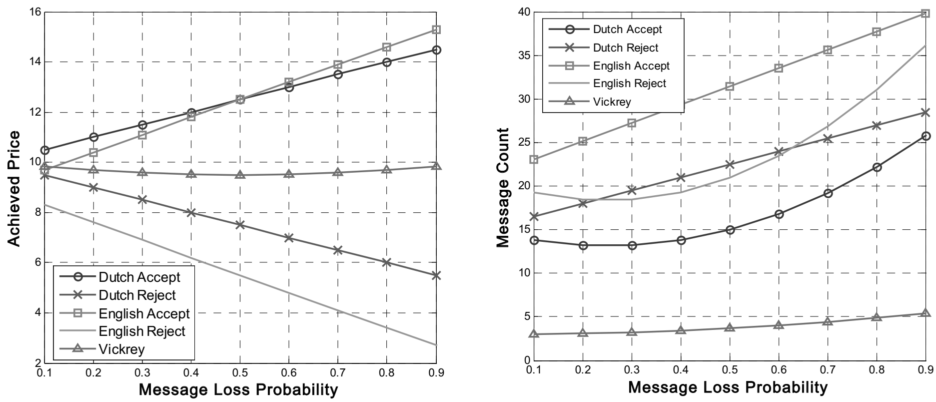

Figure 4. Achieved auction price and number of messages until auction closing under loss

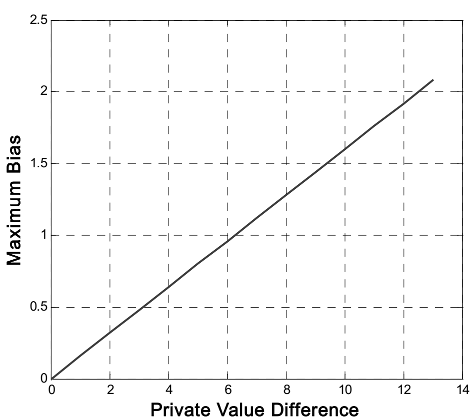

Figure 5. Maximum bias for Vickrey auction under message loss

Vickrey is least biased in the presence of message loss. The maximum bias is the price difference under all loss rates from Figure 4 (left) for Vickrey. So, it depends on the private value difference of the bidders. We computed the maximum bias in correspondence to the difference of both bidders' private values. The Figure 5 depicts the results. The Vickrey's bias increases only slowly and linearly in correspondence to larger differences. From the example in from Figure 4 (left), we conclude that other auction types lead to larger biases in all cases. Low communication effort and low bias under message loss recommend the Vickrey auction as collaboration mechanism for Smart Items.

5. Related Work

A related approach for enabling collaboration is the arteFACT framework [SGK04]. It implements a Prolog interpreter, which uses business relevant rules and proves for inconsistencies. Once it discovers one, an appropriate action may be raised. However, it presumes that all input data from the Smart Items is available at the time of rule evaluation. In contrast, auction-based collaboration may continue to operate when a Smart Item fail. Some work has been done in applying agent-based techniques on logistic scenarios, e.g. [BFV98] have modelled a group of cooperating transport companies to dynamically allocate customer orders. The authors in [FBN93] model transportation planning through decentralized partially integrated agents. A commercial system for agent-based transportation planning was developed by Living Systems[DC05]. In these examples auction-based collaboration happens on large-scale. Collaborative Smart Items could be auction-wise integrated enhancing the level of granularity of information processing.

6. Conclusion and Outlook

This paper presented a first approach to collaborative Smart Items. Collaboration is realized through an auction-based negotiation mechanism. It enables Smart Items to commonly and in-situ derive the current business context. Our research results recommend the Vickrey auction as a preferable collaboration mechanism for Smart Items due to its low communication effort and low price bias under message loss. Achieving a stable auction price under message loss let us conclude that Smart Items are able to process information reliably even in harsh industrial environments or when devices fail. Future work includes the usage of the Smart Items technology in a series of real-world application trials in order to gather a broader experience. The effects of communication delay and message loss under difficult conditions such as shielding require a deeper investigation. Also, the power consumption of the battery-driven sensor devices and scaling under limited bandwidth are crucial for the usage in various business domains.

References

[BFV98] Bürckert, H.-J., K. Fischer, G. Vierke (1998). Transportation Scheduling with Holonic MAS - The TELETRUCK Approach. Third International Conference on Practical Applications of Intelligent Agents and Multiagents (PAAM 98), 1998 .

[DC05] Dorer, K., M. Calisti (2005). An Adaptive Solution to Dynamic Transport Optimization. in: Proceedings of the AAMAS05 industry track, Utrecht, The Netherlands, 2005 .

[DKB05] Decker, C., Krohn, A., Beigl, M., Zimmer T. The Particle Computer System. Proceedings of the ACM/IEEE 4th IPSN / SPOTS 2005, Los Angeles, USA

[FBN93] Falk, J., V. Borkowski, R. Neumann und P. Mertens. TRAMPAS: A Knowledge-Based Agent System for Distributed Freight Allotment. In Artificial Intelligence Technology – Applications and Management, New Delhi, 1993, S. 394–401.

[RAD07] T.Riedel, A.Arnold, C.Decker. An OO Approach to sensor programming, European conference on Wireless Sensor Networks (EWSN) 2007, Poster Abstract

[Sch02] A. Schmalz (2002) Design Elektronischer Märkte für die Tourenplanung - Tests und Vergleiche mit zentralen Verfahren, Dissertation Universität Gießen

[SGK04] M.Strohbach, H.-W.Gellersen, G.Kortuem, C.Kray. Cooperative Artefacts: Assessing Real World Situations with Embedded Technology. Ubicomp 2004