TOWARDS ENTERPRISE APPLICATIONS USING WIRELESS SENSOR NETWORKS

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Abstract: Wireless Sensor Networks (WSN) have become a hot issue in research, and significant progress has been achieved in the past few years. Recently, the topic has gained lot of momentum and has become increasingly attractive for industry paving the way for new applications of sensor networks which go well beyond traditional sensor applications. Sensor Networks is seen as one of the most promising technologies that will bridge the physical and virtual worlds enabling them to interact. Expectations go beyond the research visions, towards deployment in real-world applications that would empower business processes and future business cases. In this paper we look at WSNs from the business software perspective, including business model, service-oriented architecture, integration with enterprise software systems as well as benefits and lessons learned. As an example use-case we demonstrate the use of WSNs for hazardous goods management in the chemical industry. Finally, based on our experiences we depict some directions that can be followed in order to pave the road to real business applications for WSNs.

1 INTRODUCTION

A "smart item" is a device that is able to provide data about itself or the object it is associated with and can communicate this information to other devices. An example of an enhanced smart item is an environmental sensor that provides a complete picture of a tracked object and its physical environment. Through automatic, real-time object tracking, smart-item technology can provide accurate data about business operations in a timely fashion, as well as help streamline and automate operations. However, bridging the gap between the physical and digital worlds requires a flexible and scalable system architecture to integrate automatic data acquisition with existing business processes and to make ubiquitous computing a reality.

Wireless Sensor Networks (WSN) constitute communities of advanced smart items and although visions have been laid out and significant progress has been done in the research domain (theory, algorithms, protocols, implementations, trials etc.), a vast number of questions still remains to be answered: what steps need to be taken so that this technology will not remain forever at the labs and that it will be more than just hi-tech toys for scientists? How can a wide economic and positive social impact be achieved? Where are the markets? Which will be the major drivers? How will we progress towards a successful, secure, and open infrastructure?

Taking into account the above challenges, our motivation comes from real-world enterprise needs. Our aim is to develop a novel service-oriented approach to support business processes that involve physical entities (goods, tools, etc.) in large-scale enterprise environments. Software systems that provide various services for the enterprise are usually based on highly decentralized, manual and thus often error-prone data collection. On the other hand, data storage and business logic execution is performed centrally in so called "back-end" systems. An important intention is to apply recent advances in the area of sensor networks, in order to distribute not only data gathering tasks but also business logic functionality to "smart" physical entities. In this way, the status of enterprises, as it is represented in business processes and in the supporting enterprise software systems, can reflect more closely what is actually happening in the real world.

It is state of the art to augment physical entities in enterprise environments with embedded technology to build automated item identification and tracking systems. These systems can support different processes related, for instance, to supply chain management in intra- and/or inter-enterprise business scenarios. Real world objects with sensors attached reveal their identity or other dynamic/static data for a communicating entity, e.g. another sensor. Information gained that way can be basically used to monitor the execution of business process tasks that are implemented by back-end systems. In the CoBIs project (www.cobis-online.de) our research focuses on the development and the integrated application-driven usage of so-called 'Collaborative Business Items' (short CoBIs) that utilize a wide spectrum of sensor networks technology.

Our vision is to delegate well-defined parts of business logic functionality, i.e. process execution from resource intensive back-end systems to relatively low cost networked embedded systems that run "at the point of activity". These tiny systems in our case build on sensor network technology that enables them building collaborating 'teams' to work together for a certain business relevant result (Strohbach et al., 2004). The approach to handle certain situations locally can lead to reduced process execution and transactional costs, to improved response times in business- and/or safety-critical situations, and also to enhanced quality of process results within a given operational environment. In addition to improvements on existing business processes, there is also a chance to identify new business cases and develop corresponding useful services based on this technology (Decker et al., 2006). From a more technical point of view, flexible handling of distributed process based on services that run on CoBIs nodes can help saving back-end systems' resources, such as CPU-time, memory, network bandwidth, etc., and can thus lead to enhanced reliability, responsiveness and scalability of the overall system.

2 BUSINESS MODEL

If WSNs are to be an integral part of commercial applications, it is expected that the different components that constitute a WSN infrastructure will be driven by key players in that domain. Figure 1 depicts on the left side the service-oriented architecture we used in CoBIs and on the right side a general abstract model of the parties involved in the design, implementation, deployment, and operation of such an application. The business model depicted is general enough and several other WSN approaches can also be mapped to it.

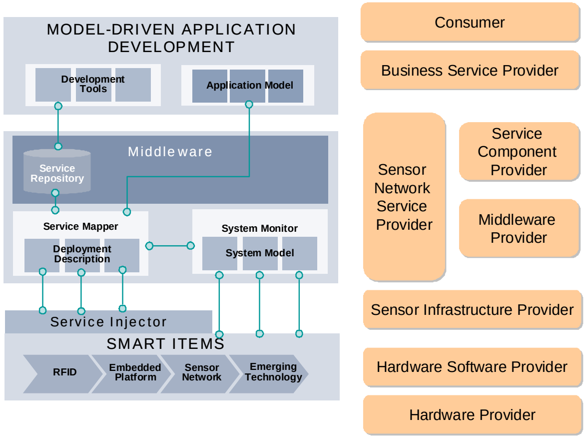

Figure 1: Architecture and Business Model.

In detail, the following roles have been identified:

- *Consumer (C)*: The end-user of the services offered by the Business Service Provider. The Consumer can be located at the edge of the service infrastructure (and be a classical end user) or it may be an application or other service, a service management system etc.
- *Business Service Provider (BSP)*: Composes services delivered by various Sensor Network Service Providers and Service Component Providers, and offers the resulting service to the Consumers. A BSP may federate with other BSPs in order to build services that are more complex.
- *Sensor Network Service Provider (SNSP)*: Provides sensor network based services. It offers facilities for the deployment and operation of the respective code into the sensor network and provides possibly generic services that run in the sensor network nodes.
- *Service Component Provider (SCP)*: Builds service components and offers them (usually to SNSP or BSP) in the appropriate form (e.g., as binary or as source code). These components usually run on middleware platforms delivered by Middleware Providers.
- *Middleware Provider (MP)*: Provides specialized middleware platforms that integrate sensor network based services
- *Sensor Infrastructure Provider (SIP)*: Provides managed sensor network infrastructure and resources (bandwidth, memory, and processing power) to SNSPs. It offers a sensor network platform over which services from SNSP can be deployed. How a SIP offers the underlying infrastructure depends on the service-level-

agreements (SLA) it has with the respective partners.

- *Hardware Software Provider (HSP)*: Supplies the software to realize the basic general execution environment capabilities including tools for executing code in the sensor nodes is provided by the HSP. It is usual nowadays that the Hardware Provider also slips in this role. This might not be always the case in the future for commoditized hardware.
- *Hardware Provider (HP)*: Manufactures the hardware components of the sensor nodes e.g. Motes, Particles, μ-Nodes etc.

It is still very early to clearly see such a model in the market. Current market players at the moment deliver almost all of the services depicted above, trying to serve one-stop, turn-key solutions. However as the market matures it is expected that in the mid-term the above roles will gradually be separated and different players will compete at each level.

3 SERVICE-ORIENTED APPROACHES

Enterprises are moving towards service-oriented infrastructures. Applications and business processes are modeled on top of and using an institution-wide or even cross-institutional service landscape. For any WSN solution to be easily integrated in this environment, it must feature a service-based approach. The overall system architecture of the CoBIs project involves a service-oriented architecture (Anke et al., 2006), dividing the functionality of supported business applications into different classes of services. The core services include the basic, enabling capabilities of a typical node, such as processing, storage, sensing, actuating and communication. The base services constitute primary functionality, mainly focused on exchanging information within the network reliably and efficiently. By combining base services, more sophisticated ones can be realized. Similar to the core services, the base services are generally platform dependent. In order to describe these services we have developed a service description language that we refer to as CoBIs Language (CoBIL). CoBIL documents are created and edited by service developers when they develop or compose a new service. A CoBIL document will be used to describe exactly one service. Typically, the service description will be stored together with the corresponding service executable(s) in the CoBIs Service Repository.

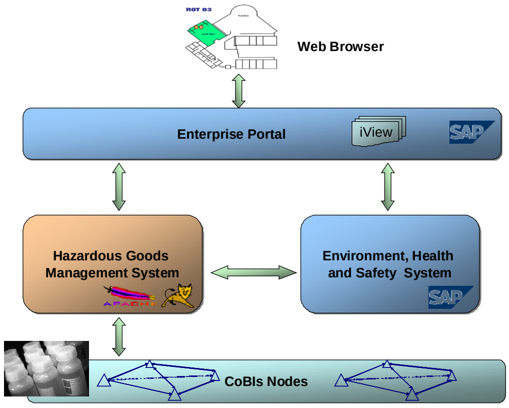

Figure 2: Management of Hazardous Goods.

The general architecture is depicted in the left part of Figure 1. We can clearly distinguish three different levels. At the bottom there are the smart items such as the sensor networks or similar systems. A middleware level couples them with the services offered by enterprise systems. The platform abstraction layer developed in this provides the enabling technology to access all CoBIs services in a uniform manner. It describes an open architecture providing a service-oriented interface to the business logic that can be adapted to different business standards. At the same time it provides means to integrate sensor node communication by supporting web service proxies for services integrated on CoBIs nodes. Therefore it constitutes a middleware layer, which is commonly transparent for both the business application and the underlying WSN systems. It even allows the direct use of WSN services in executable business process descriptions like the Business Process Execution Language (BPEL).

The applications or business processes using the WSN systems are based on several services running either on the back-end enterprise system or on the nodes themselves. This is one of the strong points of service-oriented architecture: new services can now be composed using generic ones as modular building blocks. Collaboration among sensor nodes should provide a number of substantial benefits over the existing centralized schemes:

- *Efficiency and low cost*. The sensed data will be processed within the network, communicating only the relevant information among each other and to the enterprise system. This only requires modest communication bandwidth, and low energy needs.
- *Scalability*. Sensor data is processed locally within the network, and those computations (if designed accordingly) are dependent only on other nodes nearby. Adding more nodes to the network will not degrade the performance, since additional processing is made available besides the increase

of sensor data. Local processing also avoids a bandwidth bottleneck between sensor network and back-end that would occur if all data was processed centrally.

- *Fault tolerance and reliability*. Nodes in the network are in contact with each other processing each others data and cross-verifying each other's results. Incorrect data samples or results will be noticed by other nodes, and corrected if possible. Therefore, we can avoid having a single point of failure.
- *Autonomous systems*. Nodes are almost completely autonomous and require hardly any infrastructure. No cables are needed, no installation and maintenance activity. Each node can act autonomously or in cooperation with others based on its internal goals.
- *Enhanced accuracy*. Through local cooperation, sensor nodes can collect data more accurately. These data can also be communicating with neighboring nodes and deviations or errors are easy to be pinpointed and corrected.
- *Local intelligence*: The decisions that need to be made locally are needed for a multitude of reasons. On the one hand, in order to provide business logic, the nodes are to make decisions and conversions on the information they gather. On the other hand, in order to efficiently provide the requested functionality, nodes need to share information with each other. This has a tremendous effect on an enterprise system since now the intelligence does not rely on a central point but can be distributed in the infrastructure and in places that is really needed.

4 USE-CASE: HAZARDOUS GOODS MANAGEMENT

Taking into account the business model and the trends in modern enterprise systems, our motivation was to apply WSN concepts to real world problems. In that sense we have identified the management of hazardous goods (Kubach et al., 2004) as a common problem in the chemical industry. Human error during storage and transportation of such substances can have fatal consequences for the working personnel as well as long-lasting effects on the environment, not to mention the financial issues. Although several paper-based risk management procedures exist, all of them rely mostly on labelling, inventory and the worker's experience. However by using wireless sensor networks, we can offer a more active and fine-grained approach. Such a solution can provide in real time services like conflict detection and warn the personnel about possible safety dangers would be indispensable.

We have equipped a set of drums containing different chemicals with wireless sensors (Particles) and set-up the necessary infrastructure for communication with a back-end system, allowing for remote monitoring and configuration. The back-end system is SAP's Environment, Health and Safety Application (EH&S), a standard enterprise application for managing hazardous goods installed and used by several chemical companies worldwide. The data stored in the EH&S incorporates safety-relevant substance information, such as chemical features, handling and storage constraints for compliance with international or corporate standards, etc. The sensor nodes attached to the drums can communicate both peer-to-peer and via a Platform Gateway with the SAP EH&S. As this communication is real-time, we are able to have a real-time model of the warehouse status in the back-end IT systems.

In this way, Smart Drums act autonomously. When the storage regulations are changed in SAP EH&S, the new rules are automatically pushed to all warehouses and all sensor nodes in the company. All nodes that are currently not connected to fixed infrastructure (e.g. during transportation) are updated as they reconnect. We focused in the following use-cases:

- Ensure that only a safe volume limit of a substance is stored in a storage location
- Prevent storage of incompatible chemicals in the same storage location or at non-safe distance
- Prevent storage of chemicals in unsuitable storage areas
- In case of a violation of the above rules, alert warehouse staff and offer advice on how to resolve the situation
- Automatic suggestion of safe storage location for each new drum arriving at a warehouse

Within this context, Smart Drums are able to respond to dynamically changing context conditions. Such changes can occur in their local environment, but can also be caused by administrative changes within the EH&S system. An overview of the system prototype used in this lab trial is depicted in Figure 2. We can distinguish:

- *Web Browser:* the user connects via the browser to the Enterprise Portal.
- *Enterprise Portal (EP):* The main entry point to the CoBIs infrastructure for users. This SAP product gives the user access to all the information needed based on the role that has been assigned to him/her. The prototype development included the production of CoBIs-specific so called iViews and the building blocks for the portal's role-based user interface.

- *Hazardous Goods Management System (HGM):* This is an application developed in Apache's Tomcat that is used for managing hazardous goods, e.g. like a simple warehouse management system.
- *Environment Health and Safety System (EH&S):* This is a standard SAP product. Via EH&S rules for handling and storage of hazardous goods including storage limit and incompatibilities are managed for each substance.
- *CoBIs Nodes:* these are the infrastructure nodes where CoBIs services are running on. For this trial, we used Particle nodes.

The HGM portal monitors the warehouse status based on the information sent by the particles nodes attached to the drums. The hazardous goods business service that runs on the items continuously checks whether the current storage conditions are compliant with the storage rules defined in the EH&S system. If the storage limit of one type of chemical is modified in the EH&S system (e.g. because of changes in official or corporate policies) this is propagated to the particles, who store the new value and start to verify the rules based on the new data. The bridges located in the warehouse periodically (with a moderate period) broadcast the current storage limit for each chemical. This ensures that even drums that have been out of communication range, e.g. during transport on a truck, receive the updated regulations as soon as they are stored in the warehouse. Instead of using periodic rule broadcasts, a more advanced, energy-aware protocol could be used to disseminate rule changes.

A system management console, allows for a uniform way of managing the CoBIs nodes. It provides an abstraction layer for management related tasks that hides the heterogeneity in nodes and their services, by providing a common management GUI. A monitoring tab provides real-time information about the CoBIs network. As we can see in Figure 3, the underlying network topology is depicted. One can select a platform via the respective tabs e.g. the platform of Sindrion (Gsottberger et al., 2004) nodes, Particle nodes (Decker et al., 2005) or µNodes. By moving the mouse pointer over the respective node, the user is able to acquire info about that specific node according to the available services e.g. battery, CPU, free memory, location, temperature, light, acceleration, and field strength. When a node is selected, additional info about the node available in the Monitoring Service (if deployed) is displayed, such as a complete list of services running on the node etc.

Within our infrastructure, the sensor nodes detect possibly dangerous situations, and inform workers and warehouse managers via alarms. Having

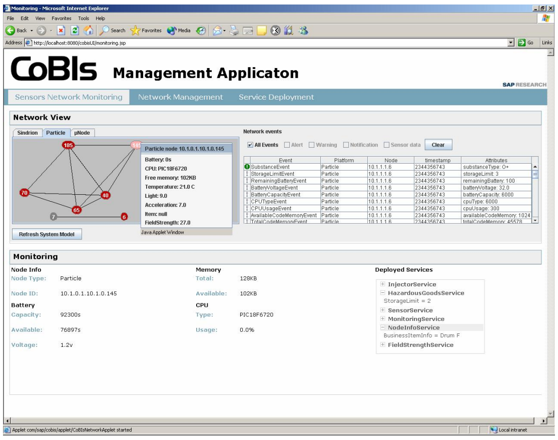

Figure 3: Management GUI.

business logic directly on the items allows for a quick detection of any dangerous situation, even if there is no network connection. Such properties were requested by corporate end-users like BP who want to prevent accidents on drilling platforms in the North Sea, where a network link is not always available. This approach also makes the complete system more scalable, since decisions can be taken locally, at the point of activity and the back-end is only subsequently informed about the decision-result. The business logic is encapsulated in services that can be deployed to the nodes. The use of service-oriented architecture (SOA) makes the management of such complex systems more responsive and brings it closer to real-world situation where they can be applied.

The direct business benefits of using WSNs as illustrated by this trial are:

- Automatic compliance with legal or corporate regulations concerning the storage of hazardous goods
- Warning of security and management staff about potentially dangerous situations
- Increased efficiency / safety of handling by suggesting a safe storage location for each new drum arriving in the warehouse and advice for resolution of alert situations
- Introduction of smartness within the on-site items increasing reliability, scalability, and autonomy of the approach

5 THE PERSPECTIVE OF WSN IN ENTERPRISE SERVICES

A CoBIs system, just like any other wireless sensor or ubiquitous system will not be set up and run for the sake of its own. It is designed to support a business process by either providing real time data, executing business logic on the items, or providing decisions for the further process flow. WSNs or ubiquitous systems will only be deployed in the future, if the costs for setting up and maintaining it are less than the costs that are saved (bottom-line growth) plus the additional top-line revenue that is generated. This fact is depicted in Figure 4.

The technology will lead to increased turnover (because of higher process efficiency or quality or reduced loss) and / or lower operational costs (because of increased automation). Both effects increase the yield. That increase caused by CoBIs sets the upper boundary for additional money a company would be willing to invest into the new technology. Of course, some properties like increased workplace safety or faster time to market do not easily fit into that scheme. However, one can try to monetarize these benefits over the whole system lifetime and treat them as saved costs.

When a company sets up a CoBIs network to increase efficiency of its current business processes, the dominant share of costs will not be hardware costs (since it is expected to become very cheap in the future) but the development of embedded software for the embedded processors and secondary components as well as for the integration logic to integrate the sensors into the current enterprise systems. The CoBIs framework already covers many aspects of device integration like platform abstraction so that application developers can deploy their services in a WSN-agnostic way i.e. without writing WSN-platform specific code etc. However, it must be ensured that the costs for the remaining development that is needed to deploy supported hardware in a scenario are minimal.

Having analyzed, designed, implemented and trialed a WSN based enterprise service, we have often come to conflicts between market needs and technology, and we have identified some directions which we think need to be successfully tackled before WSNs empower future enterprise services. Some key results include:

- The concept of collaborative smart items that can execute business logic is worthwhile and truly innovative solutions for real world needs can be realized. For SMEs there is room to invent and innovate at hardware and software level. The industry is making some attempts to test the new technology, however most of the projects remain simple trials and no wide-spread real-world commercial platform/solution exists; something that is however understandable taking into consideration the challenges that remain to be solved.
- As we move towards the "Internet of Things", the CoBIs approach represents a sophisticated implementation of it. The things are not passive objects

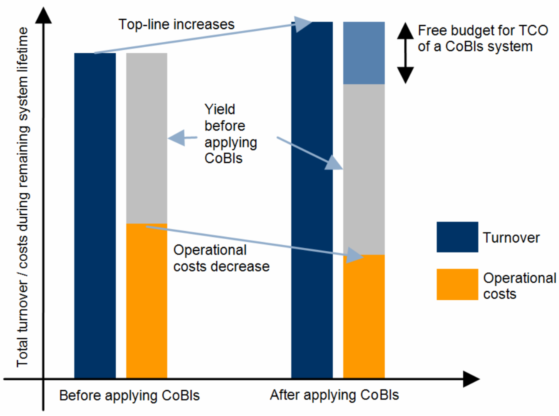

Figure 4: Budget for installing and maintaining a SOA WSN solution e.g. CoBIs.

of sensors and actuators, but actually can host intelligence and take part in collaborative scenarios. The idea of distributing logic within the network (back-end-gateway-nodes) and not only at end-nodes enables the implementation of a fine-grained open service infrastructure and is a promising approach that may effectively deal with robustness, scalability, adaptability and interoperability.
- Openness of the infrastructure should be the focus. We need to agree on common, open, extensible interfaces at different levels, so that the underlying parts can evolve independently. This should be invisible to upper layers which only see a common web-service enabled interface to any sensor network platform. In that case we can expect innovation at all levels in parallel and better integration of the whole infrastructure.
- The WSN market and its economic prospects are not clear to the wide public contrary to simple forms like RFID tags. There is still a lot of "hype" in the community and WSNs are still seen by many commercial companies at the moment as toys for scientists rather than real business opportunities. However, this might change in the mid-/long- term especially if real world scenarios are demonstrated successfully. For the last to happen, the research community should not try to simply tackle general problems in WSNs, but primarily focus on real-world industrial problems and take into account their requirements. In other words, the solutions developed by the WSN community should be built to satisfy real-world requirements rather than building solutions first and trying to identify problems later. We do not foresee a "one-size-fits-all" WSN platform, but rather clusters solving domain-dependent problems.
- Regulators and policy makers have to be considered more intensively in the WSN community since at this early stage they provide guidelines

for interoperability, consumer protection. Adherence to standards could be is still rather the exception and not the rule and can still be a strong value proposition. The impact of wide-spread WSNs on traditional regulated infrastructure has to be assessed. For instance issues like roaming, billing, network access, radio spectrum management etc will probably arise.

- Security, trust and privacy needs to be investigated. CoBIs assumes a closed infrastructure and at the moment the trials were conducted simply to prove the concept. However if similar scenarios are to be commercialized, a solution to the security related challenges needs to be found.
- New tools that help with (also wireless) mass-deployment of services as well as with design of models and business process adaptation for WSN based infrastructures need to be developed. WSN networks are expected to be too complex and therefore abstraction layers and tools to manage this complexity are needed at several levels.
- One new class of tools could analyze business processes, expressed e.g. in BPEL that make use of sensor network services and automatically identify sub-processes that can be processed autonomously by the WSN. The sensor network could be augmented with execution capabilities for efficiently encoded business process descriptions.
- The hardware used needs to be reduced in size, cost and energy consumption, increased in computing power and able to act reliably. This is expected to be solved in the mid- / long-term.
- Both industry and academia should work towards developing appropriate business models, standards for several levels in WSNs, and tackle the security issues. Integration of the semantic web and a service based infrastructure (as followed by CoBIs) provide a really promising approach.

The WiSeNts Research roadmap (Marron et al., 2006) provides an excellent source for a more general view of the challenges, trends and roadmap for WSNs.

CONCLUSIONS

We have presented our opinions and experiences from the design, analysis and realization of a WSN based service solution for the management of hazardous goods. We have investigated from the business perspective focusing on aspects such as service-oriented architecture, better support for business processes etc and laid out the motivation behind our decisions. We have also presented a business model for WSNs while in parallel we have provided some directions that from the business perspective need to be tackled if WSN technology should transform from a mere toy for scientists to a powerful tool, enabling real-world business applications. There is still a long way to go, however initial efforts are promising and we expect that the whole area will be radically reshaped within the next years.

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