TOWARDS SERVICE ORIENTATION ON RESOURCE CONSTRAINED DEVICES

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Abstract: For the flexible integration of enterprise applications and business processes, the Service Oriented Architecture (SOA) concept and the web service technology are the state of the art today. Especially for powerful hardware, a lot of web service and related technologies were developed during the last years. But with the development of Future Internet technologies, there is a demand for integrating all kinds of devices into a SOA. This includes especially devices with extremely limited resources, such as wireless sensor nodes, which are not capable of running today's web service technologies. In this paper we disclose the need for research action on different layers of the web service technology stack. We discuss promising solutions for running standard compliant web services in sensor networks and integrating sensor network and enterprise IT web services as well as BPEL business processes seamlessly. We introduce the *L2D2* project in which our concept will be realized and proven.

1 INTRODUCTION

In the international computer science researching community, a lot of groups are working on the development of technologies to build up the *Future Internet* (European Union, 2008). The scope of topics which are related to the Future Internet is widely spread.

It includes the development of internet test beds such as *WISEBED* (Fischer et al., 2008) as well as computing grids and especially the *Internet of Things* (Erl, 2007; Fleisch and Mattern, 2005). In our point of view, the integration of a plethora of devices into the Internet is one of the most important changes that will be seen in the next years. This targets not only classical mobile devices like notebooks, PDAs or cell phones, but includes connecting all kinds of everyday devices like refrigerators, toasters or cars on the one hand as well as machines, production equipment and wireless sensor networks on the other. These devices are often based upon simple microcontrollers instead of powerful processors, resulting in severe resource constraints.

From this perspective, the Future Internet is a seamless and efficient platform to connect all kinds of objects. A plurality of new services will arise based upon this standard communication platform. In addition, developers will increasingly create applications by simply rearranging existing services to new demands instead of programming every functionality completely from scratch. To realize these new software development paradigms, adequate software architectures for distributed systems and applications are needed (Dunkel et al., 2008).

Closely coupled client server architectures or web applications which are developed for a very specific purpose do not fulfill the technical and economic requirements of today's application environments. Consequently, the approach of Service Oriented Architec-

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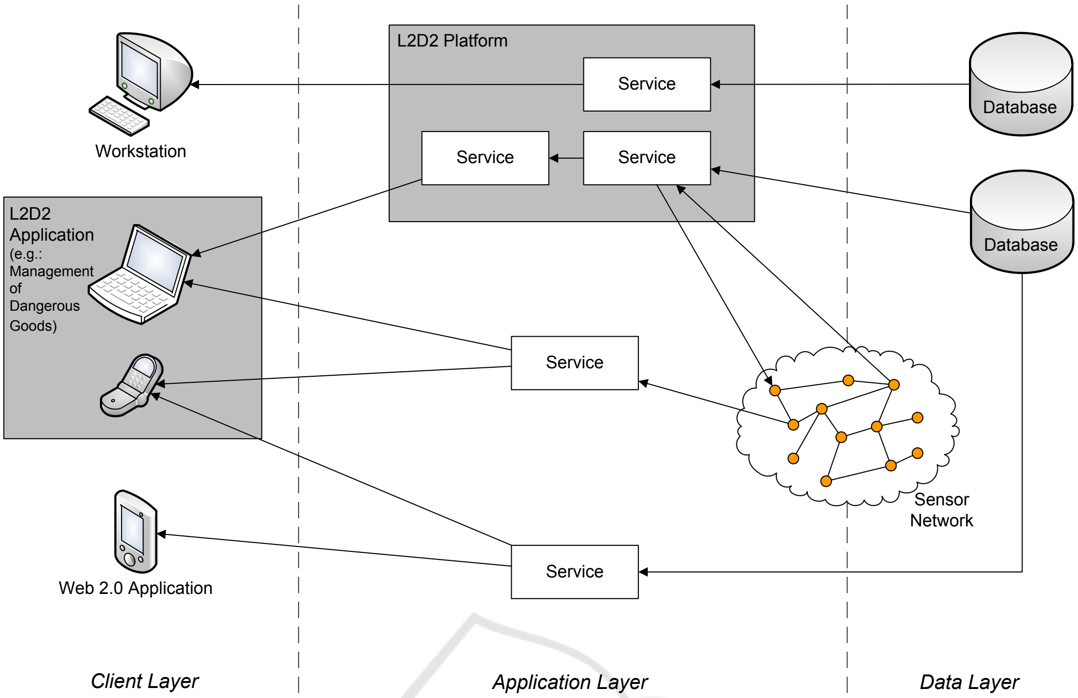

Figure 1: Architecture of the overall *L2D2* system.

tures (SOAs) has been developed to meet the requirements of today's applications development. However, SOA based applications can so far nearly only be found in the enterprise IT environment, there are still only a few approaches published which describe the flexible integration of resource constrained devices such as sensor networks into Service Oriented Architectures.

We strongly believe that only the integration of such devices will unleash the true power of the Future Internet, as machine to machine communication will be one of its most important communication patterns. Hence, in this paper we present an Internet based application example integrating different classes of devices using Web Services, and discuss the challenges that are posed when extending service orientation to extremely resource constrained devices such as wireless sensors.

2 USE CASE: LOGISTICS PLATFORM LÜBECK

Logistics is a business domain where intra- and intercompany business processes are highly integrated. Next to the producers and buyers of goods, more and more organizations of the supply chain (e.g.: airlines, shipping lines, port operators, railway companies, conveyances, and authorities) are getting involved in the automated treatment of flows of goods.

The *Logistics Platform Lübeck* (L2D2)[1] is a researching project which will be realized by the University of Lübeck, the Travemünder Datenverbund Ltd., and coalesenses Ltd. to build up a Service Oriented Architecture based platform on which all kinds of research concepts related to service orientation can be evaluated under realistic conditions. Additionally, various organizations of a logistics supply chain can offer services to partner companies. The platform will be open to partner companies to flexibly add further services at any time.

Figure 1 shows the architecture of the overall *L2D2* system. Basically the system consists of three layers. Several partners provide data. The *L2D2* platform offers service interfaces for all these data respectively software components based on these data. Additional to the services of *L2D2*, it is possible to integrate services from providers of other platforms. Next to the basic services, the *L2D2* platform provides complex composed services. Finally, the *L2D2* services as well as additional services will be composed with *Web 2.0* technologies to different applications.

An example application which will be developed

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[1] The shortcut *L2D2* is derived from the German title of the project: ”Lübecker Logistik Datendrehscheibe”.

Table 1: Services of the *L2D2* platform.

Service Type	Used Technology	Frequency of Redesign	Perspective
Basic Service	Java/C++ Web Service	constant	technical
Composed Service	Java/C++ Web Service	constant/low	technical
Business Process	BPEL	constantly changing	business

on top of the *L2D2* platform will be an application for the management of dangerous goods (*MoDG*). *MoDG* will be built up in two phases. First, we will implement services and business processes which integrate the data and services of the currently existing isolated applications of the organizations which are involved in the transportation of dangerous goods in Lübeck. Furthermore, based on these basic services, we will implement complex composite services and business processes.

In a second step, we will integrate mobile services on resource constrained devices into *MoDG* and the *L2D2* platform. The ”*smart truck*” can improve the safety of the transport and handling of dangerous goods. The idea is that every truck carries wireless sensor nodes which are communicating data about the goods wirelessly to other trucks and to further components of the enterprise IT. The communicated data is not limited to static information about the loaded goods, e.g., an electronic waybill. Furthermore, real time information of the sensed data, such as the temperature or the position of the goods, can be communicated. For example, if two trucks, carrying goods that must have a minimum distance to each other, are located to close together, an alarm will be given.

3 SERVICE ORIENTED ARCHITECTURE ON RESOURCE CONSTRAINED DEVICES

In a *SOA*, applications do not longer consist of monolithic and closely coupled software systems. Applications will be flexibly composed by using existing services on demand (Papazoglou, 2008).

Table 1 shows the different types of services of a SOA based application system. First, there are so called basic services. They are widely stable, i.e. they will only rarely be changed. Second, the so called composed services use basic services to offer more sophisticated functionality. Both services are developed by technical IT staff. They offer functionality on a technical level, e.g., a temperature measurement service. While a basic service, such as the temperature measurement service, offers very elementary functionality, a composed service is built on top of basic as well as other composed services and provides functionality on a higher level. As these two service types are building blocks of the application system, they will be implemented in an object oriented programming language such as Java or C++.

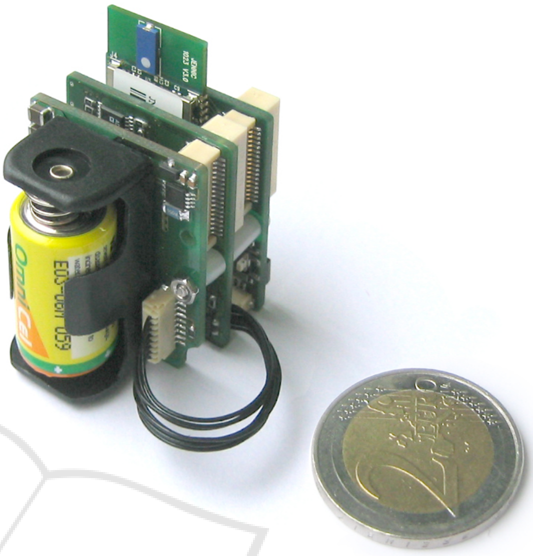

Figure 2: iSense wireless sensor.

On top of the basic and composed services, business process services implement the business logic. These processes are constantly changing. To be able to adapt these services to changing requirements as well as to let business staff modify them, the *Business Process Execution Language* (BPEL) (OASIS WS-BPEL Technical Committee, 2005) will be used to develop this service type.

In the enterprise IT context, there are a lot of well developed technologies for the implementation of a web service based SOA (including BPEL). Our main researching focus is on the integration of mobile and wireless sensor networks into our platform with web service technologies for sensor networks. The goal is to be able to implement all service types defined in Table 1 on all kinds of resource constrained devices. For a seamless integration of sensor network and enterprise IT services it is necessary to extend today’s SOA technologies rather than developing new solutions.

Figure 2 shows a typical example of the resource constrained hardware we are targeting. The depicted iSense wireless sensor network platform (Buschmann and Pfisterer, 2007) consists of a number of hardware modules that can be combined to wireless sensor nodes.

The main module (back of the node in the figure) comprises a 32-bit RISC controller running at 16 MHz including 96 kBytes of memory for both program code and data, an IEEE 802.15.4 compliant wireless communication interface which provides a data rate of 250kBit/s as well as a universal system connector. The connector can be used to attach other modules, providing sensors (center), batteries (front), GPS positioning, a PC interface et cetera.

To be independently mobile, sensor nodes are commonly battery powered. As the wireless communication interface is the main energy consumer, it will have to be turned off most of the time to prolong the battery lifetime. As a result, the networking protocols must be able to deal with this kind of temporary disconnection.

3.1 Related Work

A first step to integrate sensor network applications respectively services offered by sensor nodes into business processes is the *GWELS* (Graphical Workflow Execution Language for Sensor Networks) language and toolkit (Glombitza et al., 2009). The big advantage of *GWELS* is that sensor network services can be easily composed to business processes by people with no special IT expertise. But other than workflow execution languages such as *BPEL* or *ebXML* (Clark et al., 2001) which can be used to compose web services to business processes, *GWELS* can be used in the context of sensor networks with its extremely limited hardware. But even though *GWELS* can be integrated via a web service interface into a web service based SOA, a direct integration of sensor network services and enterprise IT services is not possible. The developers always need to use the *GWELS* web service connector. Furthermore, *GWELS* is based on proprietary communication technologies which are not compatible to any other SOA technology.

Spiess et al (Spiess et al., 2006) describe how to use BPEL for the integration of sensor networks and business processes. The work is part of the CoBIs project (European Union, 2007) which uses a wireless sensor network to monitor chemicals. Unfortunately, these publications do not describe which parts of the sensor network application itself are described using BPEL.

Piryantha et al (Piryantha et al., 2008) describe how to realize tiny web services in a TCP/IP based sensor network. The approach is not applicable for our scenario. First, Piryantha et al use a much more powerful category of sensor network devices. The hardware capabilities of the sensor nodes which we will use are to low to deal with the TCP/IP overhead. Second, we have to deal with very inconstant communication links which make it impossible to use TCP.

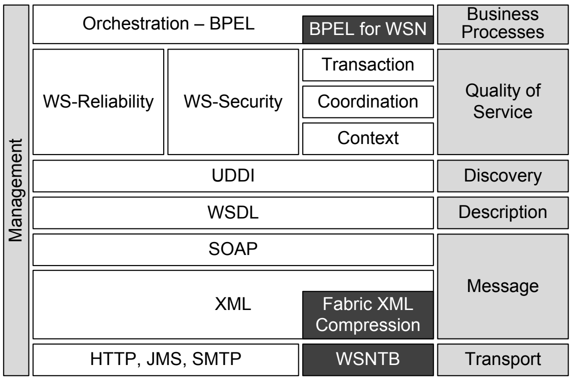

Figure 3: Extended web service stack of the *L2D2* project.

3.2 Challenges

When extending Service Oriented Architectures to extremely resource constrained devices, a number of adaptations are required:

1. XML serialization: as bandwidth is limited and communication is energy-consuming, the serialized message representation must be as compact as possible.
2. XML processing: established XML processing is not possible due to memory constraints.
3. Transport protocol: the networking protocols employed in the classical internet are too resource demanding and not well adapted to wireless communication and disconnection periods.
4. Integrating sensor network services into business processes: run-time interpretation of BPEL is not possible due to resource constraints.
5. Self description of services: memory constraints require compact WSDL representations.

Figure 3 shows the required extensions of the standard web service stack to implement the above mentioned adaptations for a web service based integration of sensor networks and enterprise web services as well as business processes (elements with white text on dark background).

It is not possible to handle plain SOAP XML messages in sensor networks. With the small bandwidth in sensor networks, it is hardly possible to exchange and process SOAP messages serialized to the verbose XML text representation. To reduce the problem of message sizes, the very simple approach would be to use GZIP (Deutsch, 1996) to compress the SOAP messages. But with this approach, it is still needed to decompress the message on the sensor node to a large XML message and process this message on the very restricted hardware. For our approach we use XML compression as described in (Werner et al., 2006) or (Pfisterer et al., 2007) to reduce the message size. The big advantage especially of Fabric/Microfibre approach of Pfisterer et al is that the compressed messages are directly decompressed respectively deserialized to programming language data structures rather than to a large SOAP XML message. Thus, on the sensor node, the deserialized SOAP message is very small and can be used right away without the need of an XML processing which requires more hardware resources than our sensor network platform can offer.

For the transfer of the compacted SOAP messages, a web service transport binding which is optimized for the requirements of communication in sensor networks is required. This *Web Service Transport Binding for Sensor Networks* (WSNTB) hides the complexity of the integration of TCP/IP and sensor network based communication from the application or web service developer. There is no difference between the addressing of services in the sensor network or in the TCP/IP network. The transport binding offers a seamless integration of both ”worlds”. While *WSNTB* will use TCP/IP for the communication outside the sensor network, it is highly flexible considering which transport or routing protocol to use inside the sensor network. *WSNTB* can be used with every routing protocol which is available for the iSense sensor network platform. For the convenient development and access of web services, an integration of *WSNTB* into a web services engine like Apache Axis2 is desirable.

To integrate web services provided by sensor nodes into the business processes of organizations, the sensor network services must be accessible by the BPEL runtime hosted on an enterprise IT server. To reach this goal it is required to extend a BPEL runtime (such as the Apache ODE BPEL runtime (Apache Software Foundation, 2009)) with the XML compression capabilities and web service transport binding *WSNTB* described above.

However, to deploy BPEL web services not only on enterprise servers but also on sensor nodes, further adaptations are required. The sensor nodes' resource constraints inhibit the interpretation of BPEL process descriptions on the node at run-time. Instead, the BPEL description has to be compiled on a PC at design-time to optimized machine code for the target platform and can then be transferred to the destination node. For the communication between the BPEL process and other services, *WSNTB* can be used as well. As sensor network web services, these BPEL processes will also be able to call web services provided by other sensor nodes as well as by enterprise servers. The representation of the XML data and message types for the communication with the BPEL process as well as the data representation of the BPEL process itself will be realized by using programming language data structures automatically generated by the Fabric/Microfibre toolkit.

The final issue to address is the service description. For the sake of compatibility, the description of web services should be done using WSDL. As web services usually describe themselves, the WSDL description consequently has to be stored on the resource constraint device itself. The required extremely compact representation of the description can be achieved by applying Fabric/Microfibre.

4 CONCLUSIONS

Two major but so far unfortunately separate trends of the Future Internet are the integration of all kinds of resource constrained devices and a consequent service orientation. To integrate these two, we pinpointed the need for research action on different layers of the web service technology stack and discussed promising solutions. We proposed *WSNTB* to address the need for a compact XML serialization, low processing overhead and a seamless transport protocol integration. In addition, we outlined how BPEL can be applied to resource constrained devices and the resulting services can describe themselves efficiently.

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