Efficient Sensor Data Inclusion in Enterprise Services

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Abstract

Modern enterprises need to be agile and dynamically support decision making processes at several levels. To achieve that, critical information need to be available at the right point in a timely manner, and in the right form. The data stream that flows from the real world devices towards enterprise systems, needs to be integrated, processed within a specific context and be communicated on-demand and on-time. In the future event-based infrastructures where millions of devices will openly cooperate, traditional approaches aiming at the efficient data inclusion in enterprise services need to be changed. This paper focuses on the requirements enterprise systems pose to clusters of devices such as the wireless sensor networks, and the directions that could be followed.

1 Motivation

Enterprises are moving towards service-oriented infrastructures where applications and business processes are modelled on top of cross-organization service landscapes. In order to be able to take efficient decisions and manage the resources in an optimal way, a direct link to the timely provision of information residing in all layers between the enterprise services and the resources needs to be established. This increases visibility at a very discrete level and can provide insights on how specific problems can be avoided or tackled. However monitoring is not enough, as controlling and adapting the behaviour of the resources needs to take place in order to close the loop.

As such, the integration of devices and their capability of automatising the information acquisition and processing coupled with management capabilities can empower existing approaches and let us tackle problems in new innovative ways. While device to business integration gains importance, we are witnessing another trend namely their miniaturization and the expansion of their computing as well as communication capabilities. In the envisioned "Internet of Things" (IoT) [Fleisch, Mattern 2005] large numbers of distributed networked embedded devices (NEDs) will be able to collaborate autonomously in order to achieve their goals. As embedded devices are becoming more sophisticated we see slowly a paradigm change characterized mostly from the efforts to migrate advanced functionality previously hosted in powerful static back-end systems, towards more lightweight mobile distributed embedded devices.

The data flow from the moment it is sensed (e.g. by a wireless sensor node) up to the moment that reaches the backend system has been processed manifold (and often redundantly), either to adjust its representation in order to be easily integrated by the diverse applications or to compute on it in order to extract and associate it with respective business intelligence (e.g. business process affected etc.). As depicted also in Figure 1 such we see a number of data processing network points between the machine and the enterprise, that act on the stream based on their end-application needs and existing context.

If we take a look at existing shop-floors, we will see that system intelligence today relies mainly on the backend systems as well as in a limited amount of monolithic computing resources where large numbers of resource constrained devices are attached to (physically or logically). The intelligence and behaviour are application-specific tailored to specific use cases, while usually this is custom-development with software and hardware vendor lock. As such, opportunities for synergetic effects are limited and costly, leading to non-maintainable "frozen" infrastructures, where introduction of new functionality not rarely implies deployment of a new solution both in hardware and in software.

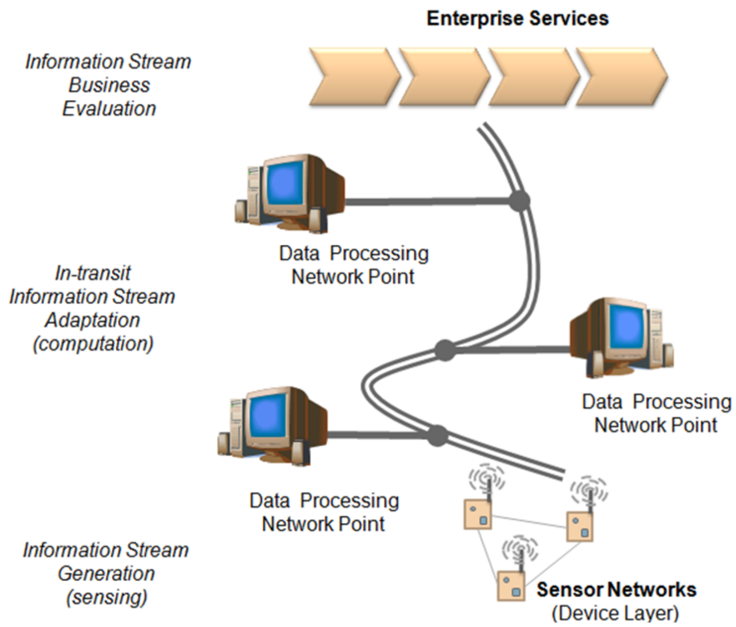

Figure 1: From sensing to business evaluation of data

Apart from that, the data acquired is often not exchanged in a timely fashion (if in coexistence with other networks and not as sole user of the communication infrastructure) and is error-prone, which leads to poor information visibility and dissemination. This results in delays in backend processes and a lower responsiveness to problems because the information is not available always in the right form and in a timely manner to be processed; thus either ignored or evaluated with high computation and time cost. On the operational level of the enterprise, managers learn about critical issues too late to react efficiently. For example due to the denoted integration gap, if a machine breaks down in the production line, it can take hours if not days until a key account manager learns about missed due dates and customer orders might get lost. On the contrary a direct linkage of the machine and its alerts with the respective affected business processes will allow an enterprise system not only to adapt its behaviour (reschedule or reassign the task) but also take measures to resolve the problem (e.g. automatic issue of repair requests) and reduce future downtime (e.g. by applying predictive maintenance approaches).

Sensor and actuator networks not only can sense the information, but via collaboration with the backend or network-based services can prioritize and evaluate in a specific context the information they produce. In parallel any decisions taken at business level can be enforced in the real-world, minimizing error-prone human interaction and effectively closing the loop between monitoring and (soft) control.

2 The Sensor Network Promise

A sensor network is a network of distributed, autonomous devices that use sensors to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, and motion. Wireless Sensor Networks (WSN) are composed of devices that are interconnected wirelessly and usually collaborate to achieve their ultimate goal. WSNs can be viewed as part of the so-called "Smart Item" family. A "Smart Item" is a device that is able to provide data about itself or the object with which it is associated, and can communicate this information to other devices. With their increasing computing and communication capabilities, Wireless Sensor Networks are playing a significant business role, moving from (passive) valuable business assets towards active business process actors. Sensor Networks have become a hot topic in research, and significant progress has been achieved in the past few years. This momentum is driving the creation of many new innovative applications that are based on the information of and interaction with sensor networks, which were not possible with traditional technologies.

Wireless Sensor Networking is one of the most promising technologies to bridge the physical and virtual worlds and enable interaction between the two realms. This bridge effectively leads to the avoidance of media breaks especially between the real and the enterprise world. Expectations for WSNs go beyond research visions, and are moving towards deployment in real-world applications that would further empower business processes and future business cases. Enterprises are moving towards a service-oriented ubiquitous infrastructure where, in the near future, it can be expected that millions of devices of different sizes and capabilities will be connected and interact with each other over IP (e.g. sensor networks communicating over 6lowpan). New innovative services are expected to empower business solutions and provide new approaches to known problems that were not possible today due to the missing granularity and real-time delivery of information that WSNs can deliver. Therefore, it is expected that WSN dependent services will be vital for future business scenarios in a number of industry domains. However, their reliable integration with existing services and business processes poses new challenges to enterprise systems as they are hardly designed to function effectively in such distributed, information-rich, highly complex future infrastructures.

The market opportunities for real-world services are huge. OnWorld study [Phani Kumar et al. 2005] projects that wireless sensor network (WSN) systems and services will be worth $ 6.6 billion in 2011. In 2012 is is expected that there will be 25.1 million WSN units sold for smart home solutions only, and increase from the 2 million in 2007. As mass market penetration of networked embedded devices is realized, services that take advantage of the newly offered functionality these devices bring, will give birth to new innovative applications and provide business advantages. The key however is to dynamically discover, efficiently compute on and assess the business effects in a timely manner considering massive data streams.

As in the last years sensor networks have become more powerful with regard to computing power, memory, and communication, they are beginning to be built with the goal of offering their functionality as one or more services for consumption by other devices or services [Jammes,Smit 2005]. Therefore, we have a paradigm shift as these devices can offer more advanced access to their functionality and even host and execute business intelligence, therefore effectively providing the building blocks of a service-oriented architecture, just as contemporary enterprise-scale IT systems do. This allows for a clear, frictionless way of integrating those embedded services into corporate business processes. A business process expert would model a business process using both embedded services and the ones offered by the back-end. This cross-technology business process will be executed anywhere within the hybrid system consisting of back-end and front-end, possibly completely in the networked embedded subsystem. This flexibility allows the business process expert to place its intelligence where it is needed, close to the point of action and distribute it over several layers among the devices and the enterprise systems [Karnouskos, Spiess 2007]. This capability, allows the creation of more flexible and sophisticated business processes, bringing companies one step closer to the "real-time enterprise" [Spiess, Karnouskos 2007].

3 Enterprise Constraints

Wireless Sensor Networks have become a hot issue in research, and significant progress has been achieved in the past few years. Although visions have been laid out, and significant progress has been done in the research domain (theory, algorithms, protocols, implementations, trials etc.), questions still remain to be answered. That wireless sensor networks have not become mainstream, although we have sporadic success stories in specific domains, traces back to several reasons including the open access to its functions and information as well as easy integration in business applications.

3.1 Interoperable integration

The majority of existing solutions are either vendor locked in a specific combination of hardware and software, which makes it difficult to introduce new functionality easy enough; or the information conveyed is of limited exploitation by third party users or for goals different to the initial ones at the time of design and realisation of the specific scenario. Having this information- and solution-limited scope and usage, any federated usage and exploitation of information that deviates from the original scope is almost impossible. To a big extend, responsible is also the community for lack of standards. Although communication standards are there, anything else above that is insufficiently addressed. A very simple example: there is no ontology and standardisation even for very basic and generic services that a sensor can offer which in turn makes its integration a very painful and an application specific task.

The industry need here is to move away from the specific implementation of the functionality as such, and focus on an open and standardised way to access this. Service Oriented Architectures (SOA) have gained wide popularity in enterprise environments and what we witness nowadays is the propagation of these concepts towards the device level. More specifically we see devices like the sensors being capable enough to offer in their built-in computation environment an implementation of their functionality as a service (SOA-Ready devices). This implies that any external entity trying to integrate the sensor can do that via a service like approach such as web services [Karnouskos et al. 2007] or other approaches e.g. REST-like.

The implications are tremendous, since now the enterprise service designer can use existing modelling tools and make them device-aware, therefore significantly reducing the pain points of integration. Apart from that the data generated by the sensor could be directly accessible (or via a gateway for extremely resource constrained devices) in their raw or wrapped form that fit exactly each application's needs. Such functionality can be reconfigured on the fly or even on-demand by deploying another service on the sensor or its gateway. Huge databases whose solely reason of existence is the centralization of data, could be obsolete, and distributed more lightweight DBs can be created matching testbed's or application's local needs. As inconsistencies arise due to dynamic nature and high rate of sensor network information [Schlesinger, Lehner 2003], such a distributed localised approach might be worth looking at. With some intelligent management and service deployment this could be an advantage over single points of failure as well as load balancing with respect to the sensor generated data that need to follow a specific path in order to reach the enterprise services.

3.2 Timely communication of sensing

Several efforts concentrate on optimising the communication among the sensors, making efficient usage of their power and communication resources, however without adequately integrating the business requirement behind this behaviour. As such, business applications often have to deal with time-specific snapshots of the measured data that are not a perfect fit to their specific needs. Furthermore, many efforts focus on having WSNs as sole users of the communication channel and paying less attention interference. Assuming that WSNs are deployed for mission critical purposes, the quality of service as well as the information needs to be guaranteed.

Commonly today, measurements will be made and propagate all the their way up to an aggregating system (depicted on the left side of Figure 2, very near to the enterprise services (in terms of layers between the service and the device that generated the message), where it will be put in a DB, then be read by an Alert Identification process that operates in that DB, identified that this corresponds to an alert and the respective enterprise services will need to notified (in the best case). Even then, until that alert reaches the respective business processes that are affected, a big percentage of time was lost in the way, by not being able to identify the initial information as an alert, and by not being able to effectively couple it immediately with the affected processes and react on it. In a "real-time" enterprise, the sensor or it gateway will be aware of the relevance of the alerts and in an event based infrastructure it would be possible to multicast this to the affected actors.

The Internet of Things envisions millions of devices generating events that will have to be stored and processed. It is neither wishable nor possible to convey this huge amount of information to the backend systems and do the processing there (even in the era of massive data centres). Communication needs to be prioritized and processed locally where it makes sense and propagate only business relevant info to the upper layers. To achieve that we will need to know the exact context we operate in.

3.3 Efficient context-specific information exploitation

Decoupling the sensor functionality from the respective business process that benefits from it, leads often to increased and unnecessary communication on all layers between the application and the sensor. What is needed is to make the sensor aware of the specific requirements of the application and be able to configure it to match its performance as well as delivery of data to the application's expectations. It is common that data gets transformed several times (as depicted in Figure 1) in different format to fit in the isolated integration solutions that rely between the source (the sensor) and the final consumer (the business service). This is due to lack of visibility of the whole path as well as lack of strong coupling of the business and the physical world.

By integrating the business context we can process locally the events generated by the sensor (e.g. business logic on device) and at relative low cost evaluate the significance for the business system. As such the external communication with backend applications is kept low, very specific and meaningful. This leads to avoidance of communication bottlenecks and high computational cost at the end-side. Of course there are scenarios where it makes sense to have a centralised collection and operation on data, but the tradeoffs in comparison to a more intelligent and distributed approach need to be carefully evaluated.

4 Distributed Business Processes

The media break we witness today can be depicted in the left side of Figure 2. As analysed the integration with business systems is done at an inflexible and usually business-relevant agnostic way - relevant only to the communication of specific data, but without a clear matching or even estimation of the effect on the business side. Furthermore due to the deployment of isolated and task specific solutions, we have ended up with sensor infrastructures that are not interoperable, can not collaborate because of data-understanding barriers and even communication difficulties although e.g. physical proximity could in theory make that possible. The result is several horizontal and vertical media breaks, that are patched up with proprietary solutions and gateway/tunnelling approaches that complicate the things further.

In such a mixed, non-standardised and highly complex infrastructure, business applications have a very hard way to dynamically discover, integrate, and interact with the sensor networks although this is wished. Vice versa, the sensor networks have very little chance of being used or even depict collaboration capabilities and take advantage of the opportunities to offer their services in tight interaction with enterprise services. Even at relative high layers where their data is aggregated and stored on DBs, this is again done in a very task specific way, leading to almost non-existent collaboration at higher layers - which in principle should have been much easier to realise. In a world where service-mashups allow us to easily compose sophisticated functionality, the sensor networks that could bridge the digital and real world can not escape and stay confined in closed systems incapable of realising their full potential.

By accessing the isolated information and making the relevant correlations, business services could evolve, acquire not only a detailed view of the interworking of their processes but also take real-time feedback from the real world and flexibly interact with it.

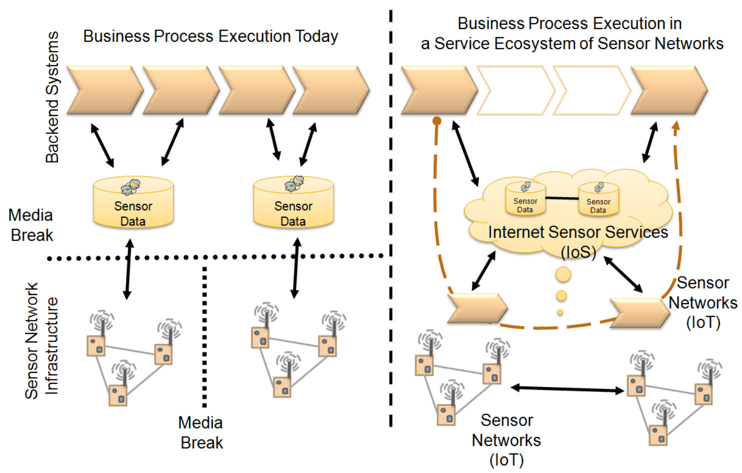

Figure 2: From media breaks to distributed business processes

As mentioned in a world envisioned by the Internet of Things where millions of devices cooperate and offer open access to their functionality, and where the Internet of Services allows the creation of mashups that mix and integrate the virtual and real world, business services can benefit tremendously from their combination. In such large scale infrastructures, tunnelling of data to backend systems or centralised databases is not a viable solution for the majority of scenarios. Of course data will be kept e.g. for billing or proof of a service supplied, but in a world where the data generation rates will increase drastically this will be the minority. Enterprise systems trying to process such a high-rate of non- or minor relevancy data, will be overloaded. As such the first strategic step is to minimize communication with enterprise systems only to what is business relevant. Thus information needs to be processed at local loops and be explicitly propagated. Correlation of information and cooperation scenarios in a goal oriented way is needed [Saukh et al. 2008].

The next step is to partially outsource functionality traditionally residing in backend systems to the network itself and the edge nodes. As devices are capable of computing, they can either realise the task of processing and evaluating business relevant information they generate by themselves or in clusters (as depicted in right part of Figure 2). The business process can now be by design distributed, where parts of the required functionality are executed at the item itself e.g. on-sensor or in-network (e.g. sensor networks and/or other services provided by ISVs). Distributing load in the layers between enterprises and the real world infrastructure is not the only reason; distributing business intelligence is also a significant motivation.

Business process can bind during execution dynamic resources that they discover locally and integrate them to better achieve their goals. Being in the world of service mash-ups, we will witness a paradigm change not only on the way sensor networks and clusters of heterogeneous devices interact with each other [Phani Kumar et al. 2005] and with enterprise systems, but also in the way integration with the real world is done. Modelling can now be done by focusing on the functionality provided (and that can be discovered dynamically during runtime), and not on the concrete implementation of it; we care about what is provided but not how.

If the media breaks are eliminated a new generation of solutions, where heterogeneous resource constraint devices use powerful enterprise systems to obtain necessary info on how to better process or decide upon the data they generate will emerge. In that sense sensor networks are becoming active players in the enterprise environments and can dynamically collaborate with them.

5 Technology: SOA-based Interaction

Interoperability will be a major challenge in this highly heterogeneous infrastructure. Although special flavours of the Internet Protocol, such as the 6lowpan which is designed for constraint devices, are expected to efficiently connect large populations of these devices with each other, being able to seamlessly support interoperable Machine to Machine (M2M) interaction over the IP network is a must in order to provide wide access to its resources and functionality. The newly created IPSO Alliance (www.ipsoalliance.org) supported by major companies advocates exactly that. A concept successfully tested in the business environment to tackle interoperability is that of Service-Oriented Architectures (SOA) where web services are used in order to focus on the functionality rather than the underlying implementation.

One possible way to implement SOA is via web services. Web services nowadays can be implemented directly on devices, providing them with the necessary technology abstraction and making them easily integrateable in heterogeneous environments. As an example the SOCRADES project (www.socrades.eu) is implementing web services on devices (SOA-Ready devices) and integrates them with modern enterprise systems [Karnouskos et al. 2007]. The devices that host web services might have their functionalities implemented using their proprietary tools in different languages. Another interesting issue is the support of the eventing in all web service enabled layers ranging from device up to enterprise services. By supporting an event instead of a pull infrastructure, we are able to better interact with the real world [Röemer, Mattern 2004], and minimize traffic, while tailored fine grained solutions can be realized. Thus it is expected that services depending on SOA-ready devices will be vital for future business scenarios in a number of industry domains. However we have to point out that existing WS approaches focus more on the management layer but not on real-time control loops, as the time notion in web services is issue of ongoing research.

One possible way to realise web services on resource constraint devices is to implement the Device Profile for Web Services (DPWS) [Chan et al. 2006]. In the past there have been efforts (e.g. Jini, UPnP) to integrate devices into the networking world and make their functionality available in an interoperable way. The latest one, coming from UPnP world and attempting to fully integrate with the web-service world, is DPWS, which defines a minimal set of implementation constraints to enable secure Web Service messaging, discovery, description, and eventing on resource-constrained devices. DPWS builds on several core Web Services standards while an implementation (WSDAPI) is also included by default in Microsoft Windows Vista and Windows Embedded CE. In August 2008, OASIS initiated the OASIS Web Services Discovery and Web Services Devices Profile (WS-DD) Technical Committee to further develop it.

Although primarily developed for the home and office environment, DPWS is being piloted also in other domains such as the automation one by major industrial players. Initial efforts indicate positive results, and therefore it is expected that in the future many devices and their services will be able to be discoverable in a web-service enabled way. Similarly another standard coming from the automation domain i.e. OPC Unified Architecture (OPC-UA) [Mahnke et al. 2009] also offers similar functionality. Both standards are expected to be supported by various products including sensor networks that will come to the market in the short term. Bringing OPC-UA and DPWS together under one common way to access devices depending them, could be feasible (a big portion of both is based on common standards) and could provide a real benefit for enterprises.

6 Challenges for the Mainstream Adoption of Sensor Networks

Several issues have been identified and still need to be addressed, if (wireless) sensor networks are to leave the research labs and establish themselves successfully in the business domain [Marrón, Minder 2006]. With respect to the enterprise interaction focus is needed on:

- Mobility: Sensor nodes are expected to be mobile in the future, yet most existing trials and efforts assume they are relative static. This mobility might be incidental (e.g. environmental influence as in the case of wind/water sensor nodes), active (e.g. in the case of automotive industry) or passive (e.g. attached to an object moving independently). As this largely impacts the whole operation of WSNs, more research needs to be done that matches domain/scenario requirements with WSN capabilities.

- Security and Privacy: Data collected and processed by WSNs need to be protected to guarantee their integrity and eavesdropping. Although as standalone info they may provide limited information, their overall collection in conjunction with context specific info (i.e. available in back end systems) may reveal business strategies and secrets. Novel ways to match scenario requirements without penalizing performance or other requirements need to be trialed in real-world environments.

- Deployment: WSNs deployment is expected to be a continuous process in the future and not a one-time activity. This implies that the network must be able to cope with adding/removing/replacing sensor nodes and dynamically adapt itself (e.g. in communication and management plains).

- Resource Dependency: Different domains have different requirements on resource availability on each node, which is directly linked with cost, size, and energy of the nodes. WSNs come in several flavours from simple miniature devices costing some cents to more complex ones costing hundreds of dollars. Research efforts need to focus on application modelling that takes into account the optimal resource availability satisfying their requirements. This includes context-based condition monitoring that e.g. could take advantage of energy harvesting possibilities available in the operating environment.

- Openness: Openness of the infrastructure should be the focus. There needs to be agreement 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, one can expect innovation at all levels in parallel and better integration of the whole infrastructure.

- Self-sustainability: Sensor network infrastructures must be able to work in a dependable fashion, depicting "self-*" behaviour [Karnouskos 2007] for example, self-configuration (automatic configuration of components), self-healing (automatic discovery and correction of faults), self-optimization (automatic monitoring and control of resources to ensure the optimal functioning with respect to the defined requirements) and self-protection (proactive identification and protection from arbitrary attacks).

- Interoperability: Most existing efforts consist of homogeneous devices running the same software or only slight variations thereof. However, in the future the sensor nodes will not only be highly heterogeneous in hardware and software, but may also be governed by competing interests. As such, interoperability at all layers has to be guaranteed, as this has an imminent effect on software complexity and management of the whole system.

- Communication Capability: WSNs are expected to interact wirelessly with the real world; this however comes in many flavours. Although today most sensor nodes communicate with each other via radio, there are examples of sensor nodes communicating via laser or even sound. Also in case of radio, a common base needs to be in place, meaning support of a high-level protocol layer that will allow cross-WSN communication (e.g. via 6LoWPAN) and bridges between the low-level communication protocols.

- Infrastructure: The infrastructural support needs to be closely examined. Although most efforts use ad-hoc approaches, if an infrastructure is always available, such as a GPRS/UMTS network or even localization capabilities via GPS, its services could be used to complement functionality of WSN services. Again, the services available on-site in the operating domain of WSNs, directly influence the WSN-aware application design, operation, and function.

- Quality of Service: QoS and its associated characteristics such as performance, robustness, dependability, and fault-tolerance are seen as critical in many business applications. As such, they directly affect the design and operation space and need to be tackled effectively. QoS does not refer only to the software part but applies more generally on what the WSN nodes should satisfy (e.g. mechanical or thermal stresses).

- Effective integration with enterprise systems: WSNs need to be easily integrateable with enterprise back-end systems and corresponding scenarios. As such new modelling tools need to be developed and new architectures need to allow cross-layer cooperation between WSN-applications and services running at the WSN node, network, and enterprise level.

7 Conclusions

Networked embedded systems such as sensor networks have become more powerful with respect to computing power, memory, and communication; therefore they are starting to be built with the goal to offer their functionality as one or more services for consumption by other devices or services. Due to these advances we are slowly witnessing a paradigm shift where devices can offer more advanced access to their functionality and even host and execute business intelligence, therefore effectively providing the building blocks for expansion of service-oriented architecture concepts down to their layer. As such, event based information can be acquired, processed on-device and in-network, without the need of storage in intermediate databases and processing by third parties, and eventually be conveyed to the corresponding business processes. This capability provides new ground for approaches that can be more dynamic and highly sophisticated, and that can take advantage of the context specifics available.

It is often argued that existing sensor networks with their today scarce resources have a lot in common with the early Internet infrastructure almost three decades ago. If this parallelism holds true, we are still in the early stages of exploring their true potential. It is expected that via efficient data inclusion generated by sensor networks in a collaborative manner with enterprise services, the latest will benefit and provide tight integration of the business and the physical world. The future enterprise environment where sensor networks will exist will be an ecosystem where collaboration and service mash-ups are common. However, for the last to be mainstream, several challenges need to be succesfullytackled.

References

[Chan et al. 2006] Chan,S.; Conti, D.; Kaler,C.; Kuehnel, T.; Regnier, A.; Roe, B.; Sather,D.; Schlimmer,J.; Sekine, H.; Thelin, J.; Walter, D.; Weast, J.; Whitehead, D.; Wright, D.; Yarmosh, Y.: Devices profile for web services. http://specs.xmlsoap.org/ws/2006/02/devprof/devicesprofile.pdf

[Fleisch, Mattern 2005] Fleisch, E.; Mattern, F.: Das Internet der Dinge: Ubiquitous Computing und RFID in der Praxis: Visionen,Technologien, Anwendungen, Handlungsanleitungen. Springer, Berlin, 2005

[Hatler et al. 2007] Hatler, M.; Gurganious, D.; Chi, C.; Ritter, M.:WSN for SmartIndustries. OnWorld Study, 2007. www.onworld.com

[Jammes,Smit 2005] Jammes, F.; Smit, H.: Service-oriented paradigms in industrial automation. Parallel and Distributed Computing and Networks, 2005

[Karnouskos et al. 2007] Karnouskos,S.;Baecker,O.; de Souza, L.M.S.;Spiess,P;:Integration of SOA-ready Networked Embedded Devices in Enterprise Systems via a Cross-Layered Web Service Infrastructure. 12th IEEE Conference on Emerging Technologies and Factory Automation, September 25-28,2007, Patras, Greece

[Karnouskos, Spiess 2007] Karnouskos,S.; Spiess, P.: Towards enterprise applications using wireless sensor networks. 9th International Conference on Enterprise Information Systems (ICEIS), 12-16, June 2007, Funchal, Madeira, Portugal.

[Karnouskos 2007] Karnouskos, S.: Autonomic sensor networks for future enterprise services. KiVS 2007 Conference, 26 Feb - 2 Mar 2007, Bern, Switzerland.

[Mahnke et al. 2009] Mahnke, W.; Leitner, S-H.; Damm, M.: OPC Unified Architecture, Springer, January 2009. ISBN-10: 3540688986

[Marrón, Minder 2006] Marrón, P.J.; Minder, D.: Embedded WiSeNTs Research Roadmap. Logos Verlag Berlin, 2006. ISBN: 3-8325-1424-4, www.embedded-wisents.org

[Phani Kumar et al. 2005] Phani Kumar, A.V.U.;Adi Mallikarjuna Reddy, V.;Janakiram,D: Distributed collaboration for event detection in wireless sensor networks. MPAC '05: Proceedings of the 3rd international workshop on Middleware for pervasive and ad-hoc computing, Grenoble, France.

[Röemer, Mattern 2004] Röemer, K., Mattern, F. : Event-based systems for detecting real-world states with sensor networks: A critical analysis. DEST Workshop on Signal Processing in Sensor Networks at ISSNIP (2004)

[Saukh et al. 2008] Saukh, O.; Sauter, R; Marrón, P.J.: Time-Bounded and Space-Bounded Sensing in Wireless Sensor Networks. Distributed Computing in Sensor Systems. 4th IEEE International Conference, DCOSS 2008, Santorini Island, Greece, June 11-14, 2008

[Schlesinger, Lehner 2003] Schlesinger, L.; Lehner, W.: SCINTRA: A Model for Quantifying Inconsistencies in Grid-organized Sensor Database Systems. International Conference on Parallel and Distributed Computing (Euro-Par 2003), Klagenfurt, Austria, 26.-29. August 2003

[Spiess, Karnouskos 2007] Spiess, P.; Karnouskos, S.: Maximizing the Business Value of Networked Embedded Systems through Process-Level Integration into Enterprise Software. The Second International Conference on Pervasive Computing and Applications (ICPCA 2007), July 26-27, 2007, Birmingham, United Kingdom.