Breakthrough Towards the Internet of Things

Leonardo W. F. Chaves and Zoltán Nochta

Abstract In this chapter we introduce the Internet of Things (IoT) from the perspective of companies. The Internet of Things mainly refers to the continuous tracking and observation of real-world objects over the Internet. The resulting information can be used to optimize many processes along the entire value chain. Important prerequisites for the IoT are that the objects of interest can be uniquely identified and that their environment can be monitored with sensors. Currently, technologies, such as different types of barcodes, active and passive Radio Frequency Identification (RFID) and wireless sensor networks play the most important role. However, these technologies either do not provide monitoring of their environment or they are too expensive for widespread adoption. Organic Electronics is a new technology that allows printing electronic circuits using organic inks. It will produce ultra-low cost smart labels equipped with sensors, and thus it will become an enabler of the IoT. We discuss how organic smart labels can be used to implement the Internet of Things. We show how this technology is expected to develop. Finally, we indicate technical problems that arise when processing large volumes of data that will result from the usage of organic smart labels in business applications.

1 The Internet of Things from Companies' Perspective

The Internet today can be described to a large extent as a ubiquitous infrastructure: it is always on and is always accessible from nearly any place of the world. After the initial era of connecting places and connecting people, the Internet of the future will also connect things (Cosnard et al. 2008).

The core idea behind the resulting Internet of Things (IoT) is to seamlessly gather and use information about the physical environment and about, potentially, any kind of object in the real world ("things") during their entire lifecycle. Physical objects,

L.W.F. Chaves (✉)
SAP Research, CEC Karlsruhe, Vincenz-Priessnitz-Strasse 1, 76131 Karlsruhe, Germany
e-mail: leonardo.weiss.f.chaves@sap.com

D.C. Ranasinghe et al. (eds.), *Unique Radio Innovation for the 21st Century*,
DOI 10.1007/978-3-642-03462-6_2,

including not only everyday products and goods but also different kinds of company assets, such as machines, tools, buildings, vehicles, containers, warehouse equipment, etc. will be augmented with sensing, computing, and networking capabilities and become active participants within business processes in future.

Making gathered information available, for example, about products' and goods' origin, movements, physical and chemical properties, usage context, etc. via the Internet will help enterprises improve existing business processes and also create new opportunities.

Companies will make use of the IoT in order to manage, i.e., to monitor and control their *internal* business processes, including the production, distribution, transportation, service and maintenance, and recycling of their products more effectively than today. Traditional enterprise processes and related software systems typically rely on manual data collection. Since manual data collection is, in many cases, error prone software systems often do not have the correct information to take the best possible decision in a given situation.

For example, a system that automatically orders spare parts for production machines and schedules the machines' condition-based maintenance requires accurate and timely information in order to ensure the continuous production and to optimize cost as well as the asset utilization of the company. In such business critical scenarios the usage of inaccurate data that do not adequately reflect the situation in the real world can lower both quality and performance of business processes and can lead people to make ineffective decisions in critical situations. Example negative implications are delayed order fulfillment, increasing costs, or out of stock situations.

The IoT will help companies capture the status of the entire enterprise and processes more accurately, in the ideal case exactly, where representations of the real world in software systems are an accurate, timely and complete reflection of the reality.

To achieve this goal, physical items of the real enterprise environment, such as the above mentioned machines and the corresponding spare parts, have to provide some "smart" functionality. For example, when arriving at or leaving the warehouse, machine spare parts can automatically reveal their identity to the respective warehouse gate without any human interaction. Based on this information, the parts warehouse inventory can always be up-to-date, helping avoid out of stock situations.

"Smart" physical items, or more precisely, miniature devices that are attached to or embedded into the items, should provide functionality that is useful but also affordable in the context of the envisaged novel business processes.

The functionalities that such smart items can offer for can be grouped into *five abstract categories* (Mühlhauser and Gurevych 2008). These categories are called:

1. Information Storage,
2. Information Collection,
3. Communication, Information Processing and
4. Performance of Actions.

A given smart item may offer any meaningful subset and combination of these functional elements depending on given requirements, available technologies and affordable costs. For example, a pallet that is equipped with an RFID tag offers information storage and communication functionality in order to automatically capture the pallet's unique Serialized Shipping Container Code at the relevant reading points.

1. *Information storage:* In companies operating with traditional information systems, data about business objects is usually stored in large centralized databases. Normally, there is no direct linkage between a physical object and the backend datasets associated with it. Smart items can help change this situation and establish a more direct linkage by storing and revealing different types of information either about themselves, or their environment. The information an item stores can be pre-determined and static (e.g., identifiers, production/expiry date, target location, weight, owner, etc.), or it can be dynamically updated during the life cycle of the item (e.g., tracking history, current location, critical temperatures the object has been exposed to, etc.). Depending on requirements, different types of memory components might be used to store the respective data on the item, such as read-only, write-once-read-many, or write-many-read-many memory modules. Information about objects can be stored in electronic devices, but also in printed labels, encoded as linear barcode or two-dimensional data matrices.
2. *Information collection:* A smart item may also be able to autonomously gather information either about itself, or its environment. Observation of different, dynamically changing parameters can be carried out by using various specialized sensors and respective technologies. One of the most important observable parameters of a potentially moving item is its location. Important location properties are objects' absolute position in a given coordinate system (2D or 3D) as well as their orientation. Objects' location can be determined by using explicit observation techniques and systems, such as the Global Positioning System (GPS). Location information may also be implicitly derived from the known position of the observing device, such as the known position of a stationary RFID reader. Knowing the identifier and the current location of a given object, a huge potential for optimizing business processes opens up. For example, based on accurate and timely location information of moving assets in a company, maintenance processes can be optimised. Objects' orientation is also measurable by multiple means. For example, when selecting read ranges carefully, a smart shelf in a store using RFID is able to determine whether a tagged product on the shelf is placed correctly or upside down. Besides the ability to determine objects' location, it may also be of interest to monitor their physical state. Measured by appropriate special sensors, temperature, speed, acceleration, motion, pressure, humidity, pressure, light intensity, mechanical stress and other parameters might be of interest. With today's sophisticated sensor technology it is also possible to determine and continuously monitor chemical properties of goods, mainly of fluids and gases. It is feasible to determine their composition and also the presence of chemicals residing in a "smart" sensor-equipped container, room, or a

chimney. This information can be useful for emissions management, but also to monitor chemical processes that take place in a barrel or container during transportation or storage to prevent the development of potentially dangerous compounds.

3. *Communication:* A fundamental capability of smart items is, of course, the ability to communicate. This capability is required whenever an item should interact either with other devices and items in its surroundings, or even with a business software system directly. In a majority of smart item systems known to us, items communicate with each other wirelessly, but wired solutions can also be found in practice. In wireless systems, including RFID, usually radio waves over various frequency bands are used as the communication medium. Other examples of media used to transmit information wirelessly are light waves, such as infrared light, and also sound waves. Information exchange between business software systems and smart items can be implemented by following the request-response scheme. Typically, the application is the requesting party. It expects responses from the items either in a synchronous, or an asynchronous mode. Another way of interaction is sending unidirectional messages from smart items to the back-end system. These messages are also important building blocks of notification and alerting scenarios. In an example case, a smart room would only contact the backend system when the room temperature has reached or exceeded a certain pre-configured threshold.
4. *Information processing:* With the increasing number of smart items in a given environment especially the problem of how to handle the amounts of collected data may arise. In order to overcome such problems, smart items might (pre-) process the gathered information autonomously. Based on information processing capabilities provided by an integrated microprocessor or microcontroller, smart items may also adapt their state or behavior to the current context and environmental conditions. For instance, an item can automatically determine its expiry date in accordance with monitored storage conditions. Items may also be requested to aggregate the potentially large volumes of data they collect. The aim of data aggregation can be to deliver only the piece of information required by the relying business process. Information processing can also be carried out in a distributed and collaborative manner. Think, for example, of multiple items in a room, e.g., furniture, window, walls, each equipped with light, sound, and temperature sensors and a proper wireless communication interface, such as Zigbee. Based on the measured and collected sensor values, the items may be able to jointly discover whether there is an intruder in the room. In such application cases, single items only provide fragments of the data required to make the respective decision and draw the right conclusions, such as to alert the police.
5. *Performing actions:* Smart items may be able to actively control and change their own state or the state of the real world by performing physical actions if required. This capability becomes obvious when considering embedded systems, which are specifically designed to operate and control real-world objects, e.g., to effectively change the room temperature or to adjust the rotation speed of an engine. Proper actuators allow smart items to actively perform movements, for

example, in response to changing environmental conditions. Smart items can also interact with human beings: human readable information may be shown on a display and optical or acoustic warnings can be issued.

The influence and integration of smart items and the IoT on companies' business processes and underlying software systems can be illustrated and characterized by process integration patterns. In Fig. 1 three integration patterns, called "*Real-time Data Delivery", "Process Control"* and *"Relocated Task Execution"* are shown (Mühlhauser and Gurevych 2008).

- *Real-time Data Delivery:* Enterprise processes require large volumes of information about the current or even past status of business relevant real world objects and their environment. Smart items may collect and deliver data in near- to-real-time to backend systems for further processing. Here, smart items play the most passive role from the business process execution point of view.
- *Process Control:* Since smart items are directly placed at the physical points of action, there is a potential to influence and indirectly or directly control the flow of the supported business processes that are implemented by backend systems. Depending on the current situation and context, as it is "seen", for instance, by distributed sensors, smart items can autonomously decide to start or stop the relevant process steps at the right time.
- *Relocated Task Execution:* The most complex usage pattern allows for well-defined parts of the business process, i.e., tasks or sub-processes, to be directly executed by smart items. The term "execution" basically means that data collection and transformation steps corresponding to the relocated process tasks are completely carried out by (collaborating) smart items.

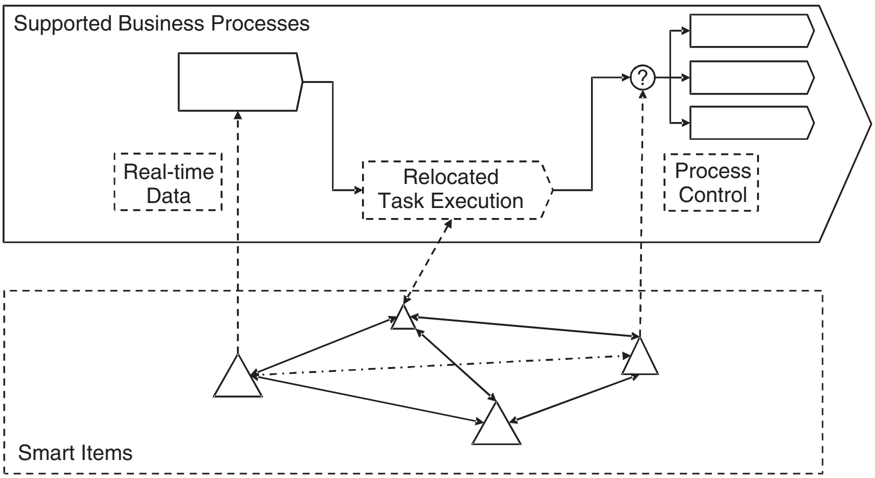

Fig. 1 Utilizing smart items in enterprise business processes (Reprinted with permission from the Publisher from Nochta, 2008)

Today, when items leave companies' internal process context, for instance, because a produced item has been sold, the item in question usually "disappears" from the issuing company's radar. In future, service providers will utilize information about real world items, information that is collected and managed by multiple independent business entities. Those services will rely on managed business applications which interested parties along the entire value chain can use for their respective purposes. Connecting today's isolated intra-company scenarios while using managed business data from multiple enterprises will not only be a major step towards the realization of the IoT, but has also significant business potential for participating enterprises. Here, we highlight one example application that follows this schema.

1.1 An Application Scenario

Product authentication services using the IoT can help brand owners protect their products against product counterfeiting and piracy as well as against illicit trading with originals (see Fig. 2). The service can use the data of participating brand owners

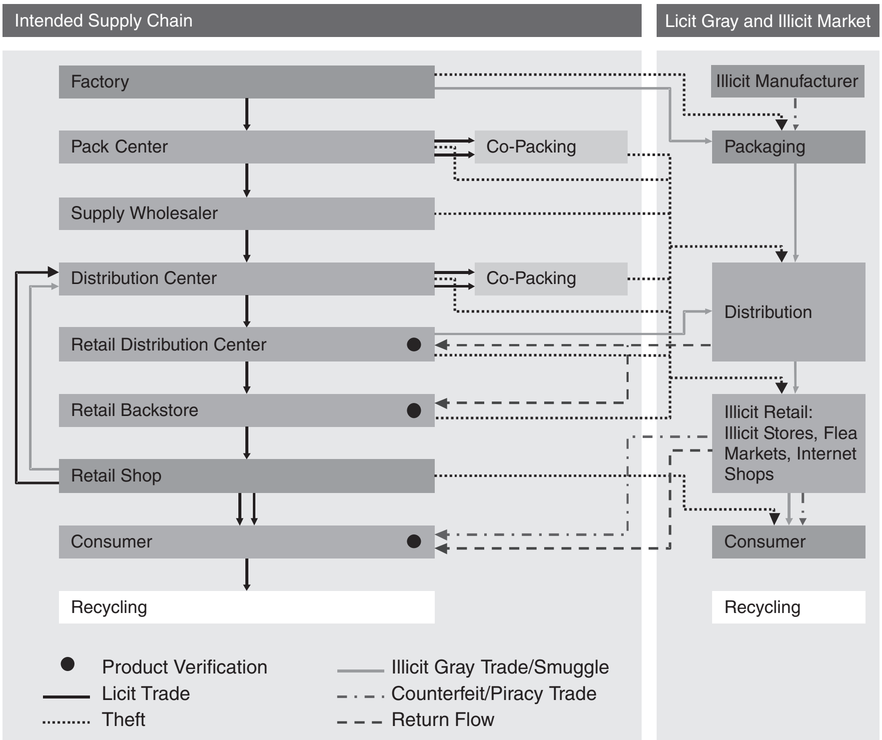

Fig. 2 Overview of illicit practices along value chains (SAP 2008).

Fig. 3 Printed security marking as captured by a cell-phone camera

in combination, whereas centrally managed application logic can be made available via the Web for licit distributors, retailers, customs, and also for end-consumers that are interested in buying only original products.

The service provides these legitimate parties along the product value chain with a unique access point to distinguish between genuine products and counterfeits in any situation by utilizing security techniques and product markings that cannot be copied without being detected. Also, based on serialized tracking and tracing information provided by value chain participants the system will help identify anomalies that indicate illegal parallel trading activities with originals, i.e., the injection of stolen or diverted products into the licit value chain.

The following example scenario illustrates the service functionality from the end-users' perspective. Before buying a counterfeit-prone product, a consumer can photograph a security label which is printed on the product package with his or her camera-equipped cell phone, see Fig. 3 below. The security label contains a data-matrix (also known as a "2D barcode") that stores item level information about the object (e.g., Serialized Global Trade Identifier, production lot number, expiry date, etc.) and a so called Copy Detection Pattern (Picard 2004). After sending the captured image to the system via the Internet, the product authentication service will analyze the received information immediately and return a secure authentication result to the user together with the feedback that the product item in question has been distributed in legal ways. An RFID enabled phone will be able to automate the entire process by automatically recognising and communicating with the smart security label.

2 Technologies to Implement the Internet of Things

The scenarios described in this chapter and the Internet of Things in general require a tight coupling of information services with the real-world. That is, technologies that are used to identify and track objects and to sense their environment are required. We will show that current smart item technologies used for this purpose today – including barcode, single crystal silicon based RFID, wireless sensor networks – face several inherent problems and are therefore unsuitable for realising the full potential from the Internet of Things today.

- *Barcode:* This is the simplest form of smart item. A one- or two-dimensional barcode can code an identification number for an item. The barcode can be printed onto a label which is later attached to an item, or it can be directly printed onto the item. It is very cheap, and it incurs negligible costs when it is directly printed onto an item. However, identification with barcodes faces many problems. Only items in line-of-sight can be identified, e.g., items inside boxes or pallets cannot be identified without significant manual work. Furthermore, only one item can be identified at once, further increasing the manual work when identifying items with barcodes.
- *Passive RFID:* When using Radio Frequency Identification (RFID), several items can be uniquely identified at once without line-of-sight contact. However passive RFID tags, i.e., the ones that operate without a battery, usually do not provide any sensor information. Even though passive RFID tags can provide immediate sensor information, they usually do not provide historical data. Furthermore, passive RFID tags are still too expensive for wide-spread market adoption. On average, current RFID tags that are fully converted to a label ready for attaching on to an object cost between 0.09 US$ and 0.15 US$ (ODIN Technologes 2010), depending on volume. Consider the supply chain of a retailer: the cost of an RFID tag is too high for large quantities of cheap products like milk or yoghurt. It appears that traditional RFID tags based on single crystal silicon chips will not reach the ultra-low costs required for applying the technology in many product segments. This is mainly because the production of RFID tags or labels requires many expensive steps that cannot be eliminated today: first the RFID chip is produced, and then it is typically attached to a strap. Also, the RFID antenna has to be produced, laminated, and finally connected to the RFID chip. Then the resulting “smart label” has to be attached to an item.
- *Active RFID:* Active RFID tags use batteries to power sensors and to aid the wireless communication. Such tags however are large and cannot be applied to every kind of object. And they are very expensive, with costs ranging from 10.00 US$ to 30.00 US$. Therefore active RFID tags are seldom attached to single items. Most of the time one active RFID tag is used to monitor one box, pallet or even container.
- *Wireless Sensor Networks:* These are networks consisting of several small computers equipped with sensors. They are similar to deployments of active RFID tags. However, in contrast to active RFID tags they can also communicate with each other. E.g., many wireless sensors deployed in a room can communicate with each other to calculate the average temperature in the room. This technology however faces the same problems as active RFID: sensors are large and expensive.

In the following section we present a new technology that combines the positive qualities of existing technologies, ultra-low costs, wireless identification and sensory information, and thus truly enable the Internet of Things.

3 Printed Organic Electronics

Printed electronics is a new technology to produce ultra-low cost smart labels, which can be a true enabler of the Internet of Things. Using conductive inks, electronic circuits can be printed (Leenen et al. 2009; Subramanian et al. 2008). This technology can produce ultra-low cost smart labels, which can be printed directly on the package of items in their manufacturing process (Das and Harrop 2007). Furthermore, the technology can help greatly extend the functionality of current smart labels by printing batteries, sensors and displays.

Organic (Subramanian et al. 2008) or inorganic (Leenen et al. 2009) materials can be printed by using standard industrial printers, e.g., printers that are also used to print newspapers and that can print several square meters per second (see Fig. 4). This results in ultra low-cost electronic components, and thus allows the use of electronic components like smart labels in scenarios where it was not possible before.

Most of traditional electronic components used today are based on single crystal silicon. These electronic components show high performance, are highly miniaturized and integrated, and their price per transistor is very low. However, they are complicated to manufacture, i.e., they require creating several masks and etching a single crystal silicon wafer (subtractive process). They also require costly clean room facilities, taking the costs of a microchip factory to several hundred millions of dollars.

With printed electronics several layers of different materials are printed onto each other to form electronic components (additive process). This reduces the overall number of steps in manufacturing, it reduces material costs and overall tooling costs, i.e., the production becomes very simple, fast and cheap. However, printed electronics show lower performance. And even though the price per transistor for printed electronics is higher than that of traditional electronics, the price per area is very low. Therefore, printed electronics are expected to replace traditional electronics in scenarios where electronics do not need to be very small or fast, and where the price of the electronic components has to be very low. This is the case with smart labels for products.

3.1 Organic Electronics and Inorganic Electronics

As already mentioned, printed electronics can use inorganic or organic materials. Inorganic materials, like zinc oxide (ZnO), show good environmental stability and performance (charge carrier mobility). However, inorganic particles are not soluble and therefore they are difficult to process. On the other hand, organic materials

Fig. 4 Organic electronics produced in a roll-to-roll printing process (PolyIC Press Picture. © PolyIC 2006)

like plastics and polymers in general have a good processability and their physical properties can be easily tailored chemically (Leenen et al. 2009). In this chapter, we focus on Organic Electronics.

With Organic Electronics, components like diodes, transistors, memories, batteries and sensors can be printed and easily integrated. This technology allows the production of new "organic" smart labels that are much cheaper than conventional smart labels. These organic smart labels can contain a multitude of sensors, like temperature, light, pressure and strain sensors. Furthermore, because of its ultra low-costs, several organic smart labels can be printed onto a single object (multi-tag). On the one hand, this increases the communication reliability of organic smart labels (refer to Bolotnyy and Robins, 2007) for similar experiments with RFID). On the other hand, it provides many sensor values for a single object. This is equivalent to each single object being a wireless sensor network, making data management more complex, but allowing fine grain monitoring of each object's condition. Table 1 compares organic smart labels to standard RFID labels based on single crystal silicon.

Table 1 Comparison of standard RFID with organic smart labels

	Passive RFID	Active RFID	Organic smart label
Sensors	Possible	Yes	Many
Battery	None	Yes	Yes
Price	0.20–1.00 US$	10.00–30.00 US$	TBD, expected to be more than 10 times lower than passive RFID (Finkenzeller 2003)
Range	< 10 m (UHF) < 1 m (HF)	In the order of 1000s of meters	not known yet
Frequency	LF, HF, UHF, Ghz	LF, HF, UHF, Ghz	HF (UHF by 2018)
Memory capacity	Up to 64 KB	Up to 1 MB	1 Bit (96 Bit by 2016)
Memory type	ROM, WORM, RW	ROM, WORM, RW	ROM (WORM by 2016, RW by 2018)

3.2 Roadmap for Printed Organic Smart Labels

The main concepts required for building organic smart labels have been researched, and demonstrators show the proof-of-concept. However, production parameters like yield have to be optimized for successful market introduction. Today, only simple organic smart labels exist, which only have 1–4 Bits of Read only Memory (ROM) and contain no sensors or batteries.

Figure 5 shows a roadmap for the general availability of printed organic smart labels. It is based on the data in (OE-A Roadmap for Organic and Printed Electronics 2009). As already mentioned, today only simple organic sensor exist. In 2012, the first fully integrated printed batteries will appear, allowing the organic smart label to be equipped with more complex sensors that can continuously monitor their environment, even in the absence of a reading device. Over the years, the memory capacity of the smart labels will increase until reaching the milestone of 96 Bits in 2016. Furthermore, memory of the type Write once Read many (WORM) will be introduced. This is a milestone in the development of organic smart labels, since they will be able to store an Electronic Product Code (EPC), which is an important standard for coding the identification number of an object. On the long term, organic smart labels are expected to implement the full EPC communication protocol. First

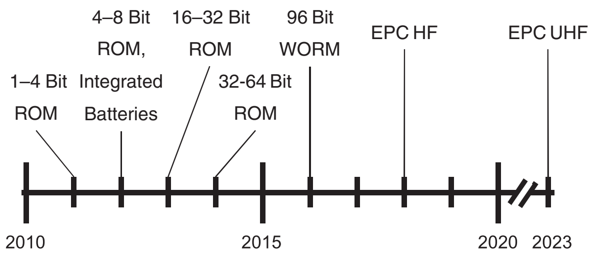

Fig. 5 OE-A roadmap for printed organic electronics

implementations will be for High Frequency (13.56 MHz) tags followed later by Ultra High Frequency (850–950 MHz).

Sensors are not shown in the figure to avoid clutter. Today, a large variety of sensors exist, like temperature, light, pressure and strain sensors while a plethora of other sensor types are being developed.

3.3 Challenges to Utilising Smart Organic Labels

The IoT consists of large-scale information systems, which encompass resource planning systems, database management systems, application servers and others. The IoT utilizes smart label technologies to couple real-world objects with business processes. The information systems within the IoT obtain data from an infrastructure network of devices, e.g., all tag reading devices from all stores of a retail chain. The main tasks are then to (1) process the acquired data, e.g., the identification information and additional sensor data, (2) perform actions accordingly, e.g., initiate an order process for replenishment. And (3) store the acquired data, often for several years, e.g., for the purpose of compliance in the food industry. However, the massive deployment of organic smart labels will result in data which cannot be efficiently processed by current systems. This is because the data volume will be orders of magnitude larger than the one that results from equivalent RFID installations, since each object will carry many smart labels. And therefore each object will contain many more sensors that may return conflicting data. Both aspects are discussed in the following.

1. *Large amounts of data:* With mass usage of organic smart labels the central challenge for information systems within the IoT is data processing and management of vast amounts of data. Identification information is always associated with metadata, such as location of an item or status within a business process. For instance, if Wal-Mart operates RFID at the item level, it is expected to generate 7 terabytes (TB) of data every day (Schuman 2004). When applying 10 s or 100 s of organic smart labels to each item, the data volume vastly increases. At peak load situations, e.g., when palettes of items arrive at a reader device, metadata changes dramatically as a flood of update operations propagate through the information systems, e.g., updating the items' locations metadata. Information systems must operate at high data rates to process the data fast enough. The massive data explosion will impose higher loads for middleware frameworks throughout the entire supply chain. Data from different sources will be combined to enable complex event processing along the supply chain. Simultaneously, the information systems are requested to provide real-time processing. Algorithms developed for RFID data compression (Hu et al. 2005) and processing (Wang et al. 2009) might provide a basis for coping with the huge amount of data resulting from organic smart labels.

2. *Data quality:* Data quality becomes a crucial aspect when multiple organic smart labels and their sensors are attached to an object. With 100 s or 1000 s of sensors per object, the data from a single smart label may move into the background. On the one hand, redundancy is provided. A failed smart label is not fatal and data from neighboring smart labels can be used for compensation. On the other hand, it is more complex to filter out inconsistent or conflicting readings. Erroneous sensors may trigger unnecessary or even costly processes and actions. The manifold relationships between information systems in the IoT make it hard to isolate the original cause. Related work to interpret (Cocci et al. 2008) and filter (Jeffery 2006) uncertain RFID data might be adapted to improve the data quality resulting from organic smart labels.

The integration of organic smart labels into the IoT presents challenges for additional research efforts. Information systems are requested to scale up with the vastly growing amount of data while simultaneously allowing real-time queries. The high load on middleware systems, event processing throughout the supply chain and the use of multiple organic smart labels per object require a flexible distribution of the data processing work load. It may be distributed among the organic smart labels, the reader device, middleware computer systems and database management systems. It also means that one needs to partly reconsider some established ways in order to accomplish these challenges.

4 Conclusions

In this chapter we introduced the Internet of Things (IoT) from companies' perspective. The Internet of Things allows tracking of real-world objects over the inter-net. It can be used to optimize many processes. However, today, current technologies used for this purpose today – including barcode, RFID tags based on single crystal silicon, wireless sensor networks – face several inherent problems as an enabling technology for Internet of Things. Organic Electronics is a new technology that allows printing electronic circuits using organic inks. It will produce ultra-low cost smart labels equipped with sensors, and thus it will truly enable the IoT. We show how the Internet of Things can benefit from such smart labels. Furthermore, we discuss how this technology is expected to develop. At the end, we point out technical problems that arise when processing huge amounts of data that will result from the usage of organic smart labels in business applications.

Acknowledgments The work presented in this chapter was partly funded by the German government (Bundesministerium für Bildung und Forschung) through the project Polytos.

References

Bolotnyy L, Robins G (2007) The case for multi-tag RFID systems. In: Proceedings of international conference on wireless algorithms, systems and applications. Chicago, IL, Aug. 1–3

Cocci R, Tran T, Diao Y, Shenoy P (2008) Efficient data interpretation and compression over RFID streams. In: Proceedings of the 2008 IEEE 24th ICDE, pp 1445–1447, Cancún, México

Cosnard M, Dickerson K, Jeffery K, Pogorel G, Prasad R, Sieber A, Weigel W (2008) ICT Shaping the world: a scientific view. Wiley-Blackwell, Chichester

Das R, Harrop P (2007) Organic & printed electronics – forecasts, players & opportunities 2007–2027. IDTechEx research report. http://media2.idtechex.com/pdfs/en/U3021T7639.pdf. Accessed 1 March 2010

Finkenzeller K (2003) RFID handbook: fundamentals and applications in contactless smart cards and identification, 2nd edn. Wiley, Chichester

Hu Y, Sundara S, Chorma T, Srinivasan J (2005) Supporting RFID-based item tracking applications in Oracle DBMS using a bitmap datatype. In: Proceedings of the 31st international conference on VLDB, **Trondheim, Norway,** pp 1140–1151,

Jeffery SR, Garofalakid M, Franklin MJ (2006) Adaptive cleaning for RFID data streams. In: Proceedings of the 32nd international conference on VLDB, Seoul, pp 163–174

Leenen MAM, Arning V, Thiem H, Steiger J, Anselman R (2009) Printable electronics: flexibility for the future. Phys Status Solidi (A) 206(4):588–597

Mühlhauser M, Gurevych I (2008) Ubiquitous computing technology for real time enterprises. Information Science Reference, IGI Global, Hershey, PA

Nochta Z (2008) Smart items in real time enterprises. In: Mühlhauser M, Gurevych, I (eds) Handbook of research on ubiquitous computing technology for real time enterprises. IGI Global, Hershey, PA.

ODIN Technologes (2010) RFID tag pricing guide™ report. http://www.odintechnologies.com/rfid-tag-pricing-guide?cmp=unknown&panel. Accessed 10 March 2010

OE-A Roadmap for Organic and Printed Electronics (2009) Organic electronics association white paper, 3rd edn. http://www.vdma.org/wps/portal/Home/en/Branchen/O/OEA/. Accessed 1 March 2010

Picard J (2004) Digital authentication with copy-detection patterns. In: Rudolf van R (ed) Optical security and counterfeit deterrence techniques V, Proceedings of the SPIE 5310:176–183

SAP (2008) SAP research: SAP research report 2007/2008. http://www.sap.com/about/company/research/pdf/SAP_RR_2007-2008.pdf. Accessed 1 March 2010

Schuman E (2004) Will users get buried under RFID data? Ziff Davis internet, November 9. http://www.eweek.com/c/a/Enterprise-Applications/Will-Users-Get-Buried-Under-RFID-Data/1/. Accessed 1 March 2010

Subramanian V, Chang JB, Fuente V, Alejandro de L et al (2008) Printed electronics for low-cost electronic systems: technology status and application development. In: Proceedings of IEEE European solid-state device research conference, Edinburgh 15–19 September, 2008. doi: 10.1109/ESSDERC.2008.4681677

Staake T, Fleisch E (2008) Countering counterfeit trade. Springer, Germany

Wang F, Liu S, Liu, P (2009) Complex RFID event processing. VLDB J 18(4):913–931

Springer

Unique Radio Innovation for the 21st Century
Building Scalable and Global RFID Networks
Ranasinghe, D.C.; Sheng, Q.Z.; Zeadally, S. (Eds.)
2011, XVI, 459 p., Hardcover
ISBN: 978-3-642-03461-9