8-7-2011

Inter-organizational Integration of Smart Objects: White Spots in the Solution Landscape

Holger Ziekow
Humboldt-Universität zu Berlin, ziekow@wiwi.hu-berlin.de

Jens Strueker
Albert Ludwigs Universitat Freiburg, jens.strueker@gmail.com

Inter-organizational Integration of Smart Objects: White Spots in the Solution Landscape

Holger Ziekow
Humboldt-Universität zu Berlin
ziekow@wiwi.hu-berlin.de

Jens Strüker
Albert-Ludwigs Universität Freiburg
strueker@iig.uni-freiburg.de

ABSTRACT

The vision of the Internet of Things (IoT) has sparked considerable efforts in research and development over the past decade. Much of these efforts were driven by applications of RFID technology for monitoring the flow of goods and prominent early adopters such as Wal-Mart and Metro Group. Also, the global standards organization GS1 provided a number of well recognized specifications that are tailored to monitor objects across organizations.

Development of the IoT has certainly benefited from the strong demand for monitoring goods in business applications. However, the dominance of these application scenarios and corresponding standards comes at the risk of neglecting requirements from other domains. In this paper, we review the focus of existing works. Our contribution is twofold. (1) Using a systematic literature review, we analyze existing research contributions and identify underrepresented areas. (2) We discuss selected approaches in detail and highlight open issues in the covered functionality. The aim of our work is to raise awareness for open potentials in the IoT service domain and to direct future research and developments.

Keywords (Required)

Internet of Things, smart objects, exchange platforms, RFID, M2M, sensors

INTRODUCTION

The so-called Internet of Things (IoT) is taking concrete shape (e.g. Mattern and Flörkemeier, 2010). Devices with little or no power, such as active or passive RFID tags, are being affixed to all kinds of physical objects, such as product components, finished products, logistic units and more (Strüker et al., 2008). Moreover, special-purpose computer systems which are able to sense information from the real world or perform actions upon it and are also able to communicate with other networked computer systems are being increasingly used. Cargo containers, for example, equipped with such smart devices are becoming capable of sensing and communicating information, such as position, temperature, humidity etc. (e.g. Macmanus 2009). One can observe similar developments in the automotive industry, where manufacturers have been preparing to connect vehicles to the Internet (e.g. BMW 2011). Other industries, such as the energy, are also in euphoric mood (e.g. Behr 2010).

Besides this newly emerging class of devices, another development drives the Internet of Things. Mature industries, which have been used to connecting costly and critical assets such as jet engines, power plant equipment or medical equipment to information systems for years (Allmendinger and Lombreglia, 2005), are increasingly giving up their proprietary communication standards (e.g. Zigbee Alliance, 2009; Dunkels and Vasseur, 2008).

From a technological perspective, the necessary conditions for a prospering IoT seem to be present. In order to understand whether this is sufficient for an economic success, it is helpful to look at the history of the Internet in itself. The Internet dramatically broadened enterprises' capabilities to exchange data at low cost. Enterprises exploited these possibilities and have incrementally moved away from traditional value chains and vertical integration towards a network of business partners (e.g. Ghodeswar and Vaidyanathan, 2008). Overall, this intensification of business cooperation, among other factors, has led to an all-time high of the world's economic activities over the last fifteen years.

The emerging IoT now promises a new level of cooperation between enterprises: Connecting smart objects to the Internet potentially means to flexibly share identification and sensor information between market actors and interacting with these smart objects. The outcome would be an additional increase in specialization, division of labor and outsourcing, leading to a plethora of new applications and services. However, exchanging data between smart objects and enterprises is challenging for many reasons. The data, for instance, will only become valuable information once it is in fact accessible in a timely manner by the systems that can put the data into context with other data sources. Smart devices generally have less computing power than PCs (e.g. RFID transponders) and are often not able to communicate at all times (e.g. a cargo transporter). Hence, data-exchange infrastructures are required which can cope, among other things, with the described time lag and intermediate between many and ever-changing market actors and their systems.

Based on our own experiences in various related research projects, we came across the following disproportion over the last years: While IS research paid much attention to the EPCglobal network approach for sharing information about object observations[1], works on Internet-based infrastructures for sharing *sensor* information and for (*directly*) *interacting* with smart devices were hard to find. As EPCglobal standards are tailored to supply chain scenarios and provide poor or limited support in other cases, a domination of this approach within the scientific discussion matters. In this paper, we therefore conduct a comprehensive literature review in order to test EPCglobal's dominant position. Subsequently, we introduce key functional building blocks for inter-organizational integration of smart objects and discuss existing solutions for the different functionalities. For each solution, we point out which concepts and design goals it is based on and which functionalities it covers.

Overall, our contribution is twofold. (1) We analyze the focus of research in the IoT domain and reveal underrepresented aspects. (2) We examine existing solutions for Internet-based integration of smart objects and identify open issues regarding holistic integration support. The paper concludes by discussing what the identified white spots in the solution landscape mean for the IoT's success and provides guidance for future research and development.

LITERATURE REVIEW

Based on a comprehensive literature review, this paper analyzes the research contributions on infrastructures for Internet-based inter-organizational exchange of smart object data. The literature search pursues two objectives: First, we want to give an overview on related work. Second, the outcome of the search in itself is then analyzed in order to generate a detailed research map. We start by defining smart objects.

Definition of Smart Objects

We define a smart device as a special-purpose computer system (device) that is able to identify itself, sense information from or perform actions affecting its environment (the real world) and which is able to digitally communicate with other networked computer systems. We impose no requirements on the system architecture of the device nor do we assume anything about a device's physical dimensions or its possibly severe constraints on energy or communication bandwidth. Given this definition, a smart device can be very small or very large, geographically fixed or mobile, possess one or more communication channels, be always on or only occasionally connected and might perform either extremely simple or very complex computations. Combining a smart device with a physical object, such as a cargo container, then creates the smart object. As Vasseur and Dunkels (2010) do, we see smart objects affected by telemetry, wireless sensor networks, embedded systems, mobile and ubiquitous computing.

Methodology

We structured the literature review following Webster and Watson (2002). Accordingly, we performed a title and abstract search in pertinent journal databases, namely Business Source Premier, MLA International Bibliography, EconLit, ScienceDirect, IEEE Xplore, ACM Digital Library and Web of Science, Springerlink. In this way, our search has included the following IS journals until the end of 2010: Academy of Management Review, ACM Transactions on Information Systems, Communications of the ACM, European Journal of Information Systems, Information Systems Journal, Information Systems Research, Journal of Management Information Systems, Journal of the AIS, Management Science, MIS Quarterly and Business & Information Systems Engineering.

We searched the listed databases for papers that mentioned relevant application areas and smart item technologies. That is, we constructed search strings that follow the pattern {application area} AND {smart object technology}, where {application area} and {smart object technology} represent the subsequent sets of keywords:

- {application area} := {SCM, logistics, manufacturing, product life cycle management, counterfeit detection, fraud detection, maintenance, asset tracking, home automation, smart grid, smart metering}
- {smart object technology} := {smart objects, smart items, RFID, sensor, smart devices, smart meter, machines}

---

[1] EPCglobal has provided a reference architecture that defines services for the EPCglobal network (http://www.epcglobalinc.org/standards).

We then manually checked all papers in the resulting list of more than 300 papers as to whether they address Internet-based exchange. With the procedure, we selected the 50 best ranked papers that fit our criteria[2]. Upon request, we will send a list of these papers. Throughout the detailed content analysis, we excluded six more papers not matching the Internet-based criterion.

Related Work

The outcome of our literature analysis shows two things: First, there is a plethora of contributions dealing with Internet-based infrastructures for smart object data exchange. Second, meta-studies discussing Internet-based exchange infrastructures for smart objects can, on the other hand, be considered a research desideratum. One of the rare exceptions is the book chapter of Guinard et al. (2010). The authors technically describe the use of the EPCglobal network for reading smart object data and also sensor data platforms such as SenseWeb[3] and Pachube[4]. Since they do not systematically compare these exchange infrastructures with each other, their analysis remains descriptive and at a high level. Interestingly, the dearth of scientific meta-studies sharply contrasts with industry's involvement in providing platforms for sharing smart object data (cp. HP's Central Nervous System for the Earth, CeNSE, Microsofts's SenseWeb or IBM's Smarter Planet campaign) and the journalistic interest in these platforms (e.g. Macmanus, 2009; Chui et al., 2010).

Analysis of the Research Contributions

Due to the described lack of meta-studies, it is currently not clear to what extent solutions in literature support flexible sharing of smart object data between market actors and across enterprise borders. However, we strongly believe that this is a necessary condition for a prospering IoT. We therefore analyzed our search outcome in more detail. In this manner, we applied a literature review as research methodology (Webster and Watson, 2002). That is, after having determined 44 appropriate research contributions, we next analyze them according to the categories listed in Table 1.

Categories	Description
Directly addresses EPCglobal services	Works that directly address EPCglobal services (http://www.epcglobalinc.org/standards) by providing an implementation for them or by analyzing their application fall into this category.
Addresses alternatives to services in the EPCglobal network	Works in this category provide solutions that are alternatives to EPCglobal services (i.e. similar or the same functionality but non-conform to EPCglobal).
Reads data	Works in this category provide read access to smart object data - such as RFID reads or sensor values - via the Internet.
Writes data	Works in this category provide write access to smart objects via the Internet (e.g. remote deployment of code, remote configuration or remote write access to storage on smart objects).
Communication via gateway	Works into this category use a gateway to link smart objects with the Internet. Such a gateway is part of the local IT infrastructure. The gateway acts as an intermediary for all communication between smart objects and a remote party.
Communication via intermediate party	Works in this category use an Internet-based intermediate party for communication. This is somewhat similar to the gateway solution, except that the service of the third party is not part of the local IT infrastructure.
Direct Communication	Works in this category establish a direct communication channel to smart items via the Internet. That is, one can directly address a certain item, rather than an intermediary that acts on behalf of it.
Participation of multiple organizations	Works in this category focus on cross-enterprise communication involving multiple organizations. Devices and enterprise systems are NOT all located within a single administrative network domain.
Branch	Retail, Automotive, Manufacturing, Pharma, Apparel, Aerospace, Energy
Exchange	This category captures the semantic level of endpoints that are linked by the presented work. We distinguish the device level, the application level, and the company level.

Table 1. Categories of the Literature Analysis

The categories are based on insights and experiences collected from real world integration projects. A detailed list of the research projects in the field of smart objects led by the authors is appended to this paper. Reports and personal notes of the

[2] Ranked by the used databases.
[3] http://research.microsoft.com/en-us/projects/senseweb/
[4] http://www.pachube.com

project leaders and documents (process and technical descriptions) of research projects were used to analyze and illustrate the particularities and commonalities of integrating smart objects. The smart object projects have their origin in the utility, engineering & construction, automotive, manufacturing and retail industries. By checking how each paper applies to the listed characteristics, we intend to draw a 'research map' on infrastructures for Internet-based inter-organizational exchange of smart object data. The resulting assignment was cross-checked by two academic experts on smart object integration. In the following, we present the key findings of our analysis.

EPCglobal Dominance in IS Research

The scientific discussion about infrastructures for inter-organizational exchange of smart objects is dominated by EPCglobal approaches. More than 36 percent of the selected papers directly address EPCglobal services, i.e. they provide an implementation for them or analyze their application. If we add the contributions providing solutions that are alternatives to EPCglobal services – i.e. they target similar or the same functionality but use concepts that are not EPCglobal compliant – the share of EPCglobal and related approaches increases to 40 percent. However, this EPCglobal emphasis within IS research covers merely a part of the IoT as an enabler for cooperations between enterprises. Focusing on EPCglobal approaches therefore yields a limited and distorted picture. First, according to our analysis, EPCglobal approaches show a strong correlation with particular branches: Fourteen out of sixteen identified EPCglobal approaches belong to the branches of logistics or manufacturing. The sector composition for all contributions is depicted in Figure 1. Second, these sixteen papers exclusively deal with RFID technology. Other technologies such as sensors, embedded systems or smart meters are not taken into consideration. Third, we will next argue that the EPCglobal approaches are also accompanied by functional limitations.

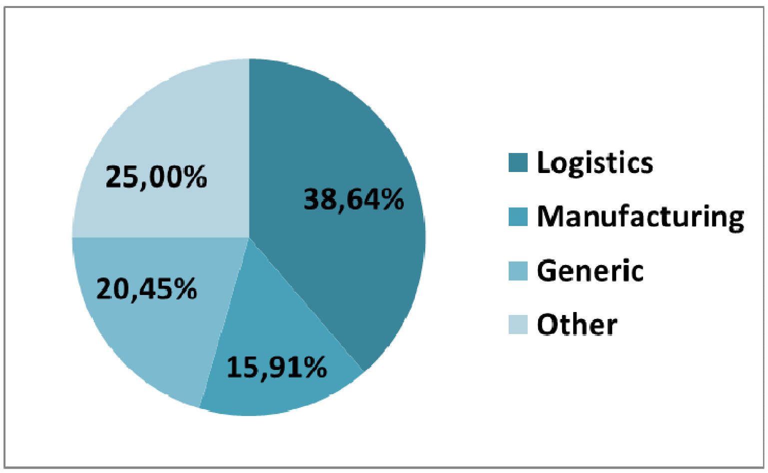

Figure 1. Branches, n=44

Object Identification vs. Interaction with Objects

To examine the smart object data sharing solutions, we have classified the contributions into the categories of 'read access' and 'write access' to smart object data. As a result, reading smart object data via the Internet overweighs, while writing is found less frequently (cp. Figure 2).

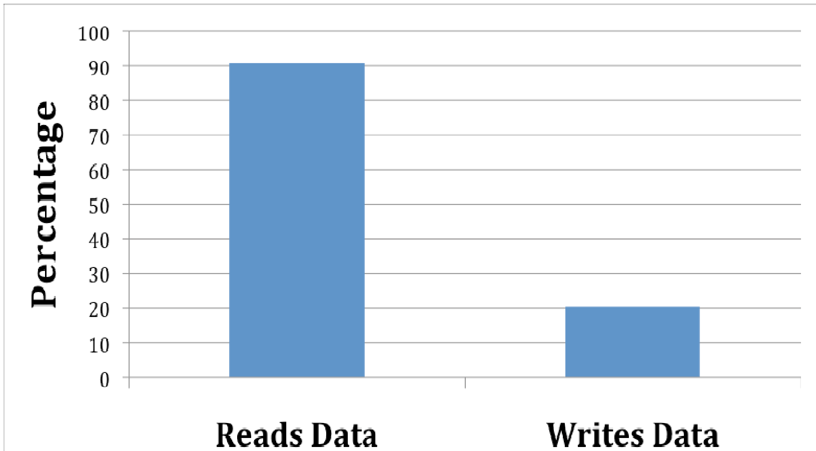

Figure 2. Access to Smart Objects, n=44

Against the background of the previously described dominance of EPCglobal approaches, the number of systems solely providing read access to smart object data is no surprise: all analyzed approaches are confined to RFID technology in the form of pure object monitoring. Consequently, write access to smart objects via the Internet, i.e. any form of remote deployment of code or remote configuration on smart objects is not an option.

Static Integration Approaches for Cross-enterprise Data Exchange

As described in Table 1, we distinguish between three communication models for cross-enterprise data exchange: communication via a gateway, an intermediate party, or direct communication. Figure 3 illustrates that the *gateway approach* is more often the object of IS research than the *intermediate party* and the *direct communication* with a smart object. With regard to intensification of business cooperation through the IoT, a gateway solution works well where devices are associated with exactly one enterprise and only affect functions that are internal to the enterprise: As the gateway acts as an intermediary for all communication between smart objects and remote parties, the latter have to rely on infrastructures outside their administrative network domain to indirectly receive or send information to a smart object. While many devices can be managed at the same time, installation, operation and maintenance are made difficult. Moreover, if the smart object data is processed by local enterprise software systems before being exchanged, obtaining interoperability between applications across enterprises then needs time-consuming agreements at the business process level. Integrating via applications therefore decreases flexibility with regard to potential cooperation partners: integration costs cause switching costs, i.e. enterprises face a lock-in effect.

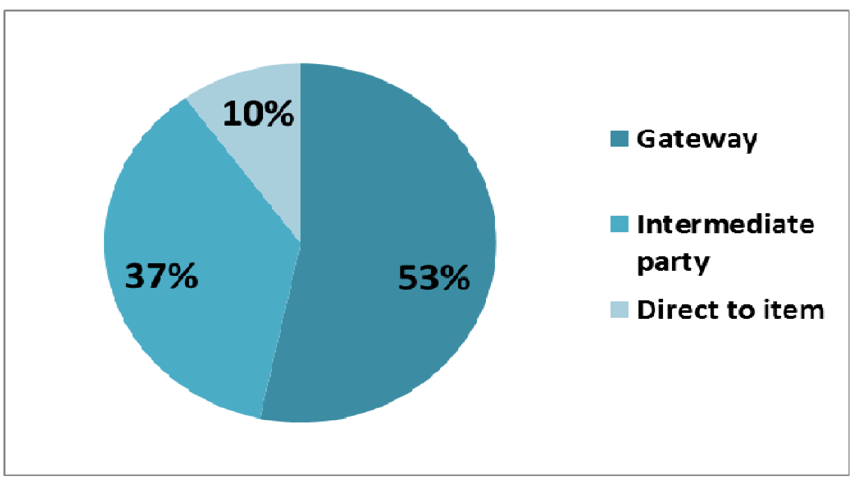

Figure 3. Communication Model, n=30

Communicating via an intermediate party can show the same problem of inflexibility. Even though an intermediary reduces the n*m contacts of device-to-device solutions to an n+m task, interoperability still matters: If the intermediary intends to integrate the smart objects and the diverse market actors at the application or company level (cp. our definition in Table 1), this will lead to relatively fixed and stable rather than more flexible business cooperations due to the high integration costs.

We have explicitly searched for works focusing on cross-enterprise communication involving multiple organizations. Table 2 illustrates that we merely found 14 contributions matching this requirement. Moreover, we looked at each paper discussing a gateway and intermediate party approach and found out that all of them deal with integration at application or company level (cp. Table 3). As previously described, this means a considerable restriction for a flexible exchange of smart object data between multiple parties.

	gateway	intermediate party	direct item to item
participation of multiple organizations	7	7	0

Table 2. Cross-enterprise communication approaches

Table 3 also reveals an underrepresented research area. In our sample, no research contribution dealing with Internet-based intermediaries provides integration at device level. This is surprising as communicating with a smart object without requiring an application-level or company-level system as mediator has several advantages. For example, an agreement on network protocols such as the ubiquitous Internet Protocol or raw data formats is much easier than finding a least common denominator at the application or enterprise level with the supporting plethora of semantic issues. An intermediary focusing on a *flexible* data exchange between many and diverse smart objects and changing market actors promises to yield benefits for the emerging IoT (Strüker et al., 2011).

communication	exchange level		
	device	application	company level
intermediate party	0	10	1
gateway	0	11	6
direct item to item	1	1	1

Table 3. Levels of exchange and means of communication

EVALUATION OF IOT SOLUTIONS

In this chapter, we review existing solutions that contribute to the implementation of the Internet of Things. We structure our discussion along the core functionalities for *data access* and *data discovery*. For each of these categories, we examine well-known solutions and representatives of different approaches. Here, we consider solutions that address the IoT domain but are not limited to a specific application. Naturally, this examination cannot be complete in a strict sense. However, the discussed solutions are selected to cover prominent architectural approaches within the domain and to provide insights on their underlying concepts. We conclude this chapter by describing exemplary use cases where current solutions have potential for improvement.

Access to Smart Objects

The most fundamental functionality of an integration infrastructure is providing access to the smart object data. A system can provide access either by acting as an intermediary in providing access to the actual smart object or by providing access to storage with corresponding smart object data. Furthermore, solutions for access differ in the supported communication paradigm for their interfaces, i.e. support for pull-based ad-hoc queries or push-based standing queries. Additionally, a system can provide processing operations as part of the accessing mechanisms. For instance, an interface may enable queries which specify filters or aggregates over the input as well as correlations between data sets. Finally, systems differ in the intended application scope. That is, they may be designed for access to data from a specific location (e.g. a production plant) or with a global scope. In this chapter, we discuss selected solutions for data access in the IoT domain along these lines. Table 4 summarizes the discussion with regard to central system attributes.

EPCIS

EPC Information Services (EPCIS) is the name of an EPCglobal standard that specifies a service for accessing object-related event data (EPCglobal Inc., 2007). It was developed to capture and persistently store time series of RFID data. Conceptually, the service is located between a data capturing middleware and the Internet. Thus, it does not enable direct access to smart objects but acts as a local intermediary for data provision. The standard specification defines event data models, interfaces to the middleware, and services for Internet-based data exchange. Consequently, the scope of data access via an EPCIS is limited to data from a specific location. The web service provides means to query data in a pull-based ad-hoc manner as well as to register standing queries for push-based notifications. For the queries, EPCIS allow the filtering over parameters of EPC related event data. However, the service interface does not support queries with aggregates over attributes or correlation of values.

Pachube

Pachube (www.pachube.com) is a solution for interconnecting smart objects via an Internet-based platform. Conceptually, it acts as an intermediary third party in the integration of sensor data. The scope of the system is global in the sense that it can serve as a central hub for data from arbitrary locations. Uniquely identifiably streams are the central data structure in the system that encapsulates all data sources. The platform enables publishing and retrieving sensor data from stream via a restful API. It also maintains histories of the streaming data and supports pull-based queries over streaming data and histories. In addition, Pachube allows the definition of triggers that call external services if pre-defined conditions in the input data occur. However, these conditions are limited to value-based filters and predefined aggregates over single streams. Note that triggers are designed to call generic services which explicitly include actuators on physical devices.

Sensor Middleware (TinyDB)

Over the last years, wireless sensor networks have received great attention in the research community and several middleware solutions for this domain have been developed (see, for instance, Samuel et al., 2005). Works in this field focus on different aspects, such as energy efficient routing and query processing within the sensor network. While the different solutions vary in technical details, they share a common set of key underling concepts. In our discussion, we refer to these concepts that are kernel of this class of systems. For illustration, we lean on the well-known solution TinyDB as representative for sensor middleware. However, alternative solutions provide similar features.

A common solution for linking sensor nodes to the Internet is to use a gateway component (called base station) to interface to external applications. Thus, the scope of the system is limited to the local sensor network managed by the base station. The interface of TinyDB provides a Java API and a declarative query language for sensor data. The declarative query language follows an SQL-like syntax and enables definition of operations, such as filters, joins and aggregates over streaming data. However, the interface is designed for query operations only. The middleware abstracts all communication to the sensor devices from the user. Query results over the streaming data are pushed by the systems to previously registered listeners.

Virtual Object Warehousing (VOWS)

VOWS is a concept for enabling object-related data exchange between organizations (Karabulut et al., 2010). The concept proposes an intermediary that provides functionality for storing and retrieving messages, similar to a shared repository. Thus, VOWS does not provide direct access to smart objects but to smart object data. A special emphasis is made on flexible policies for access control in a multi-organizational context. Information providers specify access rules and can push messages to the system. Messages can then be retrieved on demand in a pull-based manner and under consideration of current access rules.

	EPCIS	VOWS	Pachube	Sensor Middleware (TinyDB)
Access to Smart Object	No	No	Yes	No
Access to Smart Object Data	Yes	Yes	Yes	Yes
Read (item data)	Yes (focus on observations of object identifier)	Yes	Yes	Yes
Write (to items)	No	No	Indirect (via triggers)	No
Ad-hoc Queries (pull)	Yes	Yes	Yes	No
Standing Queries (push)	Yes	No	Yes	Yes
Query Expressiveness	Attribute- based filters	Not specified	Attribute- based filters, predefined aggregates, scoping	Filters, joins, aggregates
Scope	Local	Global	Global	Local

Table 4. Data access in existing IoT solutions

Discovery

With *Discovery* in the Internet of Things, we refer to solutions that facilitate the finding of sources for smart object data via an object identifier. We explicitly use this general notion to cover a range of approaches that differ in functionality and underlying architectural concepts. Below, we discuss selected solutions that are dedicated to the IoT domain and representative for different architectural styles. Table 5 summarizes the discussion with regard to central system attributes.

ONS

ONS is short for Object Naming Service. EPCglobal specified this service for discovering data sources that correspond to an object (EPCglobal Inc., 2008). The architectural concept of the ONS is adapted from the Internet's DNS and it inherits its hierarchical structure. Given an EPC as input, the service resolves URLs of corresponding data sources in a pull-based manner. The system is intended to handle EPCs at class level (rather than for individual objects) but could be extended to serial level. Resolved URLs can point to different types of data sources. However, the intended use of the ONS is linking EPCs to the EPCIS of the corresponding product's manufacturer.

EPCglobal Discovery (Bridge)

The architectural framework of EPCglobal network includes a discovery service that is explicitly intended for discovering object-related data sources at serial level. However, no ratified standard has yet been released. The Bridge project played a major role in works towards the definition and implementation of the BRIDGE discovery service (2011). For our discussion, we refer to results of this project.

The discovery service acts as a registry for object-related information sources. It uses EPCs as object identifier and stores URLs of corresponding data sources. Information providers push their URLs into the discovery service if they acquire data related to an EPC. For instance, a distribution center may observe an RFID tag at the intake, store the observation event in its EPCIS, and push a record with the EPC and the URL of the EPCIS into the discovery service. Users of the discovery service can query the stored records for an EPC and optionally apply additional constraints on record attributes. Both, ad-hoc and standing queries are supported. However, the queries only concern records in the discovery service and the actual object specific event data remain in the EPCIS of the publisher.

P2P-based Systems

P2P architectures find applications in a broad range of distributed systems. Within this article, we consider systems that use the P2P paradigm explicitly for discovery in the IoT domain. In their role as discovery service, P2P systems realize decentralized lookup of object-related data sources. For our discussion, we use the OIDA system as representative (Fabian, 2009). However, alternative solutions are similar with regard to the relevant elements of our discussion.

OIDA uses a distributed hash table (DHT) to store key value pairs in multiple locations. Distributed storage and control is a central aspect of the OIDA architecture and is a main aspect of the design. The DTH allows the storing and retrieving of object identifiers (e.g. EPCs) along with corresponding URLs. Despite the storing of EPC-related URLs being the intended use, the DHT of OIDA provides the flexibility of storing other item-related data as well. The lookup functionality for EPCs is similar to the EPCglobal Discovery as proposed by Bridge, realized, however, in a distributed fashion. Another difference is that OIDA supports pull-based data retrieval only.

Pachube

In the previous section, we discussed Internet-based platform Pachube with regard to its support for accessing smart objects. However, the platform provides means for discovering data sources as well. The discovery mechanism in Pachube is realized by a meta-data catalogue that stores information about available data streams. Users issue ad-hob queries to the catalogue using predefined attributes such as location, or type of the stream as well as content of a generic description field. However, the entries in the catalogue do not necessarily refer to specific items and queries for object identifiers are not directly supported.

	ONS	**EPCglobal Discovery (Bridge)**	**Pachube**	**P2P**
Push	No	Yes	No	No
Pull	Yes	Yes	Yes	Yes
Discovers Items	Not intended	Not intended	Possibly	Possibly but not intended
Discovers Systems (Gateways)	Yes	Yes	Yes	Yes
Query by Meta-Data (e.g. Streaming source is the entity of interest)	No	No	Yes	No
Query by Object Identifier (Object is the entity of interest)	Yes	Yes	No explicit support	Yes

Table 5. Discovery mechanisms in IoT solutions

Open Issues

In this chapter, we have discussed the functionality of well-known solutions for integration in the IoT domain. Below, we sketch some use cases where these solutions lack support and require the users to host significant proportions of the required functionality.

Case 1: Send data to an object (e.g. update maintenance instructions on the object with EPC xyz)

A user may want to write to the storage of a specific object (e.g. with a certain EPC). However, none of the discussed solutions directly support remote write functionality directly to an item. Pachube offers a workaround by enabling generic calls in triggers. However, no addressing scheme for write operations to smart objects is provided and specifying the reaction to calls is left to the user. A system that directs messages to a given object identifiers (EPC) would make implementation of this use case easier.

Case 2: Create alerts for moving objects (e.g. alert if item with EPC xyz exceeds 10°C in any observation)

To implement this use case, one needs to know all points of observation in advance. This is because standing queries are supported over predefined data sources only. A workaround would be to subscribe for item xyz at a discovery service and link in new sources as they are registered. However, this must be implemented by the user. A system that allows subscription to object specific events in a broader scope would make implementation of this use case easier.

CONCLUSION

The vision of the Internet of Things has led to ongoing efforts in research and development. It is believed that inter-organizational integration and collaboration in various branches can benefit from solutions in this domain. Specifically, increased transparency, control, and flexibility are believed to be leveraged by IoT solutions. However, our analysis shows that IS research in this field focuses only on parts of the solution spectrum. In particular, we identified a strong representation of the EPCglobal approach and applications in logistics. Also, most works are limited to monitoring items rather than providing means for bidirectional communication and control.

While this focus in research is suitable for certain applications, it does not account for the full potential of the IoT vision. This finding is also backed by our technical analysis of known IoT solutions. Among underrepresented areas, we find support for write access to items and application independent integration. However, these are vital aspects in a technological ecosystem that provides holistic support for Internet-based inter-organizational integration of smart objects.

Based on our findings, we argue that IS research in the IoT domain should be more balanced with regard to addressed applications and technologies. In our paper, we have identified focus areas of existing works and pinpointed underrepresented aspects. Our condensed findings from a broad literature analysis in the field, combined with the technical discussion of solutions, should aid researchers and developers in directing future efforts.

REFERENCES

1. Allmendinger, A. and Lombreglia, R. (2005) Four strategies for the age of smart services, in *Harvard Business Review*, (83:10), pp. 131 – 145.
2. Behr, P. (2010) Technology Companies Are Lining Up for Smart Grid Business, in The New York Times, Technology, October 22.
3. BMW (2011), ConnectedDrive, Access: http://www.bmw.com/com/en/insights/technology/connecteddrive/overview.html (3 Jan. 2011).
4. BRIDGE (2011) OPC. Access: http://www.bridge-project.eu/, (25 Feb 2011).
5. Chui, M., Löffler, M. and Roberts, R. (2010) The Internet of Things, in: McKinsey Quarterly.
6. Dunkels, A. and Vasseur J. P. 'IP for Smart Objects', *Internet Protocol for Smart Objects (IPSO) Alliance*, 2008, Access: www.ipso-alliance.org/Documents/IPSO-WP-1.pdf, (25 Feb. 2011).
7. EPCglobal Inc (2007), EPC Information Services (EPCIS) Version 1.0.1 Specification, Access: http://www.gs1.org/gsmp/kc/epcglobal/epcis/epcis_1_0_1-standard-20070921.pdf, (April 2011).
8. EPCglobal Inc. (2008), EPCglobal Object Name Service (ONS) 1.0.1, Access: http://www.gs1.org/gsmp/kc/epcglobal/ons/ons_1_0_1-standard-20080529.pdf, (April 2011).
9. Fabian, B. (2009) Implementing secure P2P-ONS. In Proceedings of the 2009 IEEE international conference on Communications (ICC'09). IEEE Press, Piscataway, NJ, USA, 988-992.
10. Ghani, J. A., Supnick, R. and Rooney, P. (1991) The experience of flow in computer-mediated and in face-to-face groups, in Janice DeGross, Izak Benbasat, Gerardine DeSanctis and Cynthia Mathis Beath (Eds.) *Proceedings of the Twelfth International Conference on Information Systems*, December 16-18, New York, NY, USA, University of Minnesota, 229 - 237.
11. Karabulut, Y., Weppner, H., Nassi, I., Nagarajan, A., Shroff, Y., Dubey, N., Shields, T. (2010) End-to-end confidentiality for a message warehousing service using Identity-Based Encryption. ICDE Workshops 2010: 33-40.
12. Macmanus, R. (2009) Top 10 Internet of Things Products of 2009, in The New York Times, Technology.
13. Mattern, F. and Flörkemeier, C.: From the Internet of Computers to the Internet of Things. Informatik-Spektrum, 2010, 33(2).
14. Strüker, J., Gille, D., Faupel, T. (2008) RFID Report 2008 - Optimizing Business Processes in Germany. IIG-Telematik, Albert-Ludwigs-University Freiburg, VDI nachrichten, Düsseldorf 2008.
15. Strüker, J., Weppner, H., Bieser, G. (2011) Intermediaries for the Internet of Energy - Message Distribution between Smart Objects and Enterprise Applications as a Business Model, in Proceedings of the 19th European Conference on Information Systems (ECIS 2011): Detroit, USA, June 9-11 (forthcoming).
16. Madden, S. R., Franklin, M. J., Hellerstein, J. M., and Hong, W. (2005) TinyDB: an acquisitional query processing system for sensor networks. ACM Transaction Database Syst. 30, 1.
17. Tractinsky, N. (1997) Aesthetics and apparent usability: Empirically assessing cultural and methodological issues, in Steve Pemberton (Ed.) *Proceedings of the SIGCHI conference on Human factors in computing systems (CHI 97)*, March 22 – 27, Atlanta, GA, USA, ACM Press, 115-122.
18. Vasseur, J. P. and Dunkels, A. (2010) Interconnecting Smart Objects with IP: The Next Internet, Burlington, USA.
19. Watson, R. T. (2001) Introducing MISQ Review – a new department in MIS Quarterly, *MIS Quarterly* 25, 1, 103-106.

20. Webster, J. and Watson, R. T. (2002) Analyzing the past to prepare for the future: writing a literature review, *MIS Quarterly* 26, 2, XIII-XXIII.
21. ZigBee Alliance, 'ZigBee Alliance plan further Integration of Internet Protocol Standards', press release, 2009. Access: http://zigbee.org/imwp/idms/popups/pop_download.asp?contentID=15754, (25 Feb. 2011).

ATTACHMENTS

Research projects that provided the basis for our category selection in the literature analysis.

Research projects	**URL**
Aletheia	aletheia.wiwi.hu-berlin.de
Auto-RFID-Kanban (2007-2009)	www.telematik.uni-freiburg.de/en/content/auto-rfid-kanban
InterVal	interval.hu-berlin.de
IT Processes in Manufacturing	lehre.wiwi.hu-berlin.de/Professuren-en/quantitativ/wi/forschung-en/IT%20Processes%20in%20Manufacturing/standardseite
Ko-RFID	ko-rfid.hu-berlin.de
MEMOQ (2007-2008)	http://www.telematik.uni-freiburg.de/en/content/messung-monetärer-qualitativer-effekte-eines-rfid-einsatzes-logistik-kmu
TORERO (2009-2011)	www.telematik.uni-freiburg.de/en/content/technical-organisational-approach-realizing-productivity-potentials-ubiquitous-computing-tec