Traceability applications based on Discovery Services

J.J. Cantero, M.A. Guijarro, G. Arrebola, E. García, J. Baños
AT4 wireless
C/ Severo Ochoa, nº 2, P.T.A.
29590 Campanillas, Málaga (SPAIN)
jjcantero@at4wireless.com

Mark Harrison, T. Kelepouris
University of Cambridge

Cambridge (UK)
mark.harrison@cantab.net

Abstract

RFID, in its different forms, but especially following EPCglobal standards, has become a key enabling technology for many applications. An essential component to develop track and trace applications in a complex multi-vendor scenario are the Discovery Services. Although they are already envisaged as part of the EPCglobal network architecture, the functional definition and standardization of the Discovery Service is still at a very early stage.

Within the scope of the BRIDGE project, a specification for the interfaces of Discovery Services has been developed, together with a prototype to validate the design and different models to enhance supply-chain control through track and trace applications.

1. Introduction

RFID technology is being used in many different fields. Despite its numerous advantages, its full potential has not yet been exploited in fields such as traceability of individual tagged items along the supply chain. For example, some months ago a press article [1] reported the tragedy of thousands of people poisoned by adulterated drugs, where a long and complex investigation was necessary to discover that the cause was the replacement, during the production process, of one ingredient by an "equivalent" one, which unfortunately was lethal for humans.

Efficient track and trace systems for drug pedigree could make it easier, faster and cheaper to discover the origin of such errors and the location of the affected products, saving precious time that may even save lives. Other industry sectors, such as luxury goods, food products, textiles and many more can benefit from these track and trace systems.

The EPCglobal network architecture [2] defines a functional component, named Discovery Services (DS), whose role is to enable the gathering of complete lifecycle information from multiple information providers across an object's supply chain or lifecycle. However, at present, despite the progress in completion of ratified EPCglobal standards for other components such as EPC IS or ONS, or some standardization initiatives [3][4][5], a technical standard for Discovery Services interfaces remains to be developed.

In this early stage of DS standardization, our work proposes a possible design for Discovery Services, together with the development of a functional prototype for concept validation purposes. Also, different models to enhance supply-chain control through track and trace applications using DS have been considered and developed.

Section II presents the EPCglobal network architecture, describing the main functional components. Section III is focused on DS functionality. Section IV presents the DS design developed, paying special attention to its internal architecture and external interfaces. Section V is focused on track and trace applications using DS. Section VI presents the main conclusions obtained and next tasks to be tackled in the future.

This work is being developed within BRIDGE project scope [6], partially funded by EC 6th Framework Program. The main objective of the BRIDGE project is to research, develop and implement tools to enable the deployment of EPCglobal applications in Europe.

2. EPCglobal architecture

EPCglobal oversees the standards development and promotes the deployment of a universal identification system based on a unique identifier or EPC (Electronic Product Code), supported by an open standards architecture for networked RFID, the EPCglobal Network (Fig. 1, extracted from [2]). A unique EPC is assigned to each serialized product by the manufacturer. This EPC identifies the manufacturer, the kind of product and the serial number. The EPC is recorded in a RFID tag and the tag is attached to the product.

Another basic element of the EPCglobal architecture is the reader, whose role is to detect the presence of tags and generate events corresponding to their movements (i.e., appearance and disappearance within the read range of a reader). The number of events registered by readers could be very high, and the treatment of all this information by business applications could be inefficient. For that reason, the EPCglobal architecture includes a low-level filtering and collection layer, whose "Application Level Events (ALE)" interface [7] allows a client application to receive packets of filtered event data from one or more physical readers, excluding duplicate EPC readings, and with the option of applying additional filtering or grouping rules defined by the client, for example to only select EPCs from a particular manufacturer or particular product line – or to only report tags which have just arrived or just departed from the read zone of the readers.

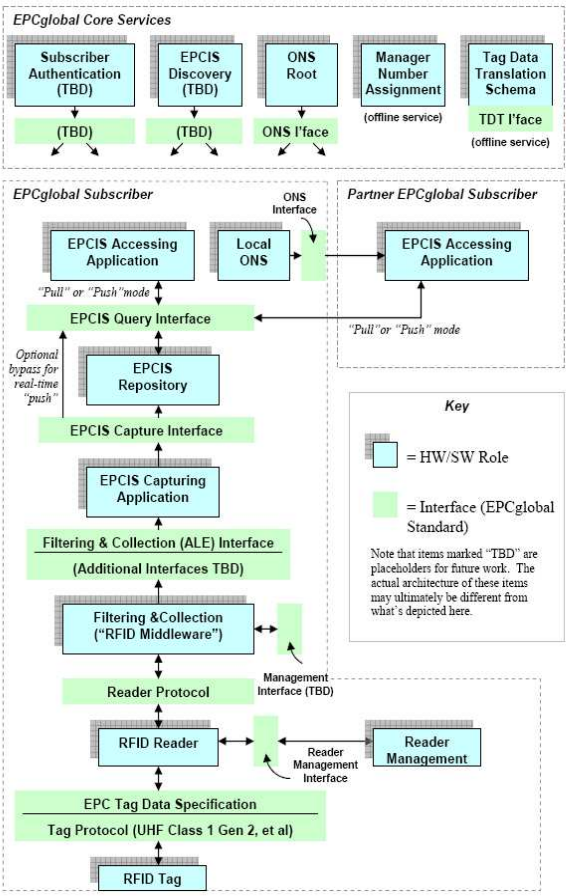

Fig. 1. EPCglobal Network Architecture

At a higher layer, these observation events from readers are enhanced with additional business context data, such as associations with particular business transactions, business process steps, such as shipping and receiving, as well as recording changes of aggregation. This enhancement process is performed by an unspecified EPCIS capture application, which may need to interact with a company's existing information systems and business logic.

The enhanced business-level event information can be recorded into an "EPCIS (EPC Information Service) Repository" [8], to allow queries to be made using the standard "EPCIS Query Interface". This interface could be used not only for internal applications, but also by trusted trading partners.

The EPCIS query interface, provides access to information about all movements related to a specific EPC that have been recorded within a single organization or site. However, it does not provide information from all the organizations that may have had some involvement with the object at some stage through its lifecycle.

It is the role of Discovery Services to enable the gathering of this complete information in a robust, efficient and secure manner from multiple information providers that hold information for an individual EPC. Note that the role of the DS is not to aggregate the information from the various information providers, but rather to provide relevant link information to clients, similar to the provision of URL hyperlinks by web search engines when queried for a keyword, except that Discovery Services will only provide the links that an authenticated client is authorized to receive.

3. Discovery Services

Based on the current EPCglobal network architecture development status, traceability applications that aim to follow the lifecycle of a specific item, identified by a unique EPC, could make use of the ONS (Object Name Service) [9] to obtain a link to the manufacturer's EPCIS. Analysing the events retrieved from the located manufacturer EPCIS, it may be possible to identify the next company in the lifecycle, and then iteratively query each company in turn (Fig. 2).

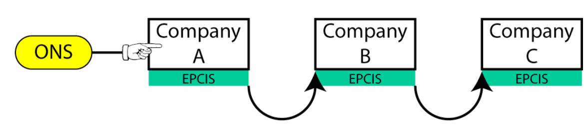

Fig. 2. Track and trace without Discovery Services

Although this is a plausible method of following an item's individual supply chain to obtain lifecycle information, it has important disadvantages such as: if an EPCIS is not available it is not possible to obtain information from the next company, nor to obtain the most recent information without traversing the entire supply chain. Discovery Services are intended to provide a solution for these identified limitations.

Whereas ONS primarily provides a link to the manufacturer EPCIS, Discovery Services (DS) could provide a list of links to all EPCISs (and potentially also other DSs) that contain events information related to a specific EPC. Therefore, Discovery Services enable the development of more efficient and robust track and trace applications (Fig. 3), although there are still significant challenges regarding security and scalability of Discovery Services.

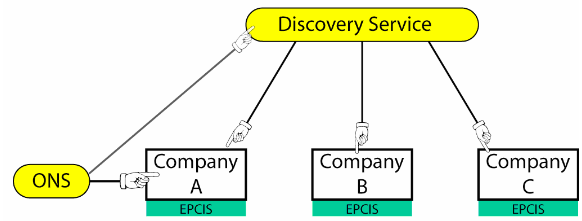

Fig. 3. Track and trace using Discovery Services

4. Discovery Services Design

The main objectives of our proposed DS design are:

- To minimize the information to be stored in a DS database (due to the huge potential volume).
- To minimize the query response time.
- To keep the external interfaces independent of the underlying implementation technology, especially the database technology.
- To allow companies to control the visibility of their data.

The proposed DS internal architecture (Fig. 4) consists of a database, proxy interfaces (dependent on database technology) and external interfaces (agnostic to the database technology) to interact with external entities: (to capture information published by EPCIS providers and to allow user applications to make queries and receive replies) [10].

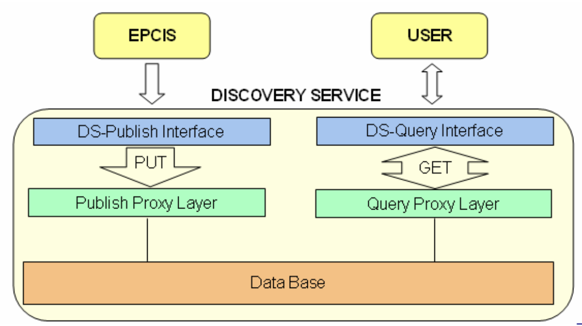

Fig. 4. Discovery Service Architecture

It may be natural to consider partitioning the scalability problem by using a network of multiple Discovery Services that each supports a particular industry sector or geographic scope, rather than trying to have a single global Discovery Service implementation for all regions and sectors.

In many situations, a company operating in a particular sector and region may routinely interact with a small number of Discovery Services. However, exceptional situations can arise (e.g. lost and found objects, missing objects), in which it can be helpful to have a high-level co-operation among multiple Discovery Services within a peer-to-peer network, so that Discovery Services are aware of each others' existence (and possibly also their scope in terms of geographic region and/or industry sector) and have a mechanism for communication or sharing or high-level indices, in order that they can assist each other.

Discovery Services are designed for the dynamic nature of supply chains and networks and the multiple paths that two apparently identical objects may take through the supply chain or network. There is support for new providers in the supply chain. Clients who have registered an interest in particular EPCs or EPC classes with a Discovery Service in the form of a standing query (a.k.a. subscription query) will be automatically notified as soon as new information providers (resources) publish records for those identifiers to a Discovery Service (subject of course to security policies specified by the provider of the information)

4.1. Information storage technology

The objective of the designed DS is to return a time-ordered list of links to multiple EPCIS instances that hold information related to a specific EPC. Therefore, the DS is designed not to duplicate or aggregate information stored within each individual EPCIS repository, but to store only sufficient relevant information to be able to create the list of links. It is worth pointing out that this list of EPCIS instances is constructed considering the identity of the client making the query and the corresponding access control policies defined by each company providing EPCIS data. The access control policies will generally depend on the business relationship and degree of trust between the client and the provider of the information.

A special case is aggregation events. An item, during its lifecycle, could become temporally or permanently a component (child) of a superior unit (parent) and after such aggregation, readers may only be able to read the parent tag and not the individual children tags of the embedded components. The proposed design allows a DS to store changes of aggregation relationships between children and parents and, if requested, the DS replies the list of links to EPCIS instances related to an item and the EPCs of the parent/children. Disaggregation events have similar treatment.

Due to the large information volumes to be potentially managed by Discovery Services (information related to millions or even billions of individual objects), the decision about the data storage technology to be used is critical, and must be taken according to different criteria such as: scalability, potential bottlenecks, response time, capacity to support multiple updates simultaneously, internal organization of data, robustness, etc.

Several technologies were compared, but finally LDAP (Lightweight Directory Access Protocol) was selected to implement the DS prototype. One of the most attractive characteristics of LDAP is an optimal response time to queries, due to the hierarchical organization of data storage. A 5-level hierarchical structure was selected (Fig. 5) during the DS design.

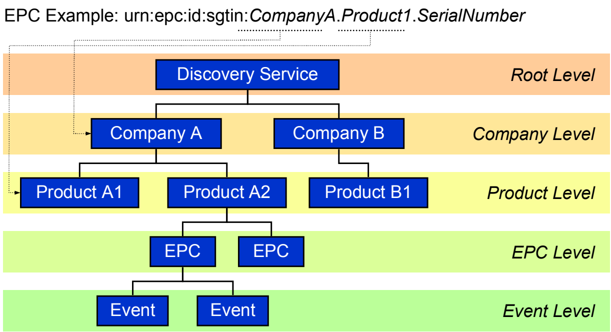

Fig. 5. Storage information structure

In the initial prototype, a centralized LDAP database is used for data storage. However, the design makes use of proxy layers, to allow for interfacing to alternative data storage mechanisms, such as distributed hash tables hosted on clusters of servers.

4.2. Proxy interfaces

Proxy interfaces (Publish Proxy Interface and Query Proxy Interface) are dependent on database technology. Their role is to interface between the external interfaces and the underlying database technology, to provide flexibility to use any underlying database technology keeping the same external interfaces.

4.3. External interfaces

The proposed DS design has two external interfaces:

- DS-Publish interface: to capture information from multiple information providers, including the addresses of their EPCIS services.
- DS-Query interface: to allow user applications to make queries and receive replies.

Web Services technology [11] was selected for the external interfaces.

The current EPCIS standard [8] does not include a specific communication mechanism between an EPCIS and a DS. For that reason, a module named IS-DS interface has been developed to be integrated with any software that complies with the EPCIS Capture interface standard (Fig. 6). Its missions are to filter relevant EPCIS event information and to send them to the DS, using the DS-Publish Interface. For example, a filter might be defined to trigger the publishing of a record to a Discovery Service when an object is first received by an organization or when it is finally shipped to another organization.

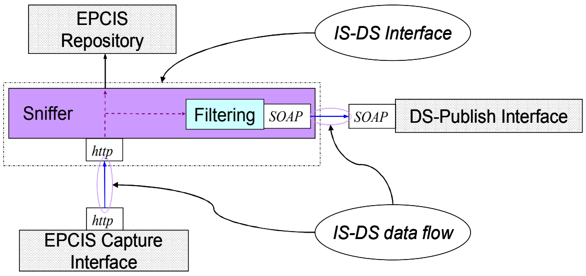

Fig. 6. IS-DS Interface

A DS prototype has been built and successfully integrated with the EPCIS implementation developed by the Accada open source project [12].

5. Track and Trace applications using Discovery Services

The current EPCglobal Network Architecture is primarily concerned with the processing of event data and the use of network standards to enable exchange of information among multiple organizations about uniquely identified objects.

However, automated data capture technologies such as RFID are not 100% reliable [13]; there can be false negative observations, in which a reader fails to detect an object that is within its proximity. With the use of modern readers and up-to-date firmware, false negatives may now be as low as 1-2 percent, providing that other factors in the environment are not significantly reducing the ability to read tags.

The consequences of missing observations can be relatively minor - perhaps resulting in some unnecessary alerts if other observation events cannot effectively compensate for missing events.

The consequence of missing aggregation events can be more significant, since it may become very difficult to do end-to-end tracking if essential aggregation events are missing.

Likewise there can be false positive observations, in which a reader reports the observation of an object that was not within its vicinity, perhaps because the tagged object happened to be next to another reader, so that the tag was effectively receiving power from both readers and could temporarily be read at a distance beyond its usual read range. The ratio of false positives can be minimized by careful planning of the location and orientation of readers - and also adjustment of their attenuation.

In many applications, RFID provides advantages over optical barcodes, since it does not rely on line-of-sight to the tag and can often eliminate the need for manual scanning of each individual object. However, there is a danger that occasional unreliability of RFID data capture and the reduction of human interaction and supervision can lead to more serious errors and wrong decisions.

For this reason, the BRIDGE project is also developing enhanced serial-level track and trace models that gather the relevant event data from across the supply chain, then use probabilistic algorithms and machine-learning techniques to refine the raw event data, to provide more reliable information to business applications. This is illustrated conceptually in Figure 7.

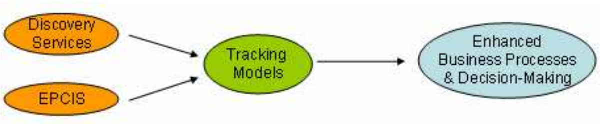

Fig. 7. Tracking models

A technical report [14] from the BRIDGE project describes these models in further detail. Locations across the supply chain, including hierarchical sub-locations within each organization are represented as nodes on a user-definable graph and recorded as a configuration within a relational database table. Historical event data is gathered either via single one-off queries to Discovery Services and multiple EPCIS repositories – or else continuously, via standing query subscriptions. The event data is then analysed and used to update database tables that record statistics about the transit times between nodes and the branching probabilities of an object of a particular class or type moving from one node to another. A state transition model represents the partial probabilities of an object changing from one state (e.g. location) to another. A sensor model represents the partial probabilities that an object is in a particular state (e.g., location) given a particular observation. This is illustrated in Figure 8, where sensor model relates the state variable x to observed evidence y, while the transition model expresses the sequence of transitions over time.

A number of algorithms, involving first order Hidden Markov Models are used iteratively with these models, in order to filter and smooth the data, as well as predicting the current and future location of objects and the individual path that an object is most likely to have taken.

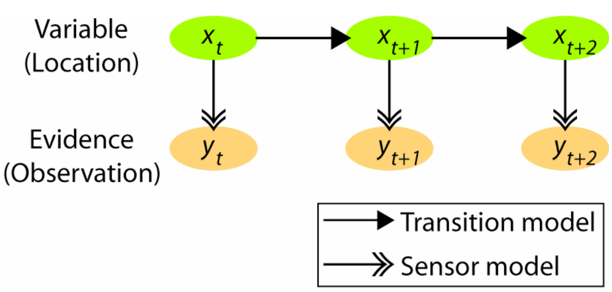

Fig. 8. State transition model

This information processing combined with further analysis and the use of user-definable 'rules' enables the detection of delays and unexpected behaviour, such as diversion and deviation from expected routes.

Ongoing work in the BRIDGE project (within the Security work package and in the Anti-counterfeit work package) is checking the plausibility of the flow patterns and sequences of events, in order to develop techniques for quickly and efficiently detecting suspicious behaviour.

The initial theoretical framework is currently being developed as an extensible software prototype and will be tested against real data gathered from the BRIDGE Pharmaceutical Traceability pilot, involving the tracking of individual objects across multiple organizations. This data will be analyzed for suspicious behaviour, such as the existence of duplicate IDs, flow patterns that cannot be traced back to the original manufacturer. Such pre-analysis of available event data would be of great value to customs officers, allowing them to focus their efforts on shipments that have suspicious event trails.

The models also support the use of mobile readers within plants - although there may be a need to configure a mobile reader to indicate that it is being used within a particular business location or for a particular task. The track and trace models rely upon event data gathered from EPC Information Services (EPCIS) and Discovery Services. EPCIS itself is agnostic about whether an event is generated from an object moving past a static reader - or an object being scanned by a mobile reader. EPCIS also remains agnostic about the data capture technology used - whether RFID, barcode or other.

6. Conclusions

The first stages of both the definition of the discovery services and track and trace models have been completed. An early prototype of the DS has been built, tested and integrated with one IS. Work on implementing security features is undergoing. After the integration of the tracking models and algorithms with the Discovery services and EPCIS interfaces, the next step will be to validate the effectiveness of the tracking system and extend the models and algorithms according to the business context of each use case. The ultimate aim is to enable companies to use the proposed system to improve their processes and decision-making.

Further extensions to the model and software prototype are envisaged during the remainder of the BRIDGE project, in order to adapt the model for use in the manufacturing sector, for use with returnable transport items such as pallets, roll-cages and trolleys, as well as integration of sensor data for monitoring the condition of objects throughout the supply chain or throughout their lifecycle.

An application programming interface (API) to the enhanced tracking models will also be developed, which will allow business applications to make requests or set rules at a high level of semantics, while the API takes care of the underlying details of the required data collection and choreography of algorithms to process the event data into meaningful information.

7. Acknowledgment

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References

[1] W. Bogdancih and J. Hooker, "From China to Panama, a Trail of Poisoned Medicine", The New York Times, 2007-05-06.

[2] EPCglobal, "EPCglobal Architecture Framework", 2006-07-01.

[3] Extensible Supply-chain Discovery Service Concepts (IETF draft-young-esds-concepts-00).

[4] Extensible Supply-chain Discovery Service Commands (IETF draft-thompson-esds-commands-00).

[5] Extensible Supply-chain Discovery Service Schema (IETF draft-thompson-esds- Schema -00).

[6] www.bridge-project.eu

[7] EPCglobal, "The Application Level Events (ALE) Specification version 1.0", 2005-09-15.

[8] EPCglobal, "EPC Information Service (EPCIS) version 1.0", 2007-04-12.

[9] EPCglobal, "Object Naming Service (ONS) version 1.0", 2005-10-04.

[10] AT4 wireless, "Serial Level Lookup service Prototype Components and Interfaces", 2007-05-07.

[11] www.w3.org/2002/ws

[12] www.accada.org

[13] J. Brusey, C. Floerkemeier, M. Harrison and M. Fletcher, "Reasoning about uncertainty in location identification with RFID", in Workshop on Reasoning with Uncertainty in Robotics at IJCAI-2003, Acapulco, Mexico, 2003.

[14] BRIDGE project Public Deliverables – WP03 (D3.1) "Serial-level Inventory Tracking Model", available from www.bridge-project.eu