Automatic Monitoring of Logistics Processes using Distributed RFID based Event Data

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Abstract. Decreasing sizes and a static decline in production costs are fostering the use of RFID tags and sensors in cross-company logistics networks. Additionally, the EPCIS specification comprises interface standards for capturing and querying RFID based event data and storing it in a standardized data format. This contribution examines the potential of the given technological means for the automatic monitoring of complex inter-organizational logistics processes. We identify requirements for the monitoring of individual quality objectives using distributed event data and describe the architecture of a monitoring system addressing them. Furthermore, we argue that such a system can be nearly seamlessly integrated into existing EPCglobal compliant RFID infrastructures.

1 Introduction

The RFID technology is nowadays mainly used in intra-organizational settings to capture identification and status information of trade items. Currently, inter-organizational applications are developed and investigated because of their potential to enable new beneficial business scenarios. To foster their adoption among multiple industries, EPCglobal[1] develops and ratifies standards to enable cross-company RFID application scenarios and to overcome problems caused by heterogenic RFID infrastructures. Complex logistics processes exhibit a predestined utilization context for these standards. They comprise combined point-to-point transportation and distribution or consolidation processes of goods between partners in a logistics network. The primary objective is to move goods along supply chains by complying with specific requirements concerning conditions of transported goods or the transportation process itself. These conditions cover for example times or locations of departure and delivery as well as quantities or conditions of transported goods. They mainly result from customer needs, competitive pressure or laws. We refer to these requirements as *Service Level Objectives* (*SLOs*) which are negotiated and defined on an individual shipments and transportations legs base.

[1] http://www.epcglobalinc.org

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Logistics Service Providers (*LSPs*) have to ensure the compliance to several SLOs during logistics process execution. To realize this, they negotiate dedicated contracts with subcontracted Carriers. These contracts are called *Forwarding Instructions*. They serve as a basis for documents called *Waybills* which are used as accompanying documents for transported trade items by Carriers. RFID related event data is currently used for Tracking and Tracing [1] applications to monitor SLOs associated with transportation processes and transported goods. Unfortunately, these applications are either proprietary developments or require the availability of *Electronic Data Interchange (EDI)* communication infrastructures. These imply extensive integration efforts and thus cannot easily be provided by small or medium businesses. Furthermore, they are restricted to the evaluation of single events against thresholds and thus neglect the potential of correlating event data which could be used to monitor more complex SLOs. To benefit from this potential, efficient mechanisms that integrate event data from distributed EPCglobal compliant RFID infrastructures have to be developed and combined with mechanisms that correlate it to business relevant monitoring information [2]. This contribution addresses the question, how a system for the monitoring of individual SLOs during transportation process execution can be designed respecting existing interface and data format standards to enable minimal adoption efforts. Furthermore, our work focuses on the development of mechanisms to integrate distributed RFID based event data and to correlate it to detect anomalies during the execution of complex transportation processes.

The remainder of this paper is structured as follows: Section 2 describes the technologies our work is based on. Section 3 defines the requirements a monitoring system has to meet in this individual context. In Section 4 an architecture and its components are presented which address the given requirements. Related work in this area is evaluated in Section 5. Section 6 summarizes our work and gives an overview about future work directions and objectives.

2 Technology Background

The Uniform Business Language (UBL)[2] document standard allows for the XML representation of common business documents including Forwarding Instructions and Waybills. It is driven by the not-for-profit consortium OASIS (Organization for the Advancement of Structured Information Standards). Due to this standard, a set of common SLOs concerning transportation processes can be described in XML documents and processed automatically. Modern RFID and sensor technologies enable the automatic identification (Auto-ID) of tagged items by eligible readers in combination with environmental information [3] and thus can be used to monitor SLOs. Sensors are able to detect physical or chemical changes in the surrounding of goods or the goods themselves. The information of interest and thus the actual sensors applied depend on their utilization context. Especially, in logistics scenarios the sensor information of interest is often about temperature, humidity and vibration settings of transported goods. Data captured by sensors can be stored on tags or directly sent to

[2] http://ubl.xml.org

readers mainly depending on the power management of associated RFID tags. Readers can be statically installed at multiple locations along supply chains, like goods issue or goods receipt gates, or dynamically moving with transportation vehicles to capture data of tagged goods. In logistics the utilization of passive UHF tags which exclusively store an identifier is common due to minimal production costs and efforts as well as small sizes. This identifier is referred to as *Electronic Product Code* (*EPC*) [4]. It allows for the unique identification of goods within the EPCglobal Network. EPCglobal is an industry consortium fostering the standardization of technologies for the automatic identification of objects. The so far ratified standards represent a key driver for cross-company RFID usage scenarios because they are already adopted by several industries. The most relevant outcome of the EPCglobal consortium for our work is the EPC Information Services Specification which includes interfaces for capturing and querying RFID based event data in a specified data format [5]. Software systems implementing these interfaces and data formats are called *EPCIS Repositories* which enable inter-organizational access and exchange of EPC related event and meta data. Stored data can be queried by either ad-hoc queries with immediate responses or by so called *Standing Queries* (*Subscriptions*). These Subscriptions for specific queries are periodically evaluated by an EPCIS Repository and matching event data is sent to the requesting application. Data stored in EPCIS Repositories is enriched by information about an object's business context, location, and condition at the time of detection by an RFID reader. Additionally, mechanisms for user defined extensions are provided to represent any possible kind of information associated with tagged objects like data captured by sensors. Modern event processing technologies enable the correlation of such data according to specified processing instructions. There are currently several solutions available which process events to derive rich business relevant information like Esper[3], Coral8[4] and Streambase[5].

The combination of these technologies provides the potential to use RFID based event data for the automatic and near real time monitoring of transportation processes in logistics networks to detect anomalies according to specified SLOs.

3 Requirement Analysis

RFID based event data is captured in EPCIS Repositories of partner companies participating in a transportation process. Carriers use vehicles equipped with RFID readers that periodically capture RFID data and pass it to the respective EPCIS Repository. An LSP has access to a monitoring system which integrates and correlates captured event data to evaluate the compliance to concrete SLOs. Such a system would support LSPs with their management of complex logistics processes and allow participating partners to be informed about problems or succeeded deliveries immediately and to react accordingly. Therefore, it has to meet the following requirements:

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[3] http://esper.codehaus.org
[4] http://www.coral8.com
[5] http://www.streambase.com/complex-event-processing.htm

R1: Fine-grained Description of Process Individual SLOs. An LSP has to be provided with fine-grained description mechanisms for the SLOs which are to be monitored. Furthermore, logical rules like negations, disjunctions or conjunctions on these SLOs have to be expressed which can be automatically processed by the monitoring system. An appropriate data format has to be provided and respective documents have to be put in a dedicated document repository which can be accessed by the monitoring system.

R2: Integration of Distributed RFID Event Data. As described in Section 3, RFID based event data is captured in distributed EPCIS Repositories. Only relevant event data has to be sent to the monitoring system in near real time for further processing.

R3: SLO based Monitoring Instructions Generation. SLOs are individually negotiated for any transportation process. Therefore, monitoring instructions like event patterns [6] have to be defined frequently. The definition of monitoring instructions has to be executed automatically, because a definition done by users would imply too high expectations on their programming skills and not scale due to the high number of transportation processes which are to be coordinated in short time intervals.

R4: Processing of Monitoring Instructions and Event Data. The processing and matching of automatically generated monitoring instructions with the event data gathered from distributed EPCIS Repositories has to be performed by an appropriate event processing engine. It has to correlate event data resulting from different sources according to the given instructions. Furthermore, it has to create notification events if a certain set of incoming event data matches an instruction. Then, either a violation or a successful fulfillment of a specific SLO has been detected.

R5: Management of Monitoring Results. The monitoring system produces results in the form of notification events which mainly correspond to the output of the installed event processing engine. The system has to support two kinds of output: instantaneous notifications and historical log files. The historical log files have to be persistently stored in combination with the associated SLO descriptions. This allows for the later processing or exchange of this data.

R6: Notification of External Business Applications. The monitoring system has to provide mechanisms to notify external business applications if an SLO violation or its fulfillment has been detected. Therefore, it has to expose an interface which could be accessed by applications to subscribe for certain kinds of notifications. They would then be informed as soon as a respective notification occurs by the monitoring system.

R7: Minimal Integration Efforts Into the EPCglobal Architecture Framework. The integration effort of the monitoring system into existing EPCglobal compliant RFID infrastructures has to be kept at a minimum. This implies that interfaces and data formats specified by EPCglobal have to be supported to allow users with compliant infrastructures to use the system with minimal efforts in time and costs.

4 Conceptual Design

This section describes the architecture of a monitoring system which integrates event data from distributed EPCIS Repositories to automatically monitor individual SLOs and addresses the requirements defined in Section 3. Figure 1 gives an overview of its components and their interactions. There are two areas distinguished in the figure which could be referred to as external system components like data sources and accessing applications and the inner monitoring system. An accessing application might be a Web Frontend for direct access to the monitoring system which would be used by an LSP or a Business Application like a planning tool which could be hosted by the monitoring systems owner or partner companies which want to be informed about certain monitoring results. Furthermore, EPCIS Repositories and the Document Repository are considered to be external system components as well. The EPCIS Repository is hosted by each partner company of a supply chain which wants to capture data related to trade items. The Document Repository is hosted by an LSP and offers access to stored Forwarding Instructions or Waybills which are put in there by LSPs or Carriers after negotiations. The documents contained are called *Extended UBL Documents*. They are instances of an UBL document standard extension we developed to enable fine-grained SLO and dependency descriptions between several documents. Together, the Document Repository and the extension of the UBL XML schema address R1.

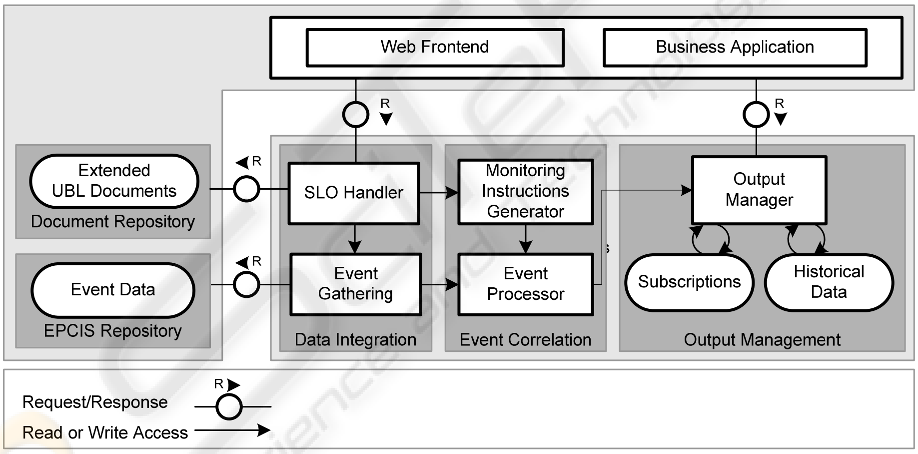

Fig. 1. Architecture of the monitoring system including accessing applications on the left and data sources on the top.

The monitoring system in the center of Figure 1 is subdivided into three logical parts: *Data Integration*, *Event Correlation* and *Output Management*. The Data Integration part includes system components that gather relevant information from external information sources and prepare it for further processing. The SLO Handler is activated when an accessing application initiates the monitoring of a specific transportation process. It queries the Document Repository to extract the relevant Waybills for all transportation legs of the given transport process. It uses the documents returned to determine its expected duration, the involved partner companies and one or more EPCs of the goods included in the shipment which is to be monitored. This data is sent to the Event Gathering component. Furthermore, the SLO Handler extracts SLO descriptions from the Waybill documents and sends them to the Monitoring Instructions Generator. The Event Gathering component addresses R2. It receives data from the SLO Handler which identifies the relevant EPCIS Repositories which have to be queried to receive event data concerning a specific shipment. This component sends event queries as Subscriptions to the given EPCIS Repositories which persist during the expected duration of the transportation process and are deactivated afterwards. During that time the submitted queries are executed periodically according to a time schedule defined by the Event Gathering component. Resulting event data from EPCIS Repositories is sent to this component and passed to the Event Processing Engine.

The Event Correlation is the second logical part of the monitoring system. It includes the Monitoring Instructions Generator component which addresses R3. It uses data submitted by the SLO Handler to automatically create event patterns. The generated event patterns describe correlations of single events to complex events which are translated into a new semantic meaning. To evaluate for example if the transportation duration of a certain shipment does not exceed 24 hours after the departure from its origin it has to be searched for an event indicating the departure and an event indicating the final arrival at the shipments destination. Additionally, it has to be examined if the time interval between the time of departure and the time of arrival is less than 24 hours to infer that this SLO has been met. Event patterns have to express this event correlation and constraints information. Operators supported by common pattern description languages include disjunctions, conjunctions, negations or temporal sequences and periods. Our architecture design proposes a processing of patterns and event data by an Event Processing Engine which relates to R4. It receives event patterns from the Monitoring Instructions Generator and matches them against incoming event data from the Event Gathering component. The Event Processing Engine generates notification events and sends them to the Output Manager if event patterns are matched by sets of certain events.

The third logical part of the monitoring system is the Output Management which addresses R5 and R6. The system produces historical and instantaneous monitoring data. Historical monitoring data is stored in an internal database by the Output Manager. It can be queried by eligible users or applications. Instantaneous monitoring notifications are produced by the Event Processing Engine. They are sent to accessing applications by the Output Manager which beforehand evaluates Subscriptions stored in its internal database to discover which applications are interested and where to send the notifications.

For clarity reasons Figure 1 does not depict any interfaces which are used by the system components to expose and access functionality and in addition address R7: The EPCIS Repository implements the interfaces specified in [5]. These include the Query Interface to provide access to stored event data for applications and the Capture Interface which can be accessed by appropriate RFID middleware solutions to send RFID based event data to a Repository. The monitoring system itself implements a Query Callback Interface which is accessed by an EPCIS Repository when event data is sent according to a Subscription.

5 Related Work

The monitoring of individually negotiated quality objectives of transportation processes is nowadays nearly exclusively practically performed in the cool chain industry. This implicates that research in this area concentrates on this industry. It is mainly investigated how data could be efficiently captured using sensor or Auto-ID technologies and how it can be stored in rather proprietary software systems [7], [8]. The correlation of resulting event data to more complex information is not considered. Furthermore, it is often assumed that relevant data is stored centrally and cross-company usage scenarios are not examined.

Additionally, there are approaches that aim to detect anomalies in distributed event data in near real time. In this context anomalies suggest the presence of counterfeit products. Other approaches describing the monitoring of certain quality objectives do mainly work with fixed policy descriptions [9], [10]. Altogether, they do not consider the automatic generation of processing instructions like event patterns based on these policies which is essential for practical adoptions. Still, there are some approaches in research which study the evaluation of distributed RFID based event data to proof authenticity of goods [11], [12]. However, they do not describe how distributed event data can be integrated for such an evaluation. They rather provide an additional database to redundantly store the event data of interest. In addition, they do not describe how the evaluation of event data can be automatically performed instead of time consuming and error prone interpretations by consumers.

Already well established approaches to perform long term evaluations regarding the compliance of service providers to concrete *Key Performance Indicators* (*KPIs*) are supported by Data Mining mechanisms on data stored in huge Data Warehouses [13]. These mechanisms can be applied to RFID based event data. They differ from our approach in their potentially redundant representation of stored data and in their long term character by allowing high response times due to very complex computations. This is mainly due to the long term character of KPI definitions which are unlike the short term intention of SLOs for transportation processes.

6 Conclusions and Future Work

In this contribution we argued that current standards compliant RFID infrastructures, technologies for event correlation, and XML based business document standards enable service oriented logistics monitoring applications that require less integration efforts than existing tracking solutions. This is reflected by our investigation on mechanisms that build upon the EPCglobal Framework to automatically integrate and use distributed RFID based event data for the monitoring of transportation processes. We have introduced a set of requirements a monitoring system needs to implement. Considering these, we presented a conceptual design of an architecture addressing these requirements and proposed mechanisms that integrate and correlate event data to perform the monitoring of transportation processes regarding to specific SLOs. The events stored in EPCIS Repositories cover exactly the information needed to evaluate the compliance of a given transportation process to specified SLOs. The monitoring system integrates this data by processing its structure as well as accessing and implementing the interfaces which are specified in the EPCIS Specification. Due to that, the system complements the vision of EPCglobal by using the given infrastructure to derive business relevant information and putting cross-company separated event data in a new context.

Our future work focuses on the development of an algorithm to automatically generate monitoring instructions based on given SLO descriptions. To support the notification of external business applications by the monitoring system, we are going to model possible notification events. A data model which has to be exchanged between cooperating companies external applications will enable them to immediately process notifications as they are received. Additionally, we are continuously engaged in developing the prototypical implementation of our concepts which will be later used for their evaluation. For example, we are going to analyze the influence of missing or distorted event data on the results of the monitoring system.

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