Enabling Self Organising Logistics on the Web of Things

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Abstract: This position paper outlines a standards based approach to enabling self organising logistics on the Web of Things by exploiting the technological framework of a Multi Agent System (MAS). Logistics items(containers and carriers of goods) tagged with RFID transmitters communicate with the MAS by transmitting data as events. The specification of event data is based on EPCIS[1] - a GS1 standard for an event oriented representation of the location and state of material as it moves between organisational boundaries. Communication between software agents is facilitated via a data pipeline. Implementation of the pipeline is proposed using Semantic Web standards and linked data technologies which are key enablers of interoperable systems on the Web of Things.

1. Introduction and Motivation

Increasing complexities in globalised markets driven by competitive supply chains, have had significant implications on the operation and planning strategies for transport logistics. Logistics items are now required to be proactive, agile and “self organising” in order to minimise the loss of revenues in supply chains[5]. On the other hand, implementing self organisation, which is usually governed by autonomously driven systems, generates unprecedented volumes of data in different formats that needs to be managed and analysed for increasing the operational efficiency within the systems and realising the benefits of the process.

Consider the scenario of arranging the logistics for perishable goods, where sensors, RFID active tags and smart container devices are currently capable of monitoring relevant conditions during transport, such as security, position, acceleration and environmental parameters inside containers, amongst others. When the temperature in a container that contains perishable goods drops below a specific threshold, due to a failure in the cooling system of a truck, alternative transportation needs to be organized in a timely manner to accomplish the delivery goal according to the original schedule. In order to realise this, a self organising framework that can interpret the sensor readings and arrange the alternative means of transport based on predefined heuristics, can significantly increase the efficiency of the logistics subsystems and thereby that of the supply chain. However, the implementation of such a framework would require a data management layer that is capable of unambiguously identifying data elements, interlinking the datasets and making sense of the large volume of the resulting interlinked information.

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[1] http://www.gs1.org/gsmp/kc/epcglobal/epcis

This position paper outlines a standards based approach to enabling self organising logistics on the Web of Things by exploiting the technological framework of a Multi Agent System (MAS)[6]. Logistics items(containers and carriers of goods) tagged with RFID transmitters communicate with the MAS by transmitting data as events. The specification of event data is based on EPCIS[2] - a GS1 standard for an event oriented representation of the location and state of material as it moves between organisational boundaries. Communication between software agents is facilitated via a data pipeline. Implementation of the pipeline is proposed using Semantic Web standards and linked data technologies which are key enablers of interoperable systems on the Web of Things.

Self organisation of the logistics items is enabled by the MAS by executing risk averting actions defined as part of a rule base encoding domain specific rules, on the real time interlinked event and logistics datasets. Although logistics includes storage, transport and transshipment of goods, this paper focuses on the transport part of logistics, which is especially relevant to illustrate the self organising capabilities of a MAS.

2. Self organisation in logistics

Self-organisation arises in a system with no central control when an optimal and efficient behaviour eventually emerges from the joint effort of all its participants [1].

When thinking of logistics as a self-organising system, one could see it as a network consisting of nodes operated by humans and supported by IT systems, e.g., warehouses, seaports and airports, but also nodes that can move, such as trucks, barges, etc. In this network, logistics items with some degree of intelligence should be able to travel concurrently. These intelligent items are, for example, products, packages, cargo and containers equipped with RFID tags and smart sensors. The nodes of the self-organising network should be able to access not all the data stored or triggered by other nodes, but only the data that is relevant to accomplish the node's local goals. An example of node's local goal for a warehouse could be "fill in your storage capacity and trigger a signal to the system when you are completely full". Moreover, nodes should have knowledge of (relevant parts of) the network infrastructure and collaborate with other nodes in order to optimize the use of network resources according to a commonly shared (global) goal, for example, reduce waiting times, enhance load factor, support sustainability, etc.. Moreover, nodes that move in the network should have local goals, for example, local goals for a truck could be "get to your target warehouse as quickly as possible" or "go to the nearest warehouse that has available capacity".

Not only RFID technology is essential to realize self organising logistics, but also wireless communication technology such as Wi-Fi, GSM or satellite networks that enables data sharing among logistics items and agents. Logistics items should sense their position and progress along the supply chain through GPS sensors. However, GPS may be not always available during

[2] http://www.gs1.org/gsmp/kc/epcglobal/epcis

transportation, for example, when an item is indoors, in the open sea, or when a container is not on the top deck. In these cases, logistics service providers should be capable and willing to provide these data to the system.

3. Semantics and Linked data to enable self organisation in logistics

We exploit the concept of a data pipeline as proposed in the Cassandra Project[3] to enable the sharing of information within the underlying technical infrastructure of a MAS supporting the logistics layer in the supply chain. Our proposed approach uses ontologies, linked data, RESTful Web services and a domain specific rule base to enable self organisation in logistics.

Ontologies provide a shared understanding of the domain knowledge, while linked data described using ontologies as metadata enables interlinking between various sources of information. RESTful Web services enable communication between agents, and domain specific rules encode the constraints required to fulfill user and system specific requirements.

We use the EEM[4] (EPCIS Event Model) ontology to describe EPCIS events and the LogiCO[5] (Logistics Core Ontology) ontology to describe recurrent concepts in logistics. Real time information about the events raised by the RFID scan of logistics items as well as information about the items themselves are exchanged as linked data between the agents. The rules encode heuristics, described in terms of event data variables, to take corrective actions when exceptions are raised in the system.

The concept of a virtual pipeline that enables communication between the heterogeneous logistics subsystems in the supply chain is essential to realise the vision of interoperability. Besides achieving data integration among the immediate stakeholders, the pipeline allows other trusted agencies and authorised sources to get access to the data in a secure way as and when the need arises. In our proposed framework, the implementation of the virtual pipeline is realised through the principles of linked data. Dereferenceable HTTP URIs of datasets to be shared are made available to the relevant parties who can augment them with further information, thereby adding to the data history of the logistic items. The augmented datasets can then be further shared in the supply chain.

EEM is an OWL 2 DL ontology for modelling EPCIS events. EEM conceptualises various primitives of an EPCIS event that need to be asserted for the purposes of traceability in supply chains. The modelling decisions [2] behind the conceptual entities in EEM reflect the EPCIS abstractions included in the ontology. For further details on EEM and its applications in real world scenarios, the interested reader is referred to [2,3].

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[3] http://www.cassandra-project.eu/
[4] http://purl.org/eem#
[5] www.cassandra-project.eu/userdata/file/Articles/LogisticsCoreOntology_v2.7.1.owl

LogiCO is an OWL 2 DL ontology for modelling foundational concepts that are commonly used in logistics regardless of the specific standard used to represent them. LogiCO regards logistics as the set of activities that take place among several actors in the supply chain in order to deliver certain products at the right time, right place and under the right conditions, by using suitable physical resources. Further details about LogiCO can be found in [4].

A conceptual architecture of the proposed system, customised for the perishable goods scenario described in Section 1 is shown in Figure 1. At a high level, we consider three abstract layers: the physical layer which consists of the containers and carriers of goods, the raw data layer where sensor readings and event data from RFID scans are recorded, and the self organising layer which interconnects the various logistics subsystems with the linked data pipeline.

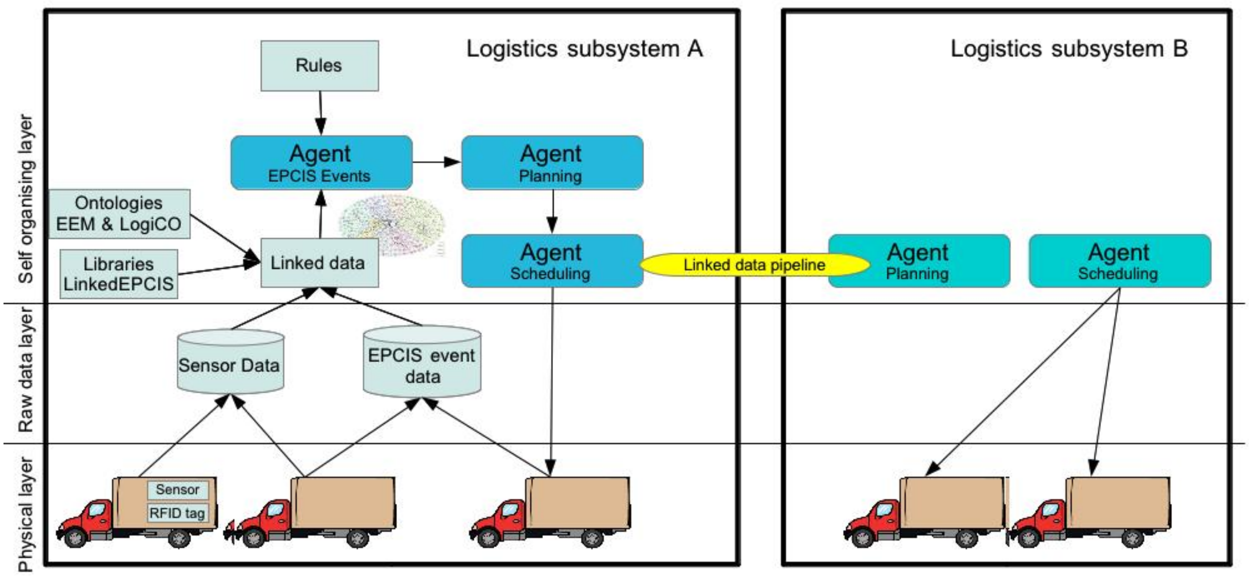

Figure 1

Containers are equipped with sensors that record any environmental parameters of interest and RFID tags that are used to generate EPCIS events when scanned by a reader. The recorded raw data is stored in an intermediate repository for historical analysis and mining. The data is then transformed to its linked data version by undertaking an ETL (Extract, Transform and Load) process that utilises ontologies, external libraries and other linked data sources.

The underlying MAS has three major agents that undertake the crucial tasks of analysing incoming linked data using the predefined rule base. When an exception that requires replanning and rescheduling of the containers is detected, the planning agent is invoked. The data needed for the replanning is made available as linked data. The planning agent may augment this information with the new schedule or simply send the schedule as linked data to the scheduling agent. If the new scheduling request cannot be completed internally, the scheduling agent invokes the planning agent from a different logistics subsystem via the virtual data pipeline and sends the scheduling request. All communications happen by dereferencing HTTP URI in accordance to linked data best practices.

It is worth noting that the nature of linked data communicated internally would differ from that communicated to external agents from a different logistics subsystem. The data sent to external agents would need to be augmented with provenance information, access control requirements and security policies.

4. Conclusions

Self organisation can provide a dynamic and distributed mechanism for increasing the operational efficiency in logistics, compared to traditional mechanisms centralised in one component that is dedicated to retrieve and process information from several distributed sources and take decisions consequently, often relying on humans that make phone calls and exchange e-mails. Whilst these traditional solutions can be highly efficient in normal conditions, they are not responsive to real time changes and unpredictable events - the so called "operational risks". Self organisation helps coping with operational risks, therefore minimising revenue losses and enabling the overall visibility of logistics items in the supply chain. A standards based approach on the other hand serves as a strong foundation for enabling interoperability between the diverse systems deployed by the trading partners. In this position paper we have proposed a framework based on the EPCIS specification - a GS1 standard, ontologies, Web services and linked data that provide an overarching set of technologies for empowering the MAS underlying logistics operations with self organising capabilities.

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