TOWARDS FOURTH-PARTY LOGISTICS PROVIDERS
A Business Model for Cloud-based Autonomous Logistics

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Abstract: Cloud computing denotes a paradigm shift in computing that enables a flexible allocation of hardware and software resources on demand. Therewith, it is particularly appealing for applications with a high degree of computational complexity and dynamics. This paper identifies logistics planning and control as a promising application for clouds. However, two prerequisites must be met for cloud-based logistics control. Firstly, the platform-as-a-service layer must provide a synchronisation of the physically distributed real-world material flows and the data flows in the cloud. Secondly, appropriate and scalable control software must be implemented on the software-as-a-service layer. Apart from outlining the technical foundations, this paper describes how both steps enable a business model that is usually referred to as fourth-party logistics.

1 INTRODUCTION

The cloud computing paradigm envisions that hardware and software resources are flexibly allocated on demand. Usually, three different layers are distinguished (Rittinghouse and Ransome, 2010):

Infrastructure as a Service refers to a scalable hardware infrastructure.

Platform as a Service covers a system environment for application deployment in the cloud.

Software as a Service means that users are provided with the whole software demanded by them.

Employing clouds raises several questions which cover, for instance, service reliability, connectivity, and security. Indisputably, these questions are worth being addressed. Nevertheless, these questions are out of the scope of this paper which lays its particular focus on advantages and resulting use cases.

A promise of cloud computing is that users can significantly decrease their investments for own IT infrastructure. In principle, only thin clients are required to access cloud resources through the Internet. The required computational power is billed based on the resources actually used. Particularly the ability to allocate services dynamically distinguishes cloud computing from application service providing in general. Conventional IT infrastructures must be capable of handling the maximally expected load. Cloud computing approaches this challenge by bringing together users with complementing demands, i. e., load peaks of some users coincide with idle times of others (Rittinghouse and Ransome, 2010).

The ability to flexibly adapt to both increasing and decreasing demands makes cloud computing particularly appealing for applications that exhibit a high degree of computational complexity and dynamics. This particularly holds for logistics planning and control. As a foundation, characteristics of the logistics domain are examined and the resulting requirements are matched to properties of cloud computing (Section 2). The first requirement is that the software for logistics control is scalable. To this end, an agent-based approach for autonomous control in logistics is presented (Section 3). The second requirement is that the physically distributed logistics processes are connected to the control system. The necessary synchronisation of material and data flow is accomplished with Internet of Things technology (Section 4). Combining both aspects with cloud computing allows implementing a business model which is often referred to as fourth-party logistics, 4PL in short (Section 5).

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The contribution of this paper is thus a new business model for logistics control based on cloud computing. The foundation of this business model is the integration of agent-based autonomous control in logistics and cloud computing by means of Internet of Things technology.

2 CHALLENGES OF LOGISTICS PLANNING AND CONTROL

Logistics is of considerable importance as a backbone of the globalised economy. Goods are procured from all over the world, processed, and distributed to customers which can again be located all over the world. Managing such supply networks is a challenging task due to three properties:

Complexity which is due to the high number of logistics objects and their manifold parameters.

Dynamics induced, e. g., by transient customer demands and changes in the environment.

Distribution as logistics processes frequently span companies, countries, and even continents.

Computing optimal plans that incorporate all relevant aspects takes a considerable amount of time (Applegate et al., 2007). Due to the dynamics, optimal plans are therefore often already outdated in the moment their generation is finished (Windt and Hülsmann, 2007). This is particularly challenging for logistics control which requires quick responses to exceptions that occur while plans are executed.

Given that logistics planning and control can be executed in parallel, cloud computing is a promising approach to tackle the challenges caused by complexity and dynamics with increased computational power. The problem, however, is that optimisation problems in logistics are usually solved with discrete linear programming which is known to be NP-complete (Hopcroft and Ullman, 1979). Although the artificial Travelling Salesman Problem, as an example, might appear simple at first glance, it nevertheless exhibits a factorial computational complexity. Even with sophisticated heuristics, the seemingly inexhaustible hardware power of clouds can often not suffice for solving such problems in acceptable time (Applegate et al., 2007).

This means that an adequate Software-as-a-Service layer is required that is capable of reducing the computational effort and coping with the local dynamics occurring. Given this prerequisite (which will be addressed in Section 3), it is possible to benefit from the scalable Infrastructure-as-a-Service layer of clouds. This is particularly beneficial in order to tackle global dynamics occurring. These dynamics may be due to economical or seasonal influences as well as special sales concepts. Examples for the former ones are the financial crisis of 2007–2010 as well as Christmas sales. An example for the latter one are sales concepts with a continuously changing range of products (Schuldt, 2010). With cloud computing, logistics companies would be able to scale their computational power for process control in accordance with these effects.

Unlike many other cloud applications, however, logistics control exhibits another challenge. Logistics control demands frequent interaction with the real world. On the one hand, this means that the software system must be informed about events occurring in the real world. On the other hand, the system must be able to react on these changes, i. e., its decisions must be executed in the real world. The required synchronisation of material and data flows is particularly challenging because logistics processes are inherently distributed. This high degree of spatial distribution prevents local information from being available for central decision-making (Jedermann and Lang, 2008). This is part of the Platform-as-a-Service layer (which is dealt with in Section 4), which connects the Infrastructure-as-a-Service and the Software-as-a-Service layers.

To summarise the findings so far, the requirements for cloud-based logistics control are as follows:

1. On the Software-as-a-Service layer, it is necessary to implement an adequate control software that is capable of coping with both the computational complexity and dynamics.
2. On the Platform-as-a-Service layer, it is necessary to synchronise real-world material flows with the data flows in the cloud to account for the physical distribution of logistics processes.

3 AGENT-BASED AUTONOMOUS CONTROL IN LOGISTICS

As elaborated in the previous section, conventional approaches to logistics planning are not applicable for on-line control. Due to their asymptotic computational complexity, even the computational power of clouds does not suffice (Section 2). A particular challenge is the dynamics of logistics processes that renders optimal plans outdated in the moment their generation is finished. Think, for instance, of a shipping container loaded with perishable goods. The shelf life of the goods decreases if the interior temperature increases. If a sensor network within the container detects such an increase in temperature, it is thus necessary to re-route the container to another location nearby and to send another container with similar goods to the original destination. Other reasons for re-planning include traffic or weather conditions. All these reasons for dynamics have in common that they only affect some logistics objects and by far not the whole network.

Motivated by this finding, the paradigm of autonomous control in logistics delegates decision-making to the participating logistics objects themselves (Windt and Hülsmann, 2007). Autonomous control enables logistics objects to process information, to make and execute decisions, and to cooperate with each other based on objectives imposed by their owners. The advantages over centralistic approaches are as follows (Schuldt, 2010):

1. The computational effort is significantly reduced by computational decomposition.
2. The scalability of process control is significantly increased by parallelising decision-making.
3. Reactivity and robustness are significantly increased by local exception handling.

Potential autonomous logistics entities are components, articles, sales units, cardboard boxes, pallets, and shipping containers.

The technologies enabling autonomous logistics are identification, localisation, sensors, communication, as well as local data processing. Figure 1 depicts an architecture for autonomous logistics entities (Schuldt, 2010). The identification unit uniquely identifies autonomous logistics entities (Hribernik et al., 2009). The localisation unit allows self-localisation of logistics entities, e. g., based on global navigation satellite systems (Hofmann-Wellenhof et al., 2008). The sensor unit continuously monitors the environmental and the interior state of the logistics object (Al-Karaki and Kamal, 2004; Jedermann and Lang, 2008). The communication unit enables coordination with other entities. The heart of autonomous logistics entities, however, is the data processing unit which checks whether the original planning for the object is still valid or whether it must be updated. Its decision-making can be implemented by means of intelligent software agents. Example applications of agent-based autonomous logistics cover adaptive truck routing incorporating driving time estimation based on traffic and weather conditions (Gehrke and Wojtusiak, 2008) and autonomous container dispatch (Schuldt, 2010).

A physically distributed application of software agents is possible (Adorni et al., 2001). For instance, this makes sense in order to continuously monitor

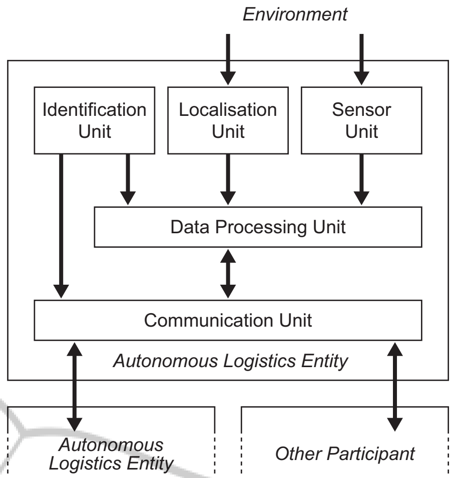

Figure 1: Architecture for autonomous logistics entities.

sensor measurements without the necessity to transmit them over communication networks. Embedded systems attached to the logistics objects, however, are not designed for extensive reasoning tasks. Instead, clouds are a promising platform for such re-planning.

Agent-based implementations natively support parallel execution. In contrast to sequentially executed software solutions for logistics control, software agents are thus well prepared for virtualisation. Multiagent platforms such as JADE (Bellifemine et al., 2007) support multiple so-called agent containers in which agents can be deployed at different locations. Agents can then communicate with each other also over the boundaries of their particular agent container. Interoperability can be ensured because the agent concept has been shown to be sufficiently close to the service-oriented architecture (SOA) model (Moreau, 2002). A number of concepts exist which interface multiagent platforms with SOA middleware, such as WS2JADE (Nguyen and Kowalczyk, 2007), middle agents (Sycara, 2001), and other gateway architectures which allow transparent, fully automatic interoperation (Greenwood and Calisti, 2004).

In order for cloud-based autonomous logistics to be operationalised, however, an adequate approach must be developed to synchronise the material and data flows in the respective logistics processes. The actual logistics objects – whether they be physical such as goods, containers, trucks and transport hubs or immaterial such as orders – need to be connected both to the agents which are their digital counterparts in the cloud and to existing logistics IT infrastructure such as dispatch, route planning, and enterprise resource planning systems in order for cloud-based logistics service provision to be feasible. In terms of the architecture for autonomous logistics entities (Figure 1), this means that the data processing unit which is then located in the cloud must be connected to all other units.

4 MATERIAL AND DATA FLOW SYNCHRONISATION

To summarise the findings thus far, agent-based autonomous logistics helps cope with the computational complexity and dynamics on the Software-as-a-Service layer (Section 3). Another important prerequisite (Section 2), however, is the synchronisation of material and data flows on the Platform-as-a-Service layer. In particular, three challenges have to be addressed:

Unique identification of logistics objects to establish a link between real world objects and their agent counterparts.

Data integration from various sources in a meaningful manner.

Dynamic data source integration such as RFID, sensors, sensor networks, and other systems integrated in logistics objects.

For these purposes, the concept of the Internet of Things becomes relevant. In essence, the Internet of Things extrapolates the idea of the Internet – a global, interconnected network of computers – to describe a network of interconnected things, such as everyday objects, products, and environments. As such, the concept represents the convergence of a number of recent multi-disciplinary developments such as Ambient Intelligence (Ducatel et al., 2001), Ubiquitous (Weiser, 1991) and Pervasive Computing (Gupta et al., 2001), Auto Identification (Cole and Engels, 2002), and Intelligent Products (Meyer et al., 2009). At the heart of the concept lies the idea that objects – things – are capable of information processing and communication with each other and with their environment. For cloud-based logistics control, the logistics objects are the things which the multiagent system enables to process information and communicate.

An important prerequisite for autonomous logistics based on cloud computing is its integration into existing logistics infrastructures. Therefore, it is important to synchronise real-world material flows and data flows in the cloud. This mapping can be accomplished based on the identification standards of the EPCglobal Architecture Framework (Hribernik et al., 2009). ID@URI using the Dialog system (Främling et al., 2006) is an alternative that combines unique article identifiers with Internet addresses where additional information about the object can be retrieved.

Furthermore, it is necessary to integrate data from various sources in a semantically meaningful manner. To this end, semantic mediators can be applied. Figure 2 illustrates a concept for a generic data integration concept for logistics clouds with the Internet of Things. It is an extension of a concept for generic data integration in autonomous logistics (Hribernik et al., 2010) which satisfies requirements both towards the coupling of the material and data flows as well as towards providing unified access to all relevant data sources including interfacing to the service consumers. At the heart of the concept lies a mediator component (Ullman, 1997; Wache et al., 2001), which is capable of composing queries to any combination of relevant logistics data sources. It achieves this by semantic mediation. Each data source is fully described syntactically and semantically by an ontology, which can be mapped onto the others by the mediator. Wrapper components handle the transformation to and from the relevant data sources in a rule-based fashion. By implementing semantic descriptions and transformation rules for widely used logistics data exchange formats such as the EDIFACT subset EANCOM or standards from the EPCglobal Architecture Framework such as EPCIS (Electronic Product Code Information Services) (EPCglobal Inc., 2007), access to the majority of relevant data sources is given. Additional, proprietary data sources can be integrated simply by adding a new wrapper with the relevant semantic description and set of transformation rules, making the concept highly extensible. This approach also allows the service consumer to either easily integrate the required services into its own logistics IT landscape, or, for example, utilise thin clients to access a web-based GUI towards the cloud services.

Finally, the proposed concept also facilitates the direct integration of dynamic data sources used in logistics processes, such as such as RFID, sensors, sensor networks and other systems integrated into physical logistics objects. By abstracting from the physical interfaces towards these data sources, the semantic mediation approach may be applied in much the same way it is to static data sources. The abstraction layer is required to be able to provide a reliable interface regardless of the physical accessibility of the dynamic data sources at any time. It is responsible for buffering, filtering and routing data to and from the respective data sources. It may consist of elements such as the FOSSTRAK HAL towards EPC-compliant RFID (Floerkemeier et al., 2007), PMI (Promise Messaging Interface) (Främling and Ny-

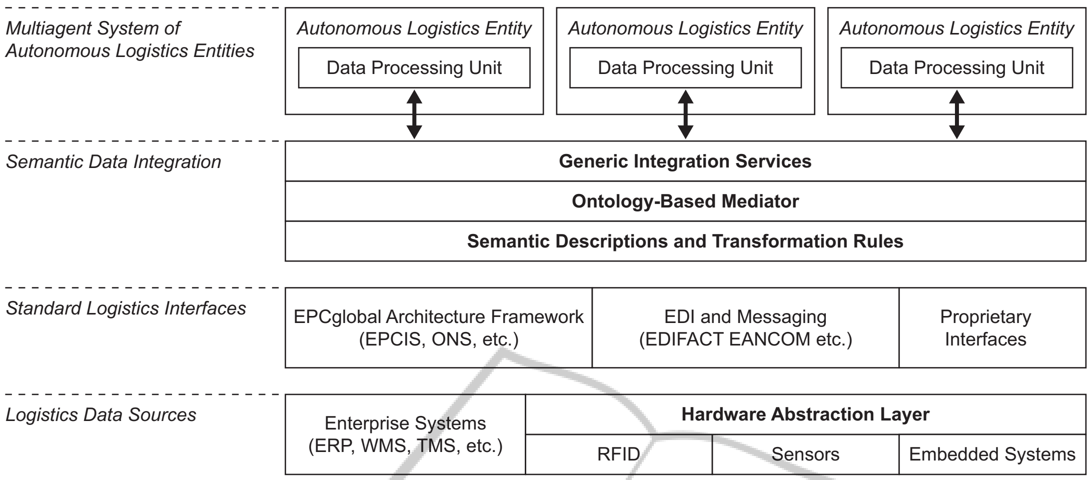

Figure 2: Data integration concept for cloud-based autonomous logistics entities.

man, 2008) towards PEIDs (Product Embedded Information Devices) (Kiritsis et al., 2003) or OSGi towards sensor components (Ahn et al., 2006).

5 BUSINESS MODEL FOR FOURTH-PARTY LOGISTICS

Despite all of the advantages cloud computing offers, the broad variety of involved technologies makes it challenging for individual logistics companies to benefit from these advantages. Logistics enterprises are experts in logistics and not in IT. Employing specialised service providers that offer logistics cloud computing is thus preferable. This leads to different business models for service providers.

5.1 Logistics Cloud Service Providers

The first three layers of logistics cloud computing correspond more or less directly to the three general cloud layers Infrastructure, Platform, and Software as a Service (Section 1). Nevertheless, service providers for logistics clouds have to ensure the services outlined in Sections 3 and 4. However, it is worth mentioning that service providers on different layers may be disjoint from each other. That is, providers on higher levels may acquire services on lower levels from other service providers.

On the Infrastructure-as-a-Service layer, there is a direct correspondence between logistics cloud computing and general cloud computing as both refer to the underlying hardware infrastructure. Consequently, service providers on this level do not need any expertise in logistics. On the contrary, it seems even advantageous if logistics companies share computing resources with enterprises from completely different branches, at least given that their computational demands complement each other. This helps utilising the resources of the infrastructure service provider more efficiently.

Logistics-specific tasks on the Platform-as-a-Service layer can be categorised as follows. Firstly, fundamental services for agent deployment in the cloud have to be provided (Section 3). This eases the deployment of agent representatives and delegates the administration of the software platform to the service provider. Secondly, the synchronisation of material and data flows has to be implemented in order to establish the link between real-world logistics objects and their digital counterparts in the cloud (Section 4). For data integration, they provide interfaces to data sources and mediate if necessary. Logistics companies do thus not have to consider these issues themselves and can thus implement their logistics control without being burdened with data integration.

The Software-as-a-Service layer of logistics clouds goes even one step further. Service providers offer a complete implementation of the software agents needed for autonomous control of a specific process. Furthermore, the administration of software agents is left to the service provider. Consequently, service providers on this layers need expertise in the field of logistics control with multiagent systems. In return, the need for IT expertise in the logistics company is reduced to a minimum because its task reduces to delivering relevant process information.

5.2 Fourth-party Logistics Providers

On the Software-as-a-Service layer, the cloud provider offers the software to control logistics processes. The Platform-as-a-Service layer provides the means to interconnect the IT systems with the real-world logistics objects. Logistics enterprises are thus relieved from concerning the IT infrastructure. Instead, their task reduces to ensuring that the required logistics resources and information are available. Apart from the cloud infrastructure, enterprises thus have to make framework contracts with logistics service providers, e. g., about transport and storage resources. These are then available to the agent representatives of logistics objects in the cloud. For instance, an agent can initiate a transport for a shipping container it represents based on the pre-negotiated framework contract.

The service of the first three layers can even be improved by also providing direct access to logistics resources, i. e., the pre-negotiated framework contracts for logistics resources become superfluous. To this end, the cloud service provider additionally offers an electronic marketplace on which logistics service providers and consumers can negotiate (Smith, 1977) on logistics services:

1. An agent wants to allocate logistics resources for its respective logistics object.
2. Matching logistics service providers are discovered by means of semantic service descriptions.
3. A negotiation between the service consumer agent and the agents of the potential service providers takes place.
4. The best offer is chosen.

This means that also the procurement of logistics services is moved into the cloud. Logistics customers thus get a ready-to-use solution for integrated logistics control. In this business model, it is not necessary to bill customers for the utilisation of cloud resources explicitly. Each transaction in the cloud is directly linked with a transaction of logistics resources. Billing for cloud services can thus be directly coupled with billing for the logistics services. The costs for computing will usually be negligible compared to the negotiated logistics services like transport.

A cloud service provider acting on this level might become what is often referred to as a fourth-party logistics provider, 4PL in short. Fourth-party logistics providers are considered to have no own logistics resources. Instead, they employ sophisticated IT systems in order to integrate services from freight operators and stockists, forwarding agencies, and outsourcing companies in the field of contract logistics.

6 CONCLUSIONS AND OUTLOOK

Logistics control is a promising field of application for cloud computing. Logistics processes exhibit both a high degree of complexity and dynamics. Therefore, a scalable IT infrastructure is required for supply network management. The computational complexity of conventional approaches to logistics planning makes them inapplicable for on-line control. By contrast, the paradigm in agent-based autonomous control in logistics can serve as the Software-as-a-Service layer of logistics clouds. In this approach, decision-making is delegated to agent representatives of the individual logistics objects. For this purpose, the synchronisation of material flows in highly distributed logistics processes and their corresponding data flows in the cloud is another challenge. It can be accomplished with Internet-of-Things technology which is implemented on the Platform-as-a-Service layer.

Providing each of the above services is a business model on its own. Both relieve logistics enterprises from IT-related tasks, thus enabling them to focus on their core business. From their combination, however, emerges another promising business model: fourth-party logistics providers who do not have own logistics resources but combine services of other providers to custom-tailored logistics.

The investigation so far shows that cloud-based autonomous control actually implies promising business models (Section 5). The feasibility of implementing the Platform-as-a-Service (Section 4) and the Software-as-a-Service (Section 3) layer has been shown in this paper. The next step following this feasibility study is thus to actually implement cloud computing for logistics control.

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