Cloud Computing for Autonomous Control in Logistics

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Abstract: Logistics processes in a globalised economy are increasingly complex, dynamic, and distributed. These properties pose major challenges for logistics planning and control. Conventional centralised approaches are frequently limited in their efficiency due to the high number of logistics objects and parameters to be considered. As an alternative, the paradigm of autonomous control in logistics delegates decision-making to the participating logistics objects themselves. This allows for decreasing the computational effort and coping with dynamics locally. Implementing autonomous logistics with intelligent software agents makes logistics control flexible and scalable with respect to transient demands. In order to meet customer demands, however, also the underlying hardware platform must be scalable. To this end, this paper examines cloud computing as a hardware platform abstraction for autonomous logistics. It discusses and compares different approaches how cloud computing can facilitate logistics control with intelligent software agents.

1 Introduction

Logistics plays a significant role as a backbone of the globalised economy. An important foundation has been laid by Malcom Purcell McLean and his later Sea-Land corporation who started employing shipping containers on a large scale in 1956 [Lev06]. The standardised shape of these containers significantly increased the handling efficiency for general cargo. In 2007, more than 65% of the general cargo handled by maritime traffic in Germany were transported by container. In absolute figures, this corresponds to an annual turnover of almost five million TEU handled in 2007 in the ports of Bremen and Bremerhaven. TEU stands for twenty feet equivalent units and is a measure for counting shipping containers. The port of Hamburg handled about ten million TEU in the same time span.

Already the pure figures give an impression of the complexity of the underlying logistics processes. To aggravate the problem, every shipping container has numerous parameters and constraints to be considered when planning and scheduling its way through the logistics network. Example parameters are the current location and destination of the shipping container, the type of the cargo loaded, as well as the scheduled time of arrival. Conventional centralised control is often not applicable due to the computational complexity [Sch10]. This challenge is even aggravated by the dynamics of logistics processes which often cause plans to be outdated in the moment their generation is finished.

The paradigm of autonomous control in logistics (Section 2) addresses these challenges by delegating process control to the participating logistics objects. The computational decomposition achieved by the confinement to relevant parameters reduces the computational effort significantly. Furthermore, reactivity and robustness are increased by coping with the dynamics of logistics processes locally [Sch10]. Therewith, autonomous logistics lays the software foundation for flexibility and scalability of logistics control.

However, the demand for flexibility and scalability with customer demands is not limited to the software layer. By contrast, also the underlying hardware layer must adapt to transient demands. A promising paradigm for this purpose is cloud computing (Section 3). Cloud computing completely abstracts from a specific IT infrastructure. Instead, resources such as CPU, storage, and network bandwidth can be acquired on demand from a service provider. The particular contribution of this paper is an analysis how cloud computing can support flexible autonomous logistics (Section 4). Therefore, its focus is on assets and drawbacks when combining cloud computing with autonomous logistics.

2 Autonomous Control in Logistics

Previous centralised approaches to logistics control are limited in their efficiency because their computational complexity prevents considering a high number of logistics objects and parameters in a reasonable time. As an alternative, the paradigm of autonomous control in logistics [WH07] addresses the challenges regarding complexity and dynamics by decentralising decision-making. 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 [Sch10]. Firstly, the computational effort is significantly reduced by computational decomposition. Secondly, parallelising decision-making makes process control scalable. Finally, local exception handling increases the reactivity and the robustness of autonomously controlled logistics processes.

Delegating the autonomy to make decisions to logistics objects presupposes their ability to make decisions. The technologies enabling autonomous logistics are:

1. Identification
2. Localisation
3. Sensors
4. Communication
5. Data processing

An application of autonomous logistics is the intelligent container [JAL+07] which is itself responsible for planning and scheduling its way through the logistics network. With identification technology, the container can recognise its current cargo. This helps choose the right sensors to monitor the loaded goods. In case of deviations from the expected location or cargo state, the container can adapt its planning. This is achieved by local data processing and coordination with other logistics objects or the cargo owner.

Local data processing is implemented by intelligent software agents [Woo99]. The continuum for deploying these agents ranges between the following extremes:

1. Physically distributed on embedded systems attached to the objects
2. On a central server or server cluster

Deploying software agents on embedded systems is particularly important if sensor measurements have to be interpreted locally in order to decrease the communication effort. However, more complex reasoning might overburden embedded systems. Then, agent representatives that are in whole or in part deployed on a central server or server cluster are preferable. In that case, identification, localisation, and sensor technology must be connected appropriately. Note that, even if the software agents are deployed centrally, the advantage of computational decomposition is still retained [Sch10].

3 Cloud Computing

Cloud computing denotes a paradigm shift in computing which abstracts the underlying IT infrastructure for users. Depending on the degree of abstraction, users do no longer have to consider the hardware and software they employ. Instead, both hardware and software are virtualised and can be acquired on demand from respective service providers. The following layers can be distinguished:

1. Infrastructure as a service
2. Platform as a service
3. Software as a service

Infrastructure as a service refers to a scalable hardware infrastructure. Platform as a service denote a system environment in which own applications can be deployed, thereby integrating services available in the cloud. Software as a service means that the whole software demanded by the user is provided by the cloud service provider.

The advantages of cloud computing over previous approaches are as follows [RR10]. Users can significantly decrease their investments for their own IT infrastructure. In principle, the required infrastructure reduces to thin clients which access the cloud through the Internet. The demanded computational power is then billed based on the actual utilisation. In conventional IT infrastructures, the in-house IT must be capable of handling the maximally expected load. As an example, consider an internet-based mail order business which needs significantly more bandwidth for its Christmas sales than in the rest of the year. As a consequence, this means that CPUs are underutilised most of the time. The particular advantage of cloud computing is that CPU, storage, and network bandwidth can be allocated dynamically. Apart from pure costs, increasing the degree of utilisation by sharing resources with other users is thus also preferable from the ecological perspective. Finally, also the reliability of services can be increased because the virtualisation eases distributing computing to redundant sites.

4 Cloud-Based Autonomous Logistics

Cloud computing allows scaling autonomous logistics applications flexibly based on the dynamically arising logistics demands. 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. As for cloud computing in general, different types of cloud computing for autonomous logistics can be distinguished.

Infrastructure as a Service. Autonomous logistics clouds on this layer directly correspond to general clouds. Users acquire a scalable hardware platform from the cloud service provider in order to install their own autonomous logistics implementation. Hardware administration is delegated to the service provider.

Platform as a Service. On the platform as a service layer, autonomous logistics clouds additionally provide a software framework that provides already fundamental services. These services may include a multiagent platform such as JADE [BCG07] as well as means for multiagent-based simulation such as PlaSMA [SGW08]. This eases the deployment of agent representatives and additionally delegates administration of the software platform to the service provider.

Software as a Service. The software as a service layer provides a complete implementation of software agents for autonomous control in logistics [Sch10]. While even the administration of software agents is left to the service provider, the user only has to deliver relevant process information.

Process as a Service. This layer is unique to autonomous logistics clouds. It does not only provide a software implementation for autonomous logistics but also provides a platform that integrates logistics service providers that actually execute the services demanded. This means that a cloud service provider acting on this level might become what is often referred to as a fourth-party logistics provider, 4PL in short.

An important prerequisite for autonomous logistics based on cloud computing is the integration into existing logistics infrastructures. Firstly, it is important to synchronise real-world material flows and data flows in the cloud. This mapping can be accomplished based on Internet of Things technology like the identification standards of the EPCglobal Framework Architecture [HHT09]. ID@URI using the Dialog system [FARKH06] is an alternative that combines unique article identifiers with Internet addresses where additional information about the article can be retrieved. Secondly, it is necessary to integrate data from various sources in a semantically meaningful manner. To this end, semantic mediators can be applied [HKHT10]. The particular advantage of platform, software, and process as a service is that the required synchronisation and integration can be accomplished transparently by the cloud service provider. That is, the user is not burdened with these issues as he or she would be in an in-house IT setting.

The billing for resources utilised from the autonomous logistics cloud depends on the layer of cloud computing chosen. If only infrastructure is provided, billing depends on the computational power, storage, and network bandwidth consumed as in general clouds. On the next two layers, the extent to which software or software components are utilised determines the price. On the process as a service layer, it is no longer necessary to charge computational power or software utilisation. Instead, each negotiation results in an execution of logistics services in the real world. Hence, it is possible to charge cloud services implicitly with the respective logistics services.

A potential drawback of autonomous logistics clouds is that the user has less influence on the IT and logistics infrastructure. In order to ensure reliable services, it is thus necessary to choose cloud service providers carefully and to contract the quality of service demanded. Besides, deploying autonomous logistics clouds might cause problems of connectivity. Depending on factors such as their position or current environment, local computing resources such as sensors, human-computer interfaces, and other systems embedded into mobile logistics objects might periodically either have network access without sufficient bandwidth or even none at all. Consequently, mechanisms are required which cater flexibly for the quality of service and off-line operational capability required dependent on application and process. Finally, security is an important aspect as data is no longer processed in-house. This issue, however, has to be addressed anyway because data in autonomous logistics may even be processed on embedded systems [WSD07]. Indeed, a market survey by Fraunhofer IML comes to the conclusion that 64% of the 70 logistics executives interviewed can imagine employing cloud computing already today [Fra10].

5 Conclusion and Outlook

Cloud computing is a promising approach in order to implement autonomous control in logistics. Clouds provide a scalable IT infrastructure on which autonomous logistics solutions with intelligent software agents can be deployed. The cloud services may range from a scalable hardware platform to complete process control by the cloud service provider. In the latter case, the cloud service provider may turn into a fourth-party logistics provider. The advantages of autonomous logistics clouds are that users no longer need to invest in own IT infrastructures. Instead, they can flexibly acquire the infrastructure demanded. Potential drawbacks to be considered are less influence as well as data security on the distributed platform.

This paper has identified the potential of cloud computing to facilitate autonomous control in logistics. The next step is an actual implementation of cloud services on the layers presented in this paper.

Acknowledgement

This research is funded by the German Research Foundation (DFG) within the Collaborative Research Centre 637 "Autonomous Cooperating Logistic Processes: A Paradigm Shift and its Limitations" (SFB 637) at the University of Bremen, Germany.

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