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Khorramshahr: A scalable peer to peer architecture for port warehouse management system

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ABSTRACT

In the growing trend of globalization, the logistics and transportation play the key role in many industries. Products are shipped from one country to another. The heart of this transportation is the port, where large quantities of goods are imported and exported on daily bases. Applying Internet of Things (IoT) technologies to port warehouses is the main area of this work. Centralized warehouse management systems are prone to a single point of failure problem and are not fault tolerant. They have also limited scalability. Another issue is that the port warehouses may run by different companies and the privacy of the detailed product information must be preserved. In this paper, we design an IoT based architecture for warehouse management, according to the facts gathered from the Khorramshahr port. The main issues that this paper tries to address are: scalability, fault tolerance, and privacy. The devised architecture is named *Khorramshahr* (named after the name of the port). The tailored version of Chord architecture is exploited for a Distributed Hash Table (DHT), which inherits the required scalability and fault tolerance. According to the devised architecture, each company can solely manage its dedicated nodes and preserve the privacy. To boost the lookup process the design is enhanced by Bloom filter and Quotient filter. Moreover, to gain performance the architecture uses a hybrid approach, which combines both the client server and the peer to peer paradigms. To evaluate the performance, the DHT of the architecture is simulated by OMNet++ and OverSim. The simulation results show that by the scaling the number of terminals from 25 to 250 the access time for an item increases only 38%. Besides, the increase in the number of requests from 10,000 to 50,000 depicts 5% and 10% improvement respectively for the lookup message latency compared to the ODSA. The simulation results also exhibit lower false positive rate for the Quotient filter approach, which makes it the first implementation candidate. Only in cases with strict constraints on memory consumption the Bloom filter approach is favored.

1. Introduction

The Internet of Things (IoT) can be seen as a three dimensional environment, in which industry is an important axis, while smart city and smart home are the other two. Ports are the key gateways to import/export industrial products in many countries. Usually, these ports have numerous warehouses. The enhancement of these warehouses with IoT technologies will help to improve the overall performance and cutting their operation costs.

The management of products in huge warehouses is a complex problem. Usually, ports have several large warehouses and a variety of products. These warehouses may be handled by different companies. Basically, the intake volume of products to the ports is high and it is not always possible to depot them in special warehouses. As a result, similar products may store in different warehouses, which makes the process of product search complicated. Another problem arises in the accounting process when a product moves from one warehouse to another. The stock checking, which is usually done by the end of each year, is a time consuming task and requires considerable effort to be spent by numerous officers. The products may spoil, decay or expire, while they are stored. Therefore, they need to be monitored and checked before exiting the port.

The issues are not restricted to the warehouses of ports. Some of the other candidate places, which may face the aforementioned problems are shipping industries, car manufacturing companies, customs, and oil refineries. In shipping and car manufacturing industries, many different parts are needed to be assembled to make the final product, which should be maintained in different warehouses. In custom a lot of

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different products require the license of entering or exiting. In the oil refinery industry these problems appear, since they need so many different products to be produced and also exploitation and/or oil diggings tasks require variety of special tools and equipment.

One of the enhancements in warehouse management systems is the invention of Electronic Product Code (EPC). It is a unique identifier assigned to physical objects worldwide. A joint venture called *EPCglobal* is organized to support the adaptation of the EPC standard (Johnson et al., Müller et al., 2010; Musa et al., 2014). The code can be stored in Radio Frequency IDentification (RFID) tags attached to the physical objects. The tag has a limited embedded memory which is enough to store the code. The stored data can be scanned by specific devices called *RFID readers*. Moreover, a standard for sharing the data across business partners are developed by the EPCglobal called *EPC Information Services* (EPCIS). Eventually, a computer network (EPCglobal network) of readers and RFID tags are to be established between trading partners.

The centralized approaches for storing and retrieving of product information face difficulties in cases where a various range of products with high number of in/out transaction must be performed in a timely manner. There is a chance that the central part of the system becomes a bottleneck. It is also prone to single point of failure. In the meantime, if a connection problem appears, the whole operations are suspended. Most importantly, since the warehouses are handled by different companies, possibly for geographical distances or different required specialties, the privacy of product information might be violated. Generally, the product information can be divided into private and public sections. It is preferred not to locate the whole information on a centralized system in cases where many competitive companies may have access to them.

One of the possible solutions to mitigate the centralized approach is to use a distributed system, in which different companies could manage their own information, and also provide a mechanism to exchange the public section of product information through network among themselves. The distributed approach removes the single point of failure problem and preserves the confidential information from being accessed by unauthorized parties.

Several outstanding researches are conducted for distributed inventory management in recent years. In general, these researches can be classified in three groups. In the first group (Amaral et al., 2011; Schmidt et al., 2011) the main focus is on a transparent and scalable information service middleware architecture. The middleware is placed between the application layer and RFID readers according to the EPCglobal architecture. The purpose is to filter the received data from the readers and send them to the application layer.

The second category of researches (Khair et al., 2013; Manzanares-Lopez et al., 2011; Xu et al., 2013) provides a solution for distributed discovery service and Object Name Services (ONS) in EPCglobal architecture. The suggested discovery services are designed to facilitate access and information exchange between intra-organizational entities. Moreover, they provide mechanisms to connect different EPCglobal networks to the Internet in order to call on every product. One of the goals is to provide efficiency in distributed discovery services to supply chain management systems, since every EPC could enter a chain in a parallel manner and reduce loading delay.

The third category of works (Furdik et al., 2016; Kürschner et al., 2008; Huang et al., 2007; Fabian et al., 2012) deals with the problem of fault tolerance and confidentiality in discovery services. The main goal is to devise secure mechanisms for every stage of discovery services.

In this paper, we introduce a new architecture called *Khorramshahr*,[1] which tries to address challenges such as the geographical scalability of warehouses, relative autonomy in managing the data and preserving the confidential information. Finally, the resource efficiency in product lookup access time are other issues we try to address.

The main features of the architecture are as follows:

- Khorramshahr uses a Peer to Peer (P2P) architectural style which makes it scalable in the number of transactions, number of warehouses and the geographical distribution.
- The double Chord approach on both DHTs (product types and product information) is used, to facilitate users from inside or outside of the port to access the required information from different warehouses.
- Memory efficient data structures such as Bloom filter and Quotient filter are utilized to reduce the response time and memory usage. Chord based DHT is implemented with both the filters and the performances are analyzed.
- To increase the efficiency of the system in looking up product types in ONS which is usually invariant, a client server architectural style with replicated data repository is used. Therefore, Khorramshahr is a hybrid architecture, which uses both P2P and client server styles in different sections.
- A distributed discovery service is designed to support access to the product catalogs, stock and property checking.
- Each node of the DHT is managed by a single company, which facilitates the privacy preservation of the confidential information.

To evaluate the performance of the proposed architecture, the DHT part is simulated using OverSim and the achieved results are compared to the works presented in Manzanares-Lopez et al. (2011) and Xu et al. (2013).

The rest of the article consists of the following sections. In Section 2 related researches are reviewed. Preliminaries of the used filters are provided in Section 4 and in the next section the problem statement is introduced. The devised architecture is described in detail, including the structural, behavioral and installation views in Section 5. The simulation results and evaluations are expressed in Section 6, and finally Section 7 concludes the paper.

2. Related work

The similar researches can be categorized in three classes of middleware for information service, discovery services in EPCglobal network, and privacy in discovery service. Some of the well-known works in each class are briefly reviewed.

2.1. Middleware for information service

Authors in Amaral et al. (2011) present a mobile software architecture framework to pervasive RFID based applications that follows EPCglobal standard. The architecture follows a modular view that facilitates the development process of RFID applications. The main parts of the architecture are middleware and WindIS which present RFID middleware and the information service respectively. The middleware is responsible for (i) data dissemination, (ii) data filtering and aggregation, (iii) reading and writing tag capabilities, and (iv) data interpretation. This layer is connected to physical devices from one end, and from the other end exchanges data with event module. The WindIS implements the EPCIS standard by providing EPC enabled systems with XML data. The eWindIS layer is a combined information service, which is comprised of three main modules, namely local database, searching, and capture. The goal of eWindIS is to work with mobile equipment that could receive information and take an immediate decision everywhere.

The work presented in Schmidt et al. (2011) concentrates on providing a distributed Application Level Event (ALE) engine for RFID middleware. It considers several warehouses, facilitated with

[1] The architecture is named after Khorramshahr Port, which is the financial supporter of this research.