P2P Networks in Ubiquitous Computing Environments to Support the Integration of Context Information into Product Lifecycle Management Systems

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Abstract: This paper aims to demonstrate how peer-to-peer networks can be used to support the integration of context information into product lifecycle management approaches in ubiquitous computing environments. In today's world of computing, the vision of Ubiquitous Computing is becoming a reality. Besides the ready availability of broadband internet access and personal computing, mobile and embedded computing devices are increasingly part of everyday environments and networking and computing capabilities already integrated into numerous consumer products. Furthermore, auto-identification technologies such as RFID allow even simple products to be uniquely identified anywhere in the world. The exploitation of these technologies allows the management of information for individual products. The integration of field data and context information into such Item-specific Product Lifecycle Management approaches is becoming increasingly important for the provision of value-added product extension services. This paper aims to describe a concept by means of which context information regarding individual, uniquely identified products can be stored and accessed in a ubiquitous computing environment on the basis of peer-to-peer networking without the necessity for integrating sensors or embedded systems into the product itself.

Keywords: Future Ubiquitous Environments, Sensor Networks, Peer-to-peer, Product Lifecycle Management, Applications.

1. Introduction

As enterprises find themselves confronted with increasingly global and dynamic markets, pressure is steadily building for Europe to reshape both its economy and society to meet the challenges of the 21st Century with respect to competitiveness, productivity, reliability and sustainability.

To face these challenges, a significant readjustment of traditional product development strategies is required to encompass new and innovative approaches of generating added value [1].

In recent years, research has been applied to the development of approaches for product development strategies capable of meeting the challenges outlined above. In this context, product information management on the level of the individual product (instance-specific product information management) can be perceived as a major driver of one such approach, specifically that of Extended Products.

The objective of the Extended Product concept is, according to [2], to offer the customer a utility package instead of merely offering him a single product. The extension of products by services "can be considered as an opportunity to differentiate one's products from those of competitors' in order to enhance competitiveness." Thoben, Eschenbächer and Jagdev differentiate such extensions based on the tangible aspects of a product and the intangible product extensions based on integrated services offered together with the products. The cohesion between the product, associated services and the product life cycle represents the scope of the term Extended Product. With regards to addressing the challenges described above, Thoben, Eschenbächer and Jagdev contend that “precisely extended products can even help to define or identify new customer needs. Servicing the customer means also to support the customer in deriving new business ideas. Consequently suppliers of products have to extend their offerings in a dramatic way. Customers may not be interested in buying products; they may very well be satisfied to obtain an added value. For this reason suppliers have to offer everything which might support the customer in achieving these benefits.”

For the above approach to be optimally leveraged for generating added value, a significant amount of information regarding individual products must be made seamlessly accessible. In the concept of Extended Products, the value of the product for the customer is dependant on the perceived usefulness and quality of the services which encompass the product extensions. Often, product extensions are directly related to the customers’ use of the product. This is the case, for example, with extension services such as maintenance or refills. The quality and usefulness of such services is heavily dependant on the service provider’s knowledge of the product’s status and the customer’s use of that product. A proactive, timely service is perceived by the customer as more valuable, due to the fact that less effort is required to receive service and product down times are avoided, which can be measured in the time and money saved by the customer. As such, proactive service provision is dependant on the transmission of suitable information about the status and usage of a product from the product to the service provider. A mechanism providing an automated acquisition and management of such information near to real-time is necessary.

One applicable field is to monitor status information of single product items in the Product Lifecycle of electronic products, e.g. to ensure safe and efficient recycling after its reconfiguration.

Another area in which it is important to monitor status information of product items is the fresh food supply chain from the point of origin to the final customer, which will be further considered in the EU funded project EURIDICE.

In the field of Mobile and Ubiquitous Computing, according to [3], *context awareness* is defined as the capability of the networking applications to be aware of the existence and characteristics of the user's activities and environments. The aim of context awareness is to allow systems to adapt their behaviour based on the current conditions and the dynamicity of the environment they are immersed in. In order to function according to a user's expectation, these systems have to consider the situation, activity, and state of the user and all other relevant entities. [3] defines the information related to these attributes as *context* information.

2. Objectives

The objective of the research described in this paper is to develop a concept by which context information regarding individual, uniquely identified products can be stored and accessed by PLM systems on the basis of peer-to-peer networking technology.

In order to derive a methodological approach to achieving that aim, the overall objective can be broken down into a number of sub-objectives, as follows: First of all, to develop a prototypical demonstrator as a proof-of-concept that peer-to-peer networking is a feasible technology for the highly distributed management of context data linked to uniquely identified products. Secondly, highlight the strengths and weaknesses of peer-to-peer as the underlying technology of such information management. And finally, to provide a point of departure from which to analyse the types of business cases which can be supported by this technology.

3. State-of-the-Art

3.1 The Product Lifecycle

According to [4], the product lifecycle can be split into three distinct phases as shown in Figure 1 below – the begin of life phase (BOL), encompassing the processes from initial market research and idea generation to sales and distribution, the middle of life phase (MOL), consisting of the process from deployment via operation and maintenance until the third and final phase, end of life (EOL) in which processes dealing with the decommissioning and eventual refurbishment, reuse or recycling are to be found. In most cases, such a product lifecycle represents a dynamic cooperation across organisational borders, with a number of different, and often entirely unrelated, organisations responsible for different steps in the product lifecycle. For example, maintenance may be carried out by a company with no formal relation to the Original Equipment Manufacturer (OEM).

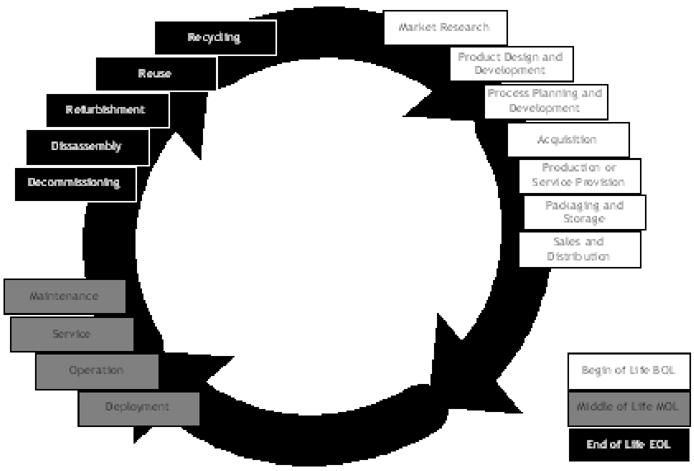

Figure 1: The Product Lifecycle

3.2 Item-specific Product Lifecycle Management

A number of different approaches for the management of item-specific product information are currently being developed under the umbrella of Product Lifecycle Management (PLM). PLM is commonly understood as a concept which *"...seeks to extend the reach of PDM (Product Data Management) beyond design and manufacturing into other areas like marketing, sale and after sale service, and at the same time addresses all the stakeholders of the product throughout its lifecycle."* [5] Contrary to this common understanding, PLM systems are as of today often not adequate solutions for the management of product item-specific information after a product enters its usage phase, because the general conditions of information management tasks are fundamentally different to the prior lifecycle phase.

During the conception of a product in the BOL phase, the number of partners involved in product data management is restricted to only a few and the main stakeholders are either members of a single organisation or tightly integrated into an information system of the coordinating organisation. The product(s) are in the sphere of responsibility of the manufacturer and physical access is granted mostly though the manufacturer. Information models and management systems to be used in this context can be specified on the basis of a restricted set of well known tasks and objectives mostly given by the manufacturer as the coordinator of the PLM-network.

On the product's entering the usage phase the situation fundamentally changes. The first and foremost change is that the number of product stakeholders continuously increases throughout the life span of the product. Simultaneously, the clear objectives of the underlying product data management concept from the BOL phase are lost along with the retirement of the manufacturer as the lead partner in the PLM-network. Moreover, during BOL the term "product" refers to a product design and its variants. Contrary to the term which is used during MOL and EOL the usage of this term doesn't necessarily include the physical product items.

Due to the disparate requirements in information management needs between the different lifecycle phases, present approaches conceived solely for product data management in the BOL phase cannot readily be applied to item-specific product information management.

3.3 EPCIS

As shown by [8], RFID in combination with the Electronic Product Code (EPC) and especially the event standard specified in Electronic Product Code Information Services (EPCIS) can be utilised to provide support for item-specific product information management. In such an approach, each of the component parts is assigned a unique identifier (such as an EPC), which, stored on an RFID chip applied to each item, can be used to track and trace the product components throughout their lifecycle. EPCIS is a specification for a standard interface for accessing EPC-related information. On its basis, each individual object can be tracked independently and real-time information about each of them can be collected, stored and acted upon. By providing a standard interface to that information, EPCIS enables cooperation partners to seamlessly query such information throughout both the supply chain and the product lifecycle. Although EPCIS events can be appropriated to support such an application, they remain a specialised standard for capturing logistics events at item level. Whilst EPCIS provides a mechanism for the extension of the event model through user-defined vocabularies [6], they do not provide explicit support for life-cycle-encompassing product information management nor do the pre-defined types specifically represent product life-cycle events.

3.4 Peer-to-Peer Networks

Peer-to-peer (P2P) networks are a form of communication and structure in computer networking. In a true P2P network, all nodes are equal. However, P2P is a highly flexible term and also describes network architectures with a central server. A third form called hybrid P2P networks combine both approaches, using specific nodes for indexing or managing peers.

One of the main advantages of completely decentralised P2P networks is that there is no single point of failure. No single network node is irreplaceable and thus, a completely decentralised P2P network is inherently highly robust.

Essentially, P2P networks are a special case of the client-server architecture, in which each node simultaneously represents both a client and a server. A P2P network is furthermore generally an overlay network, due to the fact that any given P2P system is usually independent of the concrete underlying transport protocol. The creation and management of such overlay networks is seen by [9] to be the primary contribution of P2P systems.

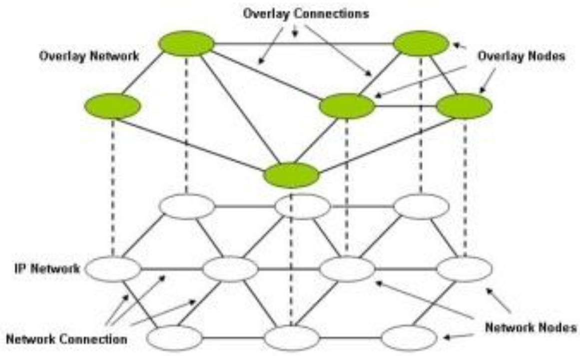

Figure 2: Overlay network on an IP network

Every peer p is identified through an address in an address space $p \in P$ and is at least a member of one group G. Every peer group administrates a part of the entire resources $R(p) \subseteq R$. Each resource $r \in R(p)$ is identified by a key $k \in K$. The location of a resource means that, starting from any peer p', the peer p has to be found, which is responsible for a certain key $k \in K(p)$. It is the administration of the binary relation $I = \{(p,k) \mid k \in K(p)\} \subseteq K \times P$, where each peer only manages a subset of all resources $I(p) \subseteq I$. In most cases a peer is not able to answer directly and it sends the request to its neighbours $N(p')$. Which of its neighbours it chooses depends on the specific algorithm.

At least two essential protocols in P2P networks are needed, so that peers can exchange resources. The first is the network protocol that must contain at least two messages, a join and a leave. To join a P2P network, a peer p must know at least one peer $p' \in (N)$, which is already a member of the network. p sends a join message to $p' \in (N)$ $p \rightarrow (join) p' \in (N)$. Depending on the concrete implementation, further messages will be triggered, to reorganize the adjacencies and information about indices. In the case that p was already a member in other networks or groups it is be possible, under certain conditions, to connect networks or groups together. The second essential protocol is the resource managing protocol. It enables the search $p \rightarrow search(k)$, insert $p \rightarrow insert(k,r)$ or delete $p \rightarrow delete(k)$ data or resources. These two protocols are the substructure of P2P networks

P2P networks are used for sharing computing resources such as CPU time, memory or contents. P2P technology allows devices on a network to talk with each on an equal basis. It's about making resources, like documents, source code, or even an actual computing device itself available across a network. Again, the inherent robustness of P2P proves highly attractive in the context of these applications. However, in performance-critical applications this also means that complex replication mechanisms need to be implemented. [9] introduces a number of properties which an optimal P2P network should fulfil, such as decentralisation, self-organisation, autonomous control, reliability, and availability. However, very few P2P implementations actually exhibit all of these characteristics.

For the purpose of this research, the authors chose not to investigate fundamental aspects of P2P but to analyse the general feasibility of employing P2P as a basis for context information management on the basis of a ready-to-use technology. Consequently, they decided to select a standard P2P technology platform, JXTA (Juxtapose), as the basis of their prototypical implementation. JXTA is an open P2P protocol specification introduced by Sun Microsystems with the goal to standardize P2P applications. According to [7], it as a set of open, generalized P2P protocols that allows any networked device, such as sensors, cell phones, PDAs, PCs, and servers to communicate and collaborate. On that basis, Project JXTA is an open source effort which actively involves the developer community.

The JXTA reference implementations available in Java and C++ provide the basic building blocks and services to enable anything anywhere application connectivity. The reference implementation offers the resources to develop collaboration, resource and service sharing and communication, to name but a few possible applications. The protocols are defined as a set of XML messages. That makes them independent of programming language and transport protocols; they can be implemented on top of TCP/IP, HTTP, Bluetooth, etc. to maintain global interoperability. The communication is realized through the exchange of messages via pipes or sockets. Messages are a container for data content and protocol information.

Every networked device can be a peer in a JXTA P2P network. Each peer could be implemented in a different programming language depending on its platform, as long as it is abide by the specification. So it is possible to link heterogeneous peers together in one P2P network.

4. Methodology

To achieve the research objective of developing a concept by which context information regarding individual, uniquely identified products can be stored and accessed by PLM systems on the basis of P2P networking technology, the following methodology was employed.

Lifecycle Phase	Business Location	UbiComp Node
Begin of Life	Warehouse	Incoming Goods
	Warehouse	Shelf / Inventory
	Warehouse	Forklift Truck
	Warehouse	Outgoing Goods
	Production	Assembly
	Packaging	Packaging
	Dispatcher	Deployment
	Sales	Delivery
	Sales	Shelf
	Sales	Cashier
Middle of Life	Usage	Personal Computer
	Maintenance	Field Personnel
	Maintenance	Incoming Goods
	Maintenance	Storage
	Maintenance	Repairs
	Maintenance	Outgoing Goods
End of Life	Recycling	Incoming Goods
	Recycling	Sorting
	Recycling	Normal Storage
	Recycling	Monitored Storage
	Recycling	Recycling
	Recycling	Outgoing Goods
	Recycling	Forklift Truck

Table 1: Ubiquitous Computing Nodes along the Product Lifecycle

First of all, a suitable exemplary product was chosen as the basis of a product lifecycle management scenario for which to develop the concept. In this research, a computer monitor was chosen. The lifecycle of the computer monitor was then modelled and analysed. The modelling of the product lifecycle was carried out on the basis of prior research into the application of EPC to the product lifecycle of electronics products carried out by the authors in a student project as documented in [10], complemented with significant additional knowledge gained from research work in the EU-funded IP PROMISE.[1] Use cases were developed for the scenario using UML 2.0.

After the scenario modelling and requirements analysis, the individual steps of the product lifecycle were mapped to EPCIS events signifying required points of interaction of

[1] PROduct Lifecycle Management and Information Tracking Using Smart Embedded Systems

the monitor with nodes in the ubiquitous computing environment. The lifecycle phases, business locations and ubiquitous computing nodes are listed in Table 1 above. For the purpose of this research, a number of the nodes needed to be simulated for the evaluation of the demonstrator. On the basis of the mapping of the product lifecycle to EPCIS events, an initial system definition followed by a detailed specification of a suitable prototype demonstrator was then carried out. Section 5 Developments presents the prototype demonstrator in more detail.

Finally, the performance of the prototype demonstrator with respect to the exemplary scenario was evaluated. The results of the evaluation are presented in this paper in Section 6 Results.

5. Developments

A prototypical demonstrator was implemented to verify the thesis that P2P is a suitable technology for the access to and exchange of context information for Item-Specific Product Lifecycle Management in ubiquitous computing environments.

It consists of three distinct components. The first component is responsible for detecting the presence of RFID-tagged products in the ubiquitous environment as well as generating and storing the respective context information in a standard format. This is the sensor node simulator.

The second and most critical component of the demonstrator is the peer node. This is the actual P2P network component which facilitates the networking of all nodes as well as searching and transferring the context information stored on the individual nodes.

The third and final component of the demonstrator simulates an Item Specific Product Lifecycle Management system. This small application is capable of visualising, in real time, the results of a search over the P2P network of the context information stored in the EPCIS events distributed across the nodes. The following sections show in more detail the individual components.

The implemented network is a true P2P network, in which all nodes are equal. No instance exists to manage indices, requests or responses.

5.1 Sensor Node Simulator

A simple application was implemented which simulates a sensor node within a ubiquitous computing environment. Here, two sensors are simulated – one temperature and one humidity sensor. The operator can set the average for the measurements of both of the sensors as well as a variation margin and the frequency of senor data generation.

The sensor node simulator is connected to an RFID reader which, if within reading distance of an RFID, records the EPC of the detected RFID along with the current simulated sensor values. It then generates a standard-compliant EPCIS Event containing the context information and stores it as an XML file according to the EPCIS Event bindings.

5.2 Peer Node

Each of these peer nodes is equally capable of storing and accessing EPCIS events uniquely mapped to products identified by EPC throughout the P2P network.

The operator may select, from the drop-down menu or enter, an EPC in the network to retrieve context information for. The peer will then submit a search for events mapped to the EPC to the P2P network. The results are sent back to the querying peer as EPCIS events in an XML binding. By clicking “create chart”, the operator can execute the context data visualisation component as shown in the following section for a graphical representation of the context information being gathered in the course of the query.

5.3 Context Data Visualisation

Figure 3 shows the visualisation of context data for a specific EPC. The results are displayed in real time, as search results come back from the P2P network. This prototype component simulates the actual item-specific PLM application.

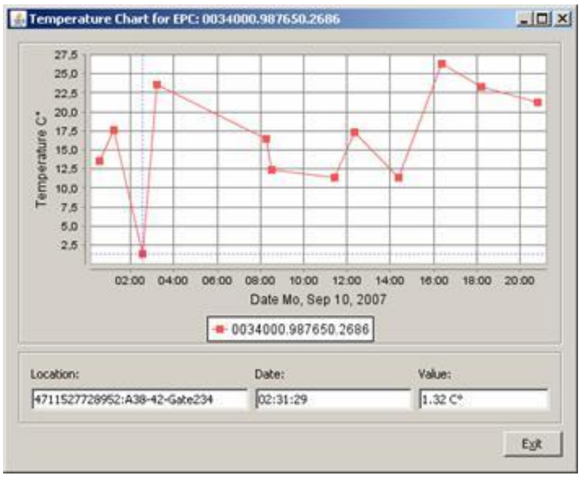

Figure 3: Visualisation of Acquired Context Data

By showing EPCIS events can be readily received from distributed points in the P2P network, it successfully demonstrates the possibility for any PLM system capable of parsing EPCIS events to integrate the context data into its product information.

6. Results and Conclusions

The results of testing the prototype demonstrator against the requirements generated from the analysis of the exemplary product's lifecycle proved to be positive. The JXTA-based P2P network succeeded in reliably providing access to context information mapped to EPC and stored across distributed sensor nodes.

Generally there is a demand for tracking and tracing goods or cargo items and retrieving their status information. This could be reached through the consistent use of RFID technology and EPCIS in conjunction with the P2P solution.

This is particularly important in the food sector, where, for example, monitoring is required to guarantee the cooling chain remains unbroken. Moreover, the entire life cycle of the food products could be monitored by the consistent employment of RFID in connection with the EPCIS. The EU-funded Integrated Project EURIDICE will further analyse the application of the results of this paper in this use case [13].

Within the scope of the research presented here, the evaluation of the prototype demonstrator showed that P2P networking is a suitable technology for the integration of context information into product lifecycle management systems. By using the developed prototype P2P system, it is feasible that highly distributed context information can easily be integrated into item-specific Product Lifecycle Management systems by equipping the nodes and the system itself with P2P nodes. System queries for context information regarding specific products can then, for example, be redirected to the P2P network on demand or simply scheduled and integrated into the system's local storage. The semantic and syntactic integration of the data is unproblematic due to the use of the standard EPCIS Event notation.

However, the evaluation results highlight a number of challenges that need to be addressed in future research.

For one, despite the reliability and robustness of the system – that is, it's demonstrated imperviousness to the temporary loss of connectivity to individual nodes – a major issue can be identified as the non-deterministic behaviour with respect to the time it takes to receive results. The time between sending a query for a specific EPC and the receipt of results proved to be extremely variable, even in tests with severely limited amounts of participating nodes. Without further work in this area, the prototype system cannot be recommended for use in time-critical operations.

A second issue demanding further research work is that of data replication. Whilst the prototype successfully demonstrated the system's robustness in the case of temporary loss of connectivity to individual nodes, the permanent loss of such a node means the loss of access to any data stored there which had not been previously queried. This issue is a fundamental research topic in the field of P2P and can be addressed by the implementation of a suitable replication algorithm such as the distributed hash tables used in systems such as Chord or CAN as described by [11]. Here, further research is required to determine which algorithms are suitable for the problem at hand.

Last but not least, research needs to be conducted into realms beyond the purely technical. This is especially critical with respect to both Intellectual Property and Data Protection Rights regarding the context information being generated and transmitted in such a system. Here, questions as to the ownership of context information and usage rights thereof need to be answered before industrial exploitation of such a system can go forward.

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