CaPLIM: The Next Generation of Product Lifecycle Information Management?

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Abstract: Product Lifecycle Information Management (PLIM) aims to enable all participants and decision-makers to have a clear, shared understanding of the product lifecycle, and to get feedback on product use conditions. Each product, whether as a physical or virtual product is designed to provide a range of services aimed at supporting daily activities of each product stakeholder (e.g., designers, manufacturers, distributors, users, repairers, or still recyclers). Such services are usually considered once, where parameters are fine-tuned once and for all. A future generation of services could attempt to self-adapt to the product context by discovering and exchanging helpful information with other devices and systems within its direct or indirect surrounding. The so-called Internet of Things (IoT) is a tremendous opportunity to support the development of such a new generation of services by taking advantage of powerful concepts such as *context-awareness*. Embedding context-awareness into the product is a possible solution to learn about the product's context and to make appropriate decisions. However, today, this is not enough because of the large number of objects, systems, networks, and users comprising the IoT that require, more than ever before, standardized ways and interfaces to exchange all kinds of information between all kinds of devices. In an IoT context, this paper opens up new research directions for providing a new generation of PLIM services by investigating *context-awareness*. The combination of these two visions is referred to as CaPLIM (**C**ontext-**a**wareness & **PLIM**), whose originality lies in the fact that it takes maximum advantage of IoT standards, and particularly of the recent Quantum Lifecycle Management (QLM) standard proposal.

1 INTRODUCTION

Since 1960's, the concept of Product Life Cycle (PLC) was used in different areas such as in product management, marketing mix, linking production processes and pricing (Utterback and Abernathy, 1975). Today, the study of the PLC is an integral part of the company strategy to plan, design and manage the whole life of their products more effectively (Asiedu and Gu, 1998). From the $1990's$ onwards, many new information systems have been brought to market, giving the opportunity to work more efficiently internally and externally, for instance by getting closer to customers, suppliers and partners (Rockart and Short, 2012). With the arrival of these new systems and applications, the concept of Product Lifecycle Management (PLM) was born to manage the entire product's life, from Beginning of Life (BoL) including design, production and distribution of the product, through Middle of Life (MoL) including use and maintenance, up to End of Life (EoL) including recycling and disposal. Lee et al. (Lee et al., 2008) explain that PLM originated from two types of management: enterprise management and product information management. Enterprise management involves material and enterprise resource planning (MRP & ERP), customer relationship management (CRM) and supply chain management (SCM). Product information management involves Computer-Aided Design/Manufacturing (CAD/CAM), Computer Aided Process Planning (CAPP) and Product Data Management (PDM). PLM evolved rapidly and now aims to integrate people, data, products, processes, organizations, equipments, and methods throughout the PLC (Stark, 2011).

To date, many solutions, concepts, standards have emerged and have been integrated into PLM systems in order to achieve, among others, Product Lifecycle Information Management (PLIM). PLIM can be defined as a subpart of PLM since it essentially fo-

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cuses on the product data aspect, while PLM deals with all elements involved in a PLC (not only product data but also people, facilities, workflows...). PLIM is commonly understood as a strategic approach that incorporates the management of data associated with products of a particular type, and perhaps the versions and variants of that product type. PLIM was first mentioned by Harrison et al. in a manufacturing context (Harrison et al., 2004), where product-related data was linked to the product itself via RFID technologies. Later, the same authors (Harrison, 2011) explained that PLIM could be interpreted as a certain extent of the so-called Internet of Things (IoT) since the IoT also relies on automatic capture of observations of physical objects at various locations and times, their movements between locations, data collected from sensors attached to the objects or within their immediate surroundings. The advent of the IoT and related concepts such as *context-awareness* provides tremendous opportunities to propose more advanced services to all product stakeholders (e.g., services able to self-adapt to the product and user contexts). Embedding context-awareness into the product is, indeed, a possible solution to learn about the product's context and to make appropriate decisions. However, today, this is not enough because of the large number of objects, technologies, and users comprising the IoT, which require standardized ways and interfaces to exchange all kinds of information between all kinds of devices. In lack of standardized approaches and protocols, it is difficult to access the right information, whenever needed, wherever needed, by whoever needs it, which is a major hurdle to efficient context-aware systems (Perera et al., 2013). This research initiative aims at investigating a new generation of PLIM services that takes advantage of both *context-aware* systems and *standardized* communication interfaces defined by IoT standards. These new types of systems will play an accelerating role to help companies to deal with complex, changing product environments and to meet the new organizational and customer needs.

Section 2 provides the necessary background on PLIM and context-awareness to better understand the ongoing relevance of the CaPLIM research initiative. The IoT standard used to support CaPLIM developments are briefly introduced in section 3. Section 4 opens up new research directions considering CaPLIM and provides preliminary thinking about the research objectives and contributions. Section 5 presents a few examples of IoT applications with various actors, within which it could be benefit to use CaPLIM services to improve various aspects of product information management.

2 BACKGROUND

PLIM deals with various information aspects and challenges that are introduced in section 2.1. Section 2.2 provides the necessary research background on context-awareness in order to better understand the ongoing relevance of the CaPLIM research initiative.

2.1 PLIM Background

PLIM aims to enable all product stakeholders and decision-makers to have a clear, shared understanding of the product's life. As mentioned, PLIM is understood to be a strategic approach that incorporates the management of data associated with products (Främling et al., 2013). These product definition data are generated when the product is first conceived, and it then continues to evolve with the addition of detailed specifications, user manuals, computer-aided design drawings, manufacturing instructions, service manuals, disposal and recycling instructions. In traditional PLIM, the product information generation process seems to end after BoL. When the product enters actual use (i.e., MoL), PLIM mainly signifies providing access to the existing information but hardly any new information is generated about the products. Within this context, there has been only slight interest in how the customer uses each individual product, or in how that product has behaved. Concepts such as "product agents" and "intelligent products" (Meyer et al., 2009) have been proposed as solutions for enabling such item- or instance-enabled PLIM. Such concepts were the cornerstones of the product instance-enabled PLIM solutions developed in the PROMISE EU FP6 project[1], in which the paradigm of *closed-loop PLM*®, recently renamed CL_2M (Closed-Loop Lifecycle Management), was introduced (Kiritsis et al., 2003). The breakthrough challenge of CL_2M is to enable the information flow to include the customer and to enable the seamless transformation of information to knowledge. CL_2M and similar paradigms like "Closed-Loop Supply Chains" (Van Wassenhove and Guide, 2003) contribute to enhance various aspects of PLIM, five of which being of the utmost importance:

1. *Information Security:* to maintain the level of security and confidentiality required by organizations (Dynes et al., 2007);
2. *Information Manageability:* to efficiently process large amounts of raw data (Perera et al., 2013);
3. *Information Interoperability:* to manage the many changes in data media and formats throughout the

[1] http://promise-innovation.com

product lifecycle and to ensure information exchanges between any kinds of products, users and systems (Panetto and Molina, 2008);

4. *Information Visibility:* to make data available for any system, anywhere and at anytime. The CL_2M consortium defines the visibility of the information as the possibility to gather, process and exchange the desired information throughout the whole life of a "thing" (Främling et al., 2013);
5. *information sustainability:* to make data capable of outliving systems, while being consistent (McFarlane et al., 2013).

Since PLIM is a wide-ranging concept intended to manage the entire PLC in all possible domains, one can understand that it is important to develop and propose sufficiently generic and portable services and systems to efficiently address each of these aspects. In this regard, the PROMISE consortium proposed a set of specifications aimed primarily at improving *information interoperability* and *visibility* throughout the PLC. Two main specifications were proposed: the PROMISE Messaging Interface (PMI) that defines what kinds of interactions between objects are possible, and the PROMISE System Object Model (SOM) that provides specifications for representing PLIM information. At the end of the PROMISE project, the work on these standards proposals was moved to the Quantum Lifecycle Messaging (QLM) workgroup of The Open Group[2]. QLM messaging standards are derived from PMI and are intended to provide sufficiently generic and standardized application-level interfaces for exchanging the kind of information required by an IoT (Främling and Maharjan, 2013) and, accordingly, to properly support PLIM infrastructures.

2.2 Context-awareness in the IoT

Context-awareness. Since the 1990's, research on context-awareness also gained a great success in the IoT community (Perera et al., 2013). The term *context-awareness* was first introduced by (Schilit and Theimer, 1994) but a definition that is widely accepted by the research community today was proposed by (Abowd et al., 1999):

> *"A system is context-aware if it uses context to provide relevant information and services, where relevancy depends on the user's task"*

Although the product context plays a significant role when dealing with the reality of product and information management (i.e., PLIM), there is still too little research on context-aware systems/products that considers the entire product's life and experience. This often leads to context-aware systems designed vendor-, domain- or application-specific, and that use communication interfaces and data formats barely compatible with each other (Baldauf et al., 2007). Such a design strongly limits data exchange interoperability in the IoT and, as a consequence, hinders the development of more advanced, standardized and pervasive services. Numerous scholars provide evidence and arguments in this respect (Dey et al., 2001), one of which being the recent survey made by (Perera et al., 2013) on context-aware computing for ubiquitous systems. The authors state that: "*sharing context information between distinct organizations is one of the toughest challenges because systems are designed in isolated factions, thus limiting their openness and collaboration*". Various types of middleware supporting context-awareness based on CORBA, CARISMA, Gaia, MoCA, Jini, *etc.*, have been developed and enable communication between different entities. However, they always fail to answer one or more requirements for data exchange interoperability in the IoT[3]. For instance, some of these solutions rely on centralized architectures like CORBA or Jini (somehow prevents "real" peer-to-peer communications), are limited to a unique message payload (e.g., CARISMA, Moca only support XML), do not include strategies to deal properly with products and systems that are mobile or located behind firewalls (e.g., the support of the "piggy-backing" property), and so on.

In this regard, QLM messaging standards are a tremendous opportunity to investigate new ways to design and use context-aware systems by taking maximum advantage of the standardized IoT interfaces, which should leverage traditional context-aware approaches and support the development of portable product management services. In order to better understand the interest of using QLM messaging standards as foundation of CaPLIM, section 4 introduces the main properties of that standards.

3 QLM MESSAGING STANDARDS

In this section, the two standards proposals derived from PMI are briefly introduced, namely the QLM Messaging Interface (QLM-MI) and the QLM Data Format (QLM-DF). These standards are described in greater detail in (Främling and Maharjan, 2013). In the QLM world, communication between the participants is done by passing messages between nodes using the set of interfaces defined in QLM-MI. Whereas

[2] http://www.opengroup.org/qlm/

[3] See (Främling and Maharjan, 2013) for such requirements.

the Internet uses the HTTP protocol for transmitting HTML-coded information mainly intended for human users, QLM is used for conveying lifecycle-related information mainly intended for automated processing by information systems. In the same way that HTTP can be used for transporting payloads in formats other than HTML, QLM can be used for transporting payloads in nearly any format. The accompanying standard QLM-DF partly fulfills the same role in the IoT as HTML does for the Internet, meaning that QLM-DF is a generic content description model for things in the IoT.

3.1 QLM Data Format

QLM-DF is defined as a simple ontology that is generic enough for representing "any" object and information that is needed for information exchange in the IoT. It is intentionally defined in a similar manner as data structures in object-oriented programming. QLM-DF is structured as a hierarchy with an "Object" element as its top element. The "Object" element can contain any number of "Object" sub-elements, which can have any number of properties, referred to as InfoItems. The resulting Object tree can contain any number of levels. Every Object has a compulsory sub-element called "id" that identifies the Object. The "id" should preferably be globally unique or at least unique for the specific application, domain, or network. XML Schema might currently be the most common text-based payload format due to its flexibility but others such as JSON, CSV can also be used.

3.2 QLM Messaging Interface

A defining characteristic of QLM-MI is that QLM nodes may act both as "servers" and as "clients", and thus communicate directly with each other or with back-end servers in a peer-to-peer manner. Typical examples of exchanged data are sensor readings, lifecycle events, requests for historical data, notifications, *etc.* One of the fundamental properties of QLM-MI is that QLM messages are protocol agnostic so they can be exchanged using HTTP, SOAP, SMTP or similar protocols. Three QLM operations are possible:

1. *Write:* used to send information updates to QLM nodes;
2. *Read:* used for **immediate retrieval** of information and for placing **subscriptions** for deferred retrieval of information from a node;
3. *Cancel:* used to cancel a subscription.

The subscription mechanism is a cornerstone of that standard. Two types of subscriptions can be performed: **i) subscription with callback address:** the subscribed data is sent to the callback address at the requested interval (two types of intervals can be defined: *interval-based* or *event-based*), and **ii) subscription without callback address:** the data is memorized on the subscribed QLM node as long as the subscription is valid. Historical data can therefore be retrieved by issuing a new QLM read query.

It must be noted that other relevant interfaces and properties (not detailed in this paper) are proposed by the QLM-MI standard, which cover most of the IoT requirements as discussed in (Främling and Maharjan, 2013).

4 CaPLIM: RESEARCH OBJECTIVES

CaPLIM is primarily intended to reliably and dynamically manage context-aware product data and services, and to efficiently support product context acquisition, discovery, and reasoning. Given this consideration, the research hypothesis of CaPLIM is twofold. First, the development of CaPLIM services should consider the whole product's life and experience, and thereby should include life cycle assessment. Second, because of changing product environmental factors, technological solutions cannot be developed in isolation from product lifecycle actors and systems; rather, all solutions must take into account changing behaviors of actors using context-aware techniques.

Using the framework of (Denyer et al., 2008) for evidence-based management research, the research contributions can be articulated around four pillars:

- *the problem in context* is introducing context-awareness to product information management;
- *the interventions of interest* are the development of CaPLIM services using generic and standardized interfaces for data exchange in the IoT so as to reach our objectives in terms of service portability and interoperability;
- *the generative mechanisms* studied are the ways through which the interventions affect the overall adaptability, portability and security of services provided to users;
- *the outcomes* of the interventions are concrete and easy-to-use algorithms, software, and methodologies that users and system managers can safely implement and adapt to their own application.

Table 1: CaPLIM contributions.

Framework	**n°**	**Contributions**
Problem in context	1*a*	Compare with traditional PLIM, what are the fundamental issues underlying CaPLIM
	1*b*	Define what is called “context” in CaPLIM and the respective working assumptions
Interventions of interest	2*a*	Provide context-aware and personalized dynamic product services (and information) using generic IoT interfaces
	2*b*	Effectively communicate with users through an easy-to-use context-aware query language
Generative mechanisms	3	Qualitatively and quantitatively evaluate the benefits to use CaPLIM strategies in real and diversified applications, systems and projects
Outcomes	4	Provide self-adapting services, techniques and algorithms to be used in any information management project/system

The major contributions related to these four pillars are presented in Table 1. As mentioned, all CaPLIM originality comes from the use of generic and standardized IoT interfaces to support the development of **portable** and **self-adapting** context-aware product services. Appropriate QLM interfaces must be solicited according to the product context, user requirements, and system constraints, and should lead to make appropriate decisions. These decisions could, in turn, eventually use specific QLM interfaces to accomplish their tasks (e.g., by subscribing new information or by controlling particular devices). Ultimate, the goal is to propose product services to address each of the five PLIM aspects introduced in section 2.1. Examples of such services include:

1. *Information Security Services:* to decide what information must be hide or shared with product stakeholders throughout the PLC. The benefits of taking into account the product *context* is that it provides more meaningful information that helps understanding a situation or data. However, at the same time, it increases the security threats due to possible misuse of the context (e.g., identity, location, activity, and behavior) (Perera et al., 2013). New services able to handle the challenging conflict between data “security” and “usability” must be proposed in CaPLIM;

2. *Information Manageability Services:* to automatically understand the raw data (e.g., generated by sensors) and related context. In this regard, CaPLIM services should integrate, among others, tools for data analysis, reasoning, and machine learning, but also strategies for refining as much as possible the *context modeling* within which the product operates in order to draw correct conclusions (e.g., an unusual value collected on a product can be due to external events and does not necessary imply a product malfunction). Such a refinement is made possible using particular QLM messaging interfaces to discover, read or subscribe in “real-time” any new information about the product and its surrounding;

3. *Information Interoperability Services:* to support a wide variety of ontologies for semantic context representation, context reasoning and knowledge sharing, context classification, context dependency and quality of context (Chen et al., 2003). CaPLIM services should support such ontologies to provide knowledge sharing in an open and dynamic distributed systems, and means for intelligent devices not expressly designed to work together to interoperate, thus achieving “serendipitous interoperability” (McIlraith et al., 2001);

4. *Information Visibility Services:* to assess and rank product-related information as well as sensors and other information systems generating this information to help deciding what information, or piece of this information, is relevant to be used and shared between product stakeholders. Assessment models developed in CaPLIM should propose dynamic combinations of information quality factors such as data accuracy, accessibility, completeness, interoperability, intelligibility, and privacy (Maurino and Batini, 2009);

5. *Information Sustainability Services:* to handle outdated or wrong product-related data, which is a frequent and significant problem in PLIM environments. Indeed, product data is often accessed and modified by different actors, stored in different systems and organizations, which leads to numerous replicas of the same data (Stark, 2011). To address this issue, CaPLIM should provide suitable peer-to-peer data synchronization mechanisms able to self-adapt according to the product context. According to (Bellavista et al., 2013), developing context data distribution strategies (including data synchronization) able to self-adapt autonomously depending on current management conditions is still an unexplored research field.

A key challenge in CaPLIM is to be able to extrapolate the key features of traditional context-aware models and to combine, or enrich them, using the generic interfaces defined in the QLM standards (or similar IoT standards) in order to benefit from their

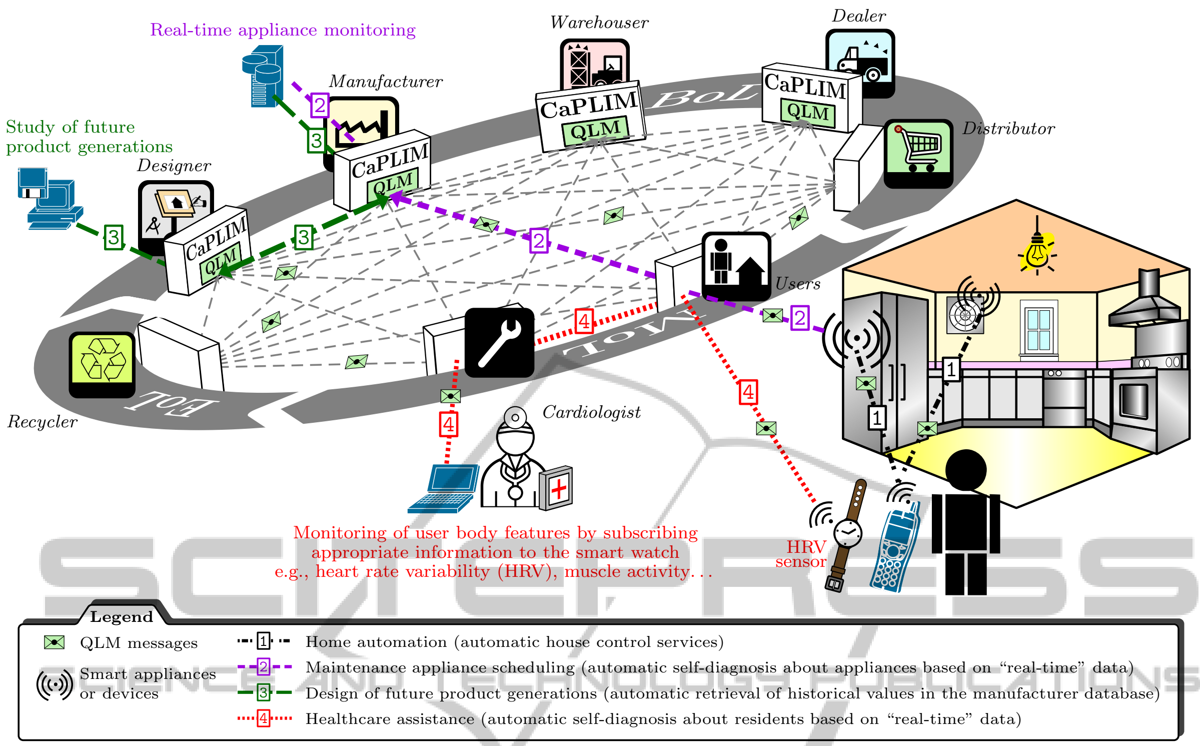

Figure 1: Possible scenarios using CaPLIM for various product information management purposes.

high portability and interoperability. Another major challenge in CaPLIM is to propose strategies to measure both *ab initio* and *in fine* the benefits of using CaPLIM solutions over traditional ones.

5 REAL-LIFE IMPLEMENTATIONS

Several demonstrators developed in PROMISE ought to be re-used in this research (i.e., updated with QLM messaging standards) to investigate, deploy, and assess CaPLIM services. Such demonstrators have the particularity to be defined in different PLC phases and contexts such as for monitoring EoL vehicles, for heavy load vehicle decommissioning (EoL), for predictive maintenance for trucks (MoL), for predictive maintenance for machine tools (MoL), or still for adaptive production (BoL).

The CaPLIM research initiative makes a point of using real-life implementations for deploying and assessing services offered to users, which will enable to refine as much as possible the CaPLIM's theoretical body. The following sections present several scenarios considering a unique platform (a smart apartment), whose objective is to show how CaPLIM services could contribute to enhance product information management from different user perspectives. In these different scenarios, first insights into concrete actions to be fulfilled/undertaken by the CaPLIM algorithms are provided. Figure 1 depicts the smart apartment and some of the actors/devices/systems involved in its lifecycle. This figure also provides a view of the QLM “cloud” that interconnects all phases and organizations/actors from the apartment lifecycle.

5.1 Home Automation

Numerous services for automatic house control could be developed and proposed by the CaPLIM initiative, whose product and user contexts will play a significant role in decisions making. In our scenario, smart appliances and users are able to exchange specific information with each other using the generic QLM interfaces (see communications denoted by “1” in Figure 1), which is a good opportunity to learn in “real-time” about their respective features (e.g., about the appliance mode “On mode”, “Sleep mode”; the energy consumed over a certain period of time...), but also to learn about the user context (at home, at work, in vacation) or to be notified about unusual event occurrences (e.g., the resident no longer move in the apartment). Such “real-time” data are more than necessary to provide the types of information required by context-aware systems.

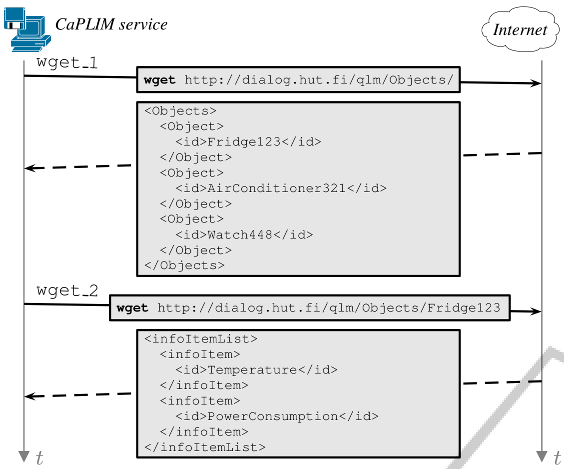

Figure 2: RESTful QLM “discovery” mechanism.

To succeed in this task, fundamental interfaces are required such as the automatic discovery of information about the product or about its (direct or indirect) surrounding. The RESTful QLM “discovery” mechanism is an undeniable asset for developing such data discovery services. An example of this mechanism using the Unix `wget` utility is shown in Figure 2. `wget_1` requests for receiving the set of devices in the smart apartment (devices that implement QLM messaging standards to be more accurate). Three appliances implement such standards, namely `Fridge123`, `AirConditioner321`, and `Watch448` (see Figure 2). Algorithms developed in CaPLIM could eventually refine their research (if needed) by retrieving the set of InfoItems related to one or several of those devices, and so on. `wget_2` (*cf.* Figure 2) requests for such information regarding `Fridge123`, whose result highlights that two InfoItems are reachable on that appliance (e.g., for read, write, or subscription operations), namely InfoItems named `Temperature` and `PowerConsumption`. One can then understand how such a mechanism will help to built dynamic and portable algorithms to discover and monitor, at any time, aspects required by context-aware algorithms.

5.2 Maintenance Appliance Scheduling

Manufacturers or a service providers could use CaPLIM services to monitor in “real-time” appliances and to eventually detect product discrepancies. This scenario is depicted in Figure 1 with communications denoted by “2”, through which the manufacturer subscribes to particular InfoItems to the smart fridge (namely InfoItem named `PowerConsumption`). Such a subscription request is provided in Figure 3 including:

- *the type of operation:* the operation is of type “read” (see row 2) since it is a subscription request;

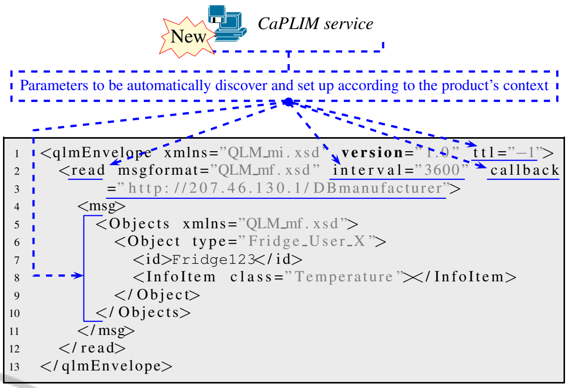

Figure 3: Automatic self-setting of the QLM parameters.

- *the callback address:* the callback address corresponds to the manufacturer’s database system (see rows 2-3);
- *the interval parameter:* set to “3600 s” (see row 2), which means that at the requested interval the subscribed value is pushed to the callback address;
- *the TTL parameter:* the TTL is set to “-1” (see row 1), which indicates that the subscription is “forever”;
- *InfoItem(s) to be subscribed:* the subscribed InfoItem is `Temperature` (see row 8).

Currently, such parameters must be specified by the user/engineer. CaPLIM should provide algorithms able to automatically set the appropriate parameter values according to the product context, the manufacturer needs, *etc.* This contribution is emphasized in Figure 3 (see *CaPLIM service*), and will help make the tasks of the engineer easier, even transparent for such configuring settings. Once subscriptions have been set up, CaPLIM algorithms should be able to process values received at the requested interval, to identify unusual behaviors, and to react accordingly.

5.3 Future Product Generations

Product designers are increasingly looking for full-services that make it possible to retrieve information about their products under in-use conditions, to learn how the product behave, and to enhance their design for generations to come. CaPLIM should provide algorithms and methodologies that could automatically retrieve such information, at the right time, in the right format and from the appropriate information system (e.g., it could be retrieved either from the manufacturer’s database system or from the fridge itself depending on privacy rules). Figure 1 illustrates the first situation where historical information related to the smart fridge of ID *Fridge123* is retrieved from the manufacturer's database (see communication denoted by "3" in Figure 1). Considering a wide panel of users (fridges to be more exact), such information could be used as inputs to machine learning algorithms, neural networks, statistical algorithms, and so on. Ultimately, CaPLIM should make use of appropriate tools according to the designer needs, the product environment under in-use conditions, and other factors.

6 CONCLUSION

To a certain extent, the IoT relies on automatic capture of observations of physical objects at various locations and times, their movements between locations, data collected from sensors attached to the objects or within their immediate surroundings. Each of these objects or products is designed to provide a range of services aimed at supporting daily activities of each product user (e.g., designers, manufacturers, users, repairers...) . Such services are usually considered once and parameters are fine-tuned once and for all. A future generation of services could attempt to self-adapt to the product context by discovering and exchanging helpful information with other devices and systems within its direct or indirect surrounding. The IoT and related concepts like *context-awareness* are key ingredients for supporting the development of such a new generation of services. Embedding context-awareness into the product is a possible solution but is not enough because more advanced and standardized interfaces are required to exchange the kind of information required by an IoT, which has a direct impact on Product Lifecycle Information Management (PLIM). In an IoT context, this paper opens up new research directions for providing a new generation of PLIM services by investigating *context-awareness*. The combination of these two visions is referred to as CaPLIM (**C**ontext-**a**wareness & **PLIM**), whose originality lies in the fact that it takes maximum advantage of IoT standards, and particularly of the recent QLM standard proposal. This new generation of services will play an accelerating role to provide new generations of services that help companies to deal with complex and changing product environments. This should lead to propose ideas for new environment-friendly products, and to improve the customer experience.

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