

# A standardized approach to deal with firewall and mobility policies in the IoT

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## Abstract

Internet of Things (IoT) is intended to provide a network where information flows could easily be set up between any kinds of products, devices, users and information systems in general. This vision is getting closer to become real due to the continuous development of new information system concepts and technologies. Nonetheless, this new reality requires special attention on particular aspects of the IoT such as security and mobility. First, people and companies want to secure their assets/data using firewalls, which inevitably leads to a challenging conflict between data security and usability. Second, products are becoming increasingly mobile, operating in environments where it can be difficult to contact them directly using their IP address (e.g., due to the presence of NAT or to access restrictions). It might therefore be necessary in some IoT applications to enable two-way communications through any type of firewall, e.g. to enable real-time control and maintenance. Quantum Lifecycle Management (QLM) messaging standards have been designed to provide generic and standardized application-level interfaces for the IoT that make it possible, among other things, to achieve such two-way communication. This paper provides a high-level description of QLM messaging standards with a particular focus on this QLM feature, along with proofs-of-concept through real-life implementations in building and automotive domains.

*Keywords:* Internet of things, Firewall, Mobile computing, Product Lifecycle Management, Piggy backing

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## 1. Introduction

In the so-called *Internet of Things* (IoT) and *Cyber Physical Systems* (CPS), mobile users and objects will be able to dynamically discover and impromptu interact with heterogeneous computing, physical resources, as well as virtual data and environments [1, 2, 3, 4]. These visions are getting closer to become real due to the every day increase of concepts and technologies such as sensor hardware/firmware, semantic, cloud, data modeling, storing, reasoning, *etc.* [5, 6]. Billions of devices are connected to the Internet and it is predicted that there will be 50-100 billions by 2020 [7]. As stated by Perera et al. [8], standardization is crucial in the IoT paradigm because it increases interoperability and extendibility, but so far there is still a real need for sufficiently generic and generally applicable application-level IoT messaging standards. This is all the more true following the interpretation of the IoT given in [9], where the IoT is used in the sense of “*a generic information system for accessing and synchronizing any kind of product-related information, mainly over the Internet.*” In this interpretation, the focus is given to the entire product lifecycle, in which the product operates through numerous business areas [10, 11]. Within this context, the primary challenge is to provide standardized interfaces to enable complex business procedures and seamless information exchange among all product stakeholders and involved systems [12]. The design of such interfaces are an essential step to enhance product lifecycle management (PLM), while enabling the creation of a true IoT [13]. However, no proper agreement on a common standard for IoT data exchange between organizations has yet been reached or even proposed. Quantum Lifecycle Management (QLM) standards have been developed as a standard that would fulfill the main IoT requirements [14]. A fundamental requirement is to enable Peer-to-Peer (P2P) communication for all devices, even in mobile or secured environments.

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The proliferation of mobile and pervasive computing devices over the past decade has made host and service mobility on the Internet a significant issue. Delivering data to a mobile host across a network address change (e.g., a NAT router) without disrupting existing connections remains a central challenge [15, 16]. To compound this problem, people take proactive measures to ensure the security, confidentiality, and integrity of their assets/data using firewall and proxy systems [17, 18, 19] that inevitably leads to a challenging conflict between data security and usability; security making it more challenging to implement new services, while usability is required in order to achieve user acceptance of those services [20, 21]. This is particularly true considering the entire product lifecycle since product-related data is a valuable resource for companies and should not be seen by other organizations [24]. Considering environments with firewall and mobility policies, it might be useful to allow information sharing in a P2P fashion despite the presence of firewalls, NATs, or similar systems (e.g., when developing real-time control or predictive maintenance services in the IoT [11, 22]).

The QLM messaging standards propose a set of interfaces that enable, among other things, real-time communications as well as two-way communications with nodes located behind firewall/NAT systems. This property exploits the possibility to place further requests as a part of a response to an earlier request over the same connection. This concept is commonly referred to as “piggy backing” [23]. Section 2 provides the IoT background from a PLM perspective to understand the general interests of introducing such a new IoT standard. Section 3 provides a high-level description of the QLM specifications, followed by section 4 that presents in greater detail the QLM piggy backing property. Two real-life applications implemented in the contexts of home automation and car diagnostics, each one dealing with different security and mobility aspects, are presented in Section 5; conclusions follow.

## 2. IoT background from a PLM perspective

Product lifecycle management (PLM), is commonly understood to be a strategic approach that incorporates the management of data associated with products of a particular type, as well as the business processes that surround it [24]. These product definition data typically consist of detailed specifications, user manuals, computer aided design (CAD) drawings, manufacturing instructions, service manuals, disposal and recycling instructions and so forth. For such traditional PLM, the product information generation process seems to end after production. When the product enters actual use, PLM mainly signifies providing access to the existing information but hardly any new information is generated about the products. This is, perhaps, a reflection of the point of view of the manufacturing industry that tends to see PLM mainly as a distributed knowledge management task of the “extended enterprise” [25] that created the product. With this view of PLM, there has been only slight interest in how the customer uses each individual product, or in how that product has behaved.

Inter-organizational data exchange is a pre-requisite for any kind of PLM in the context of the extended enterprise. In PLM, it usually signifies the transfer of electronic documents or business data from one computer system to another, i.e. from one trading partner to another without human intervention. Data exchange requires some kind of physical media for transmitting the data from one system to the other, a protocol that allows determining what a system should send when and where, one or more interfaces that send and/or receive data, and a semantic layer for understanding the data in a uniform way. The further up we go on the “protocol stack” towards the semantic level, the more challenging it is to create data exchange standards that are unambiguous, while providing a sufficient power of expression. When dealing with product instance-enabled PLM, the need for adequate standards becomes even more flagrant due to the presence of people, embedded devices, and mobile devices that need to communicate with each other in ad hoc and context-dependent ways. Concepts such as “Product Agents” and “Intelligent Products” [26, 27] have been proposed as solutions for enabling such item- or instance-enabled PLM, as well as the IoT.

Such concepts were the cornerstones of the product instance-enabled PLM solutions developed in the PROMISE EU FP6 project<sup>1</sup>. QLM standards emerged out of this project in which real-life industrial applications required the collection and management of product instance-level information for many domains involving heavy and personal vehicles, household equipment, phone switches, *etc.* Information such as sensor readings, alarms, assembly, disassembly, shipping event, and other information related to the entire product lifecycle needed to be exchanged between several organizations. The project consortium investigated potential messaging standards that would provide the kind

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<sup>1</sup><http://promise-innovation.com>

Table 1: Functional requirements for an IoT messaging interface [14]

1	Possible to implement for any kind of instances as independently of the application domain as possible
2	Possible to implement for any kind of information systems, including embedded and mobile systems
3	Support for “synchronous” messaging such as immediate read and write operations, including “client-poll” subscriptions
4	Not restricted to one communication protocol only, it must allow sending messages using protocols like HTTP, SOAP, SMTP, as file copies
5	Possibility to create ad hoc, loosely-coupled, time-limited information flows “on the fly”
6	Peer-to-Peer communication possibility for all devices, i.e. client and server functionality can be implemented for any device, depending on available processing power, <i>etc.</i>
7	Handling mobility and intermittent network connectivity, i.e. support for asynchronous messaging capabilities that imply for instance message persistence, time-to-live, <i>etc.</i>
8	Context-dependent discovery of instances, instance-related services and meta-data about them
9	Support for context- and domain-specific ontologies
10	Queries by regular expressions for retrieving information about more than one instance and more than one kind of information
11	Historical queries to retrieve values between two points in time

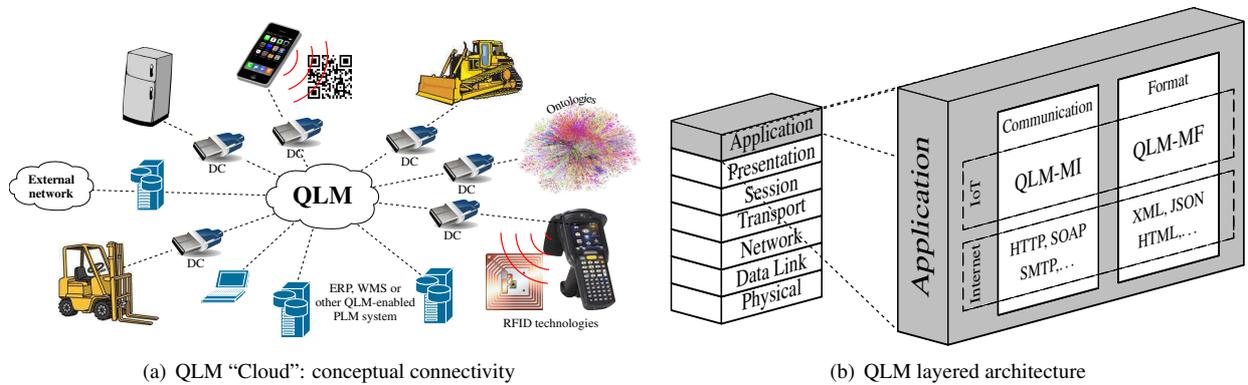


Figure 1: QLM messaging standards: QLM-MI & QLM-DF

of inter-organizational information exchange needed for the IoT. When looking for suitable candidates that would fulfill the requirements listed in Table 1, some entire families of standards were eliminated. One such family of standards are the “low-level” machine-to-machine (M2M) standards that are usually specified for intranet environments. M2M protocols and standards also tend to be developed for very specific purposes and domains, which makes them unsuitable for use as generic application-level IoT messaging standards. An extensive study of those protocols and standards is out of the scope of this paper but a detailed comparison study can be found in [28]. As a result, PROMISE created two main specifications: the PROMISE Messaging Interface (PMI) and the PROMISE System Object Model (SOM). At the end of the PROMISE project, the work on these standards proposals was moved to the QLM workgroup of The Open Group<sup>2</sup>. QLM messaging specifications are based on PMI and consist of two standards proposals [14]: *QLM Messaging Interface* (QLM-MI) that defines what kinds of interactions between QLM nodes are possible, and *QLM data format* (QLM-DF) that defines the structure of the information included in a QLM message.

### 3. QLM messaging standards

In the QLM world, communication between the participants (e.g., products and backend systems) is done by passing messages between nodes using QLM-MI. The QLM “cloud” in Figure 1(a) is intentionally drawn in the same way as for the Internet cloud. Where the Internet uses the HTTP protocol for transmitting HTML-coded information mainly intended for human users, QLM-MI is used for conveying lifecycle-related information mainly intended for automated processing by information systems. In the same way as HTTP can be used for transporting payloads also in other formats than HTML, QLM can be used for transporting payloads in nearly any format. XML might currently

<sup>2</sup><http://www.opengroup.org/qlm/>

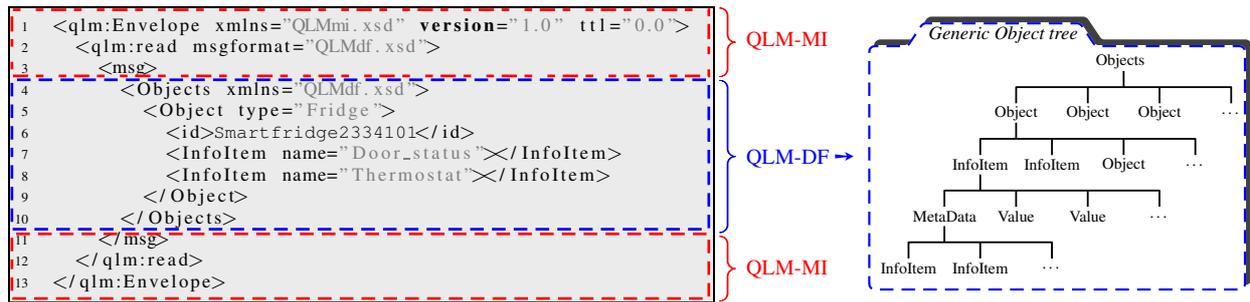


Figure 2: QLM Data Format: generic “Object” tree and example of a QLM message relying on that tree

be the most common text-based payload format due to its flexibility that provides more opportunities for complex data structures [8], but others such as JSON, CSV can also be used (see Figure 1(b)). QLM-DF partly fulfills the same role in the IoT as HTML does for the Internet, meaning that QLM-DF is the content description model for things in the IoT. Information encoded using QLM-DF can be transported also by practically any information exchange protocol, such as JMS, WSDL/SOAP, or ebXML Messaging Services (see Figure 1(b)).

In short, QLM-MI and QLM-DF are independent entities that reside in the Application layer of the OSI model, as illustrated in Figure 1(b), where QLM-MI is specified as the Communication level and QLM-DF is specified as the Format level. These two standards are respectively introduced in sections 3.1 and 3.2.

### 3.1. QLM data format (QLM-DF)

QLM-DF is specified as a simple ontology using XML Schema, which 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 way as data structures in object-oriented programming. It is structured as a hierarchy with an “Objects” element as its top element. The “Objects” element can contain any number of “Object” sub-elements. Figure 2 gives insight into both the generic hierarchy/object tree and an example of a QLM message whose structure respects this object tree. In this example, a unique object of type *Fridge* (see row 5 of the XML message) is considered. “Object” elements can have any number of properties, referred to as *InfoItems*, as well as “Object” sub-elements. In our example, the Object *Fridge* has two *InfoItems* named *Door\_status* and *Thermostat* (see rows 7 and 8). The resulting Object tree can contain any number of levels. Every Object has a compulsory sub-element called “id” that identifies the Object (see row 6). The “id” should preferably be globally unique or at least unique for the specific application, domain, or network of the involved organizations.

In object-oriented programming, objects are aware of each other both by object containment hierarchies and by reference or pointers. In QLM-DF, such object references are made by using the Object “id” element. However, in the IoT, the “id” does not refer to a specific memory location but to an IoT object whose information may even be spread over several information systems and organizations. Different methods and systems have been proposed for the discovery of such distributed information (e.g., in [29]). The simplest mechanism is to include a URL in the identifier itself as proposed by Huvio et al. [9], and then to retrieve the information by object linking as proposed by Främling et al. [30]. New methods are still being developed for solving this issue, which are out of the scope of this paper.

### 3.2. QLM messaging interface (QLM-MI)

QLM-MI has been defined to meet numerous IoT requirements listed in Table 1. A defining characteristic of QLM-MI is that QLM nodes may act both as a “server” and as a “client”, and therefore communicate directly with each other or with back-end servers in a P2P manner. Typical examples of exchanged data are sensor readings, lifecycle events, requests for historical data, notifications, etc. The main properties of QLM-MI are listed in Table 2, among which stand out fundamental ones. First, QLM-MI messages are “protocol agnostic” (see property 1), so they can be exchanged using HTTP, SOAP, SMTP, FTP or similar protocols. The most appropriate protocol to use depends on the application and also the security mechanisms of the protocols. This non-dependency on specific communication protocols makes QLM different from many (or most) other potential IoT messaging standards. Second, three basic but

Table 2: Properties related to QLM-MI

n°	Property	Description	
1	<b>Protocol agnostic</b>	QLM supports multiple underlying protocols, making it possible to transport the message using most “lower-level” protocols such as HTTP, SOAP, SMTP, FTP or similar protocols. It might also be possible to transport this message using files on USB sticks or other memory devices	
<b>Three operations:</b>			
2	<i>Write</i>	Used for sending information updates to QLM nodes. This involves a QLM response to inform the message originator about the success or failure of the operation	
	<i>Read</i>	<i>Immediate retrieval</i>	Information is retrieved immediately. This involves a QLM response from the targeted QLM node, which returns the required information
		<i>Deferred retrieval</i>	Information is retrieved in a deferred way by placing subscriptions on a QLM node. This is done with a QLM read query if the <i>interval</i> parameter has been set: <ul style="list-style-type: none"> <li>if a <i>callback address</i> is provided, then the data is sent using a QLM response at the requested interval;</li> <li>if <i>no callback address</i> is provided, then the data can be retrieved (i.e., polled) by issuing a new QLM read query and by indicating the ID of the subscription</li> </ul>
	<i>Cancel</i>	Used for canceling subscriptions before they expire. This involves a QLM response to inform the message originator about the success or failure of the operation	
3	<b>Time-to-live (TTL)</b>	If the message has not been delivered to the “next” node before TTL expires, then the message should be removed and an error message returned to the message originator (if possible)	
4	<b>Self-contained message</b>	A QLM message contains all the necessary information to enable the recipient to appropriately handle the message. In a more concrete level, the message contains all the relevant information such as the actions to be performed (read, write, subscription...), the message validity period (TTL), the mode of communication (asynchronous or synchronous), the callback address, etc.	
5	<b>Multiple payload formats</b>	Any QLM message can transport actual information using any text-based format that can be embedded into an XML message. A response may include return elements that correspond to several QLM requests. In that case, it is even possible to use different payload formats in different return elements. However, the return payload would normally be in the same format as the original request payload	
6	<b>Real-time communication</b>	QLM allows piggy backing a new request with a response. This is a crucial property both for real-time communications and to enable two-way communications with nodes located behind firewalls	
7	<b>Publication and discovery</b>	Publication of new data sources, services and meta-data can be done with QLM write operation. “RESTful” URL-based queries allow the discovery of them, including discovery by search engines	
8	<b>Target QLM nodes</b>	The receiving node(s) are then responsible of re-routing the query to the targeted QLM nodes, or sending back an error message to the requesting QLM node in case of failure	

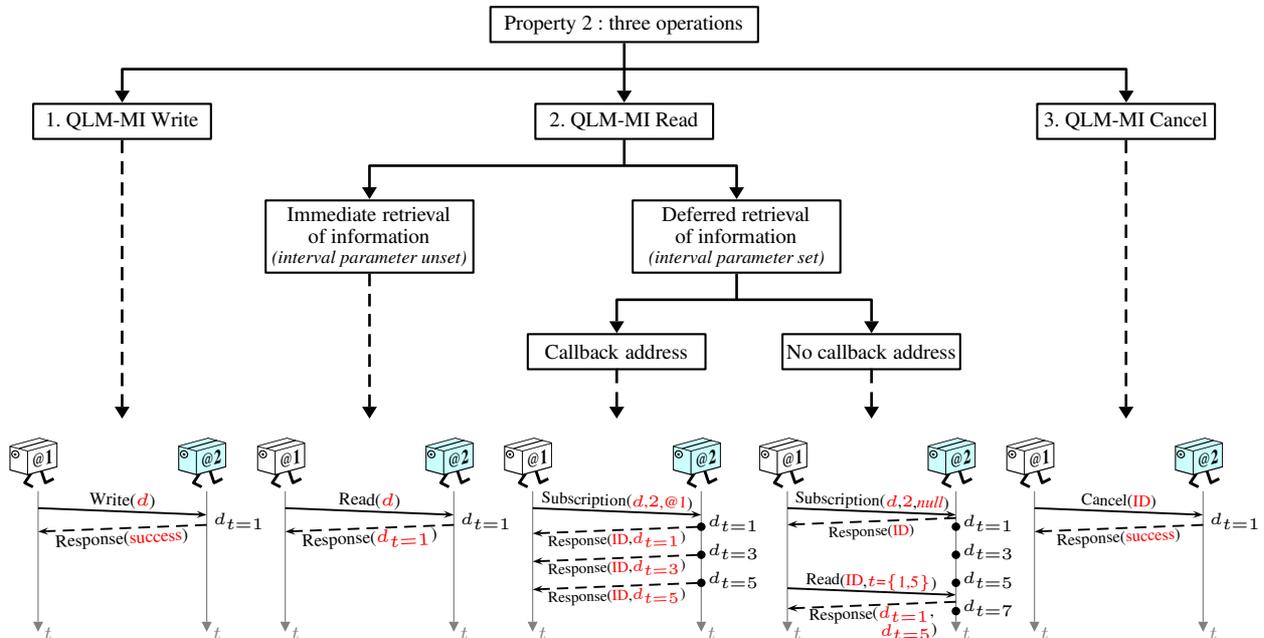


Figure 3: Basic operations and its variants defined in QLM-MI (see property 2 in Table 2)

fundamental operations are defined in QLM-MI (see property 2). Figure 3 illustrates these operations and variants. *QLM-MI Write* is a basic update operation to modify one or several InfoItem values. Figure 3 illustrates such an operation, in which:

- a node denoted by @1 updates InfoItem  $d$  at  $t = 1$  on a node denoted by @2, which then returns a success response.

Similarly, an *Immediate retrieval* of information is a basic *QLM-MI read* operation to retrieve one or several InfoItems, as illustrated in Figure 3, in which:

- node @1 retrieved InfoItem  $d$  on node @2 at  $t = 1$ , denoted by  $d_{t=1}$ .

The *Deferred retrieval* of information, also referred to as subscription mechanism, is a cornerstone of QLM-MI. As described in Table 2 and illustrated in Figure 3, two types of subscriptions are available:

- *with callback address*: in Figure 3, @1 subscribes to InfoItem  $d$  to @2, providing its address as callback with an interval of  $2s^3$ . Then, every  $2s$ , both the current InfoItem value  $d$  and the subscription ID is sent by @2 to @1, i.e. at  $t = 1, 3, 5$ ;
- *without callback address*: @1 subscribes to InfoItem  $d$  to @2 with an interval of  $2s$  but without providing its address as callback (denoted by *null* in Figure 3). @1 first receives a response with the ID of the subscription, and @2 memorizes  $d$  values every  $2s$ . Thus, @1 may request at any time one or several historical values with a read request including the subscription ID, as shown in Figure 3 where @1 requests for values memorized at  $t = 1$  and  $5$  (denoted by “Read(ID, $t=\{1, 5\}$ )” in Figure 3).

To cancel an existing subscription, node @1 simply needs to send a Cancel message with the ID of the subscription to node @2 (see Figure 3).

Note that the conceptual framework used for supporting subscriptions is the Observer Design Pattern presented by Gamma et al. [31], which signifies that a QLM node can add itself as an observer of events that occur at another QLM node. In this sense, QLM differs from e.g. JMS, which is based on the Publish/Subscribe (Pub/Sub) model. For many applications, the Observer and the Pub/Sub models can be used in quite similar ways. However, the Pub/Sub model usually assumes the use of a “high-availability server”, which the Observer pattern does not [32]. This is why the Observer model is more suitable for IoT applications where products might communicate with each other directly. Another important feature of QLM-MI is that QLM messages are “self-contained” in the sense that all the necessary information to enable the recipient to handle the message is contained in the message itself (e.g., the actions to be performed, the callback address. . .). The QLM message given as example in Figure 2 highlights the message interface in which the TTL value is specified in row 1 and the operation type in row 2 (it is a “write” operation in this example).

In this paper, a particular focus is given to property 6 that allows piggy backing a new QLM request with a QLM response to an earlier request, thus making it possible to achieve “synchronous” communications and two-way communications through firewall/NAT systems.

#### 4. QLM piggy backing model for two-way communications

Security and mobility in the IoT are the subject of intense research in various communities and domains, including surveillance, healthcare, transport, food safety, home automation and smart cities, and much more. The recent survey conducted by Yan et al. [33] on trust, security and privacy in the IoT provides insight into such applications along with the future trends and challenges in the IoT. This survey, as well as other relevant studies [2, 34, 35], show that much of the research conducted in these fields investigates how these aspects (security & privacy, mobility) can be improved/reinforced, but often at the expense of data usability. This observation was also made when extending several demonstrators from the PROMISE project into more generic and pervasive use cases, where it became necessary

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<sup>3</sup>The corresponding function is noted “Subscription( $d,x,add$ )” in Figure 3;  $d$  the InfoItem to subscribe,  $x$  the interval value (in sec), add the callback address.

to develop strategies to enable two-way “full-duplex” communications in a generic way through firewalls and with mobile systems.

The need for two-way communication with hosts (including Web browsers and mobile systems) behind different kinds of firewalls has been known since the beginning of the Web. Until about the year 2002, to the best of our knowledge, two-way communication could be implemented using technologies such as Remote Procedure Calls (RPC), Corba and Java RMI [39]. However, at that time, the security policy of most organizations became to limit internet communication to use only port 80, i.e. only allowing HTTP-based communications. SOAP was one of the first attempts to overcome that limitation by implementing RPC-like functionality over HTTP and port 80. However, there has been a tendency for several years to prefer RESTful communication models over SOAP [40, 41], which however blocks RPC-like communications due to the limitations of the basic HTTP protocol. The introduction of *XMLHttpRequest* and later of AJAX (*Asynchronous JavaScript and XML*) technologies were developed to allow web clients to asynchronously send and retrieve data from a server. AJAX simulates a full-duplex connection by polling or long-polling the webserver for updates while maintaining two connections open [42]. Polling and long-polling are not optimal solutions in terms of network traffic, latency and especially for the extra workload required by the webserver to serve the requests. For solving these issues, HTML5 proposes two new communication models: *Server-Sent-Events* and *WebSocket* [43]. *Server-Sent-Events* implements server-sent push-notifications (events) to web pages that subscribed to those events once the client has first initiated the connection. *WebSockets* defines a protocol for full-duplex connections with a remote host over a single connection [44]. One of the most interesting features of the *WebSocket* model is its ability of overcoming firewalls and proxies [45]. A *WebSocket* establishes a tunnel by issuing an HTTP CONNECT statement to the proxy server, issuing an Upgrade request. Then, a WebSocket TCP/IP connection is opened to a specific host and port that essentially allows the same kind of RPC-like connections that were possible with other protocols before 2002. Once the tunnel has been created, upstream and downstream data can flow unimpeded through the proxy. Even though especially *WebSockets* make it possible to implement RPC-like full-duplex communication, it does not address all other requirements listed in Table 1 and properties covered by QLM (see Table 2). Furthermore, these extensions to HTTP remain on a lower “protocol layer” than QLM, which signifies that QLM can benefit from the advantages provided by them for enabling more efficient implementations.

Given this observation, the QLM piggy-backing model is based on the idea that any QLM response can include a QLM-MI envelope with new QLM request(s). This signifies that if HTTP is used as the underlying protocol, then it is possible to implement full-duplex communication over an open connection, even though the initiating QLM node would be otherwise inaccessible due to firewalls, NAT or similar systems. The only restriction is that the communication has to be initiated by the “protected” node. This principle is also possible with other underlying protocols than HTTP. In that case, the possibilities and the limitations of the underlying protocol will usually be different than for HTTP. For instance, if QLM messages are sent as files on a USB stick, then the time (and other) constraints are obviously different from when HTTP is used. The same applies for protocols such as SMTP, XMPP, and others [36, 37, 38]. However, the basic QLM piggy-backing model is still valid in all those cases. Another major difference between the QLM piggy backing model and existing models is that a QLM message is “self-contained” (see property 4 in Table 2), which enables useful information for the recipient to be piggy backed with the QLM response (e.g., the type of operation to be performed: read, write, subscription. . . ; the callback address; TTL; and so on), thus providing “standardized” two-way communications with remote hosts behind a firewall. It is worth noting that the QLM piggy backing model could be viewed as a security threat since it allows transfer of messages through firewalls [46]. In practice, and as mentioned previously, two-way communications is made possible *if and only if* the protected node initiates the communication with the external node(s). In this respect, such a restriction can also be viewed as a security pre-requisite for enabling communication with protected nodes. The matter is thus to be aware of this and, accordingly, to initiate communications with trusted systems/organizations/people, or even to set up additional security procedures. Such procedures may range from the definition of Access Control Lists (ACLs) [47] to more advanced frameworks as the one developed by Chakraborty et al. [48], where the concept of *Inference Firewall* is applied to analyze the information flows between the protected and external nodes (in the context of trust relationships) and applies inferencing policies to determine one of three possible courses of action: *i*) permit the information flow; *ii*) block the information flow; *iii*) obfuscate the information flow; or as the analytics framework developed in [49] that consists in analyzing if a mobile device is compromised after it is deployed (i.e., if an attacker gains control or access to the device itself).

## 5. Case study

Two case studies inspired by real-life implementations from the PROMISE project, as well as nationally funded projects together with industrial partners, are presented in sections 5.1 and 5.2 respectively. The reason of presenting two case studies is twofold:

- *both cases deal with different firewall and mobility aspects*: the first case study deals with firewall policies, while the second primarily deals with mobility issues;
- *to show the domain flexibility of QLM*: both cases rely on different information structures that must be supported by the generic “Objects” hierarchy tree defined in QLM-DF (cf. section 3.1). Such a hierarchy is used/personalized according to the user and application requirements in both cases.

### 5.1. Home automation

In this scenario, two main actors are considered, as depicted in Figure 4:

1. *the fridge service provider*: the service provider offers users the possibility to activate specific services such as the continual monitoring of the indoor temperature of the fridge, the triggering of an alarm if a disruption occurs, and similar services;
2. *the user of the smart fridge*: the user is able to activate over a period of time one or several services.

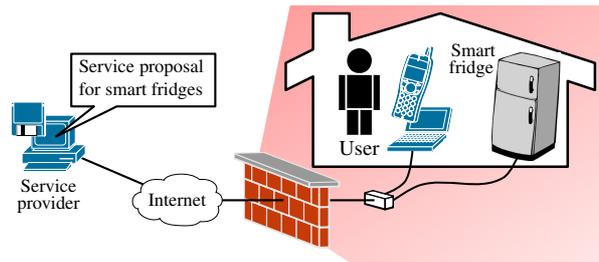


Figure 4: Fridge service provider using QLM messaging

The service availability must be guaranteed whatever the user’s communication infrastructure is (e.g., in the presence of a firewall). To comply with this requirement, the service provider uses QLM messaging to communicate with his remote devices (with the smart fridge in our scenario). A firewall is put into place between the user’s house and the Internet, as depicted in Figure 4, which does not permit<sup>4</sup> nodes from the Internet to reach the smart fridge and similar devices, but does the opposite. Sections 5.1.1 and 5.1.2 describe the different actions and results, first, without considering the QLM piggy backing property, then considering it.

#### 5.1.1. QLM response without piggy backing

Figure 5(a) provides the sequence diagram when the user requests for a specific service related to the smart fridge. On a more concrete level, the user can activate a service by selecting it via a touch screen available on the fridge, which automatically generates an appropriate QLM write request that is sent to the service provider (see arrow denoted by “1” in Figure 5(a)). The QLM write message is given in Figure 6, which includes the “id” of the smart fridge (see row 6), the name of the service to be activated (it is specified using the InfoItem name as shown in row 7: service named `Service_A22`), and the value related to this service (see row 8) that corresponds to the user expectation, i.e. to Activate the service at that time. `Service_A22` guarantees the three following features: *ii*) the continual monitoring of the indoor temperature of the fridge, *i*) the triggering of an alarm if the indoor temperature exceeds 10°C (an SMS is sent to the user’s cell phone), and *iii*) the possibility for the user to consult at any time the service provider’s web page to visualize the temperature evolution.

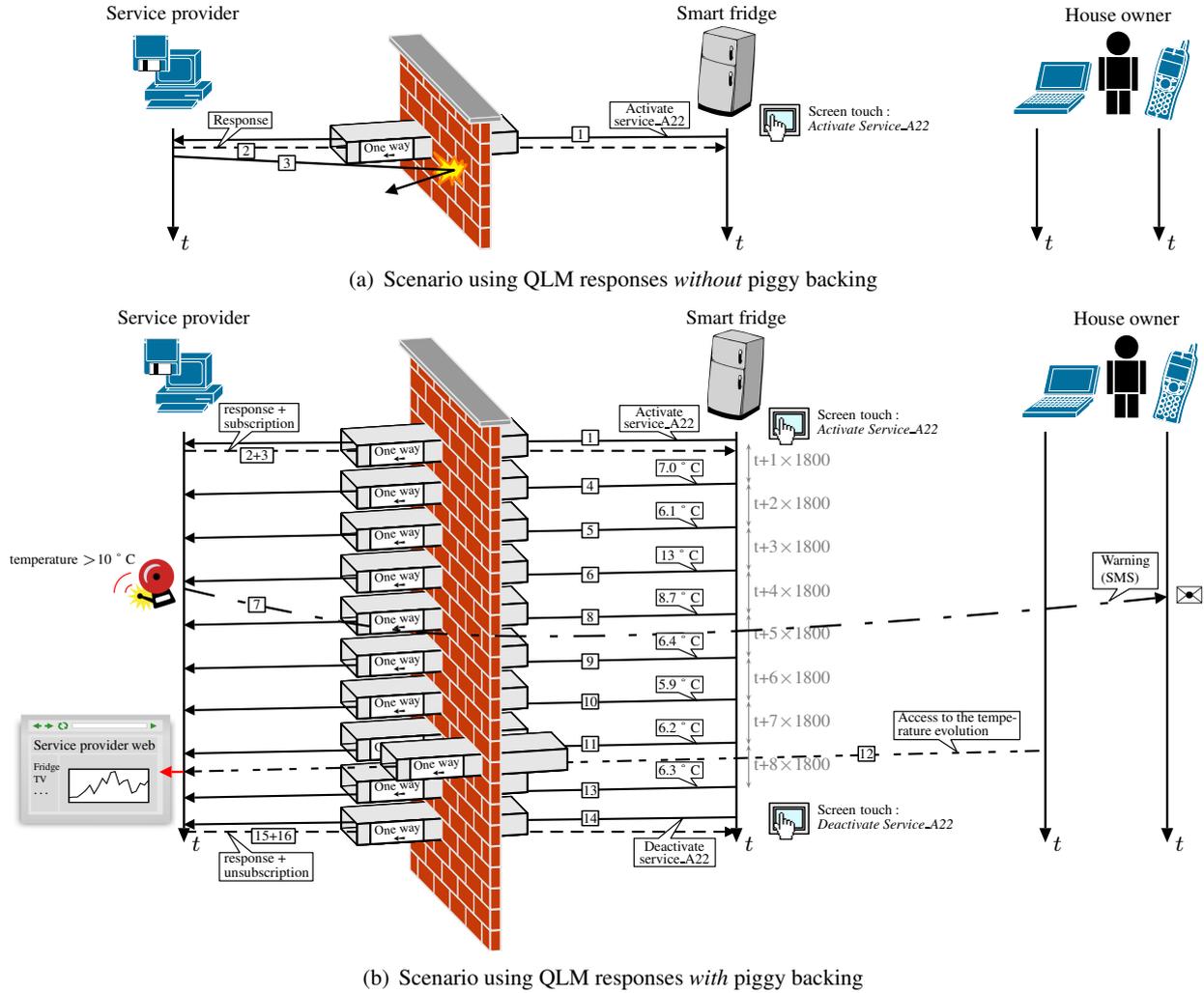


Figure 5: Sequence diagram resulting of QLM data exchanges between the smart fridge and the service provider *without* and *with* piggy backing

After receiving the Write request, the service provider automatically generates a QLM response to acknowledge receipt of the message (see arrow denoted by “2” in Figure 5(a)). This QLM response is given in Figure 7 in which the returned code “200” (see row 4) corresponds to a default value indicating the success of the operation. Subsequently to this response, the service provider sends a subscription request to the fridge (i.e., a QLM read request by setting the interval parameter) in order to subscribe to the InfoItem related to the fridge indoor temperature (see arrow denoted by “3” in Figure 5(a)). This new QLM read request is given in Figure 8, in which the interval parameter is set to 1800 and the callback address is set to `http://207.46.130.1/Servlet` (see row 2) that indicate to the fridge that every 30min (i.e., 1800s) the subscribed InfoItem value (named `Indoor_temp` in row 7) must be sent to the specified callback address. The TTL value in row 1 of the read request, equal to “-1”, indicates that the subscription is *forever*. The resulting actions of that transaction is that the QLM response is allowed to cross the firewall, while the QLM subscription request generated in an independent message is not (see arrows respectively denoted by “2” and “3” in Figure 5(a)).

<sup>4</sup>A simple port-blocking firewall has been configured, which prevents nodes from the Internet to communicate through the HTTP port 80 or through the HTTPS port 443.

```

1 <qlmEnvelope xmlns="QLMmi.xsd" version="1.0" ttl="0.0">
2   <write msgformat="QLMdf.xsd">
3     <msg>
4       <Objects xmlns="QLMdf.xsd">
5         <Object type="Refrigerator">
6           <id>SmartFridge22334411</id>
7           <InfoItem name="Service_A22">
8             <value>Activate</value>
9           </InfoItem>
10          </Object>
11        </Objects>
12      </msg>
13    </write>
14  </qlmEnvelope>

```

Figure 6: QLM write message sent by the fridge to the service provider (see arrow denoted by “1” in Figure 5(a))

```

1 <qlmEnvelope xmlns="QLMmi.xsd" version="1.0" ttl="0.0">
2   <response>
3     <result>
4       <return returnCode="200" />
5     </result>
6   </response>
7 </qlmEnvelope>

```

Figure 7: Response sent by the service provider to fridge (arrow “2”)

```

1 <qlmEnvelope xmlns="QLMmi.xsd" version="1.0" ttl="1">
2   <read msgformat="QLMdf.xsd" interval="1800" callback="http://207.46.130.1//Servlet">
3     <msg>
4       <Objects xmlns="QLMdf.xsd">
5         <Object type="Refrigerator">
6           <id>SmartFridge22334411</id>
7           <InfoItem name="Indoor_temp" />
8         </Object>
9       </Objects>
10      </msg>
11    </read>
12  </qlmEnvelope>

```

Figure 8: Subscription sent by service provider to fridge (arrow “3”)

### 5.1.2. QLM response with piggy backing

Figure 5(b) provides the sequence diagram when the user requests for `Service_A22` but, this time, using the QLM piggy backing property. The QLM write request sent by the fridge to the service provider is similar to the one given in Figure 6. However, the subscription request given in Figure 8 is now piggy backed with the initial response given in Figure 7, as illustrated through the arrow denoted by “2+3” in Figure 5(b). The resulting QLM piggy backed message is given in Figure 9, in which the subscription request (i.e., interface + data format) is included from row 5 to row 16. Contrary to the previous experiment, the fridge now receives the subscription request and is able to process it. In our case study, the DIALOG middleware<sup>5</sup> is used to integrate the QLM messaging standards and, among others, the subscription mechanisms. Accordingly, DIALOG creates the appropriate subscription, i.e. that respects the specified parameters (interval, TTL, callback address if specified, subscribed InfoItem(s)...). In this scenario, DIALOG embedded on the fridge sends the indoor temperature through a new QLM response every 30min, as illustrated in Figure 5(b) through arrows denoted by “4”, “5”, “6”, “8”, “9”, “10”, “11”, “13”.

Arrows denoted by “7” and “12” are actions related to features *ii*) and *iii*) of `Service_A22` (cf. section 5.1.1). Arrow “7” illustrates the notification sent by the service provider (via SMS) to inform the user that the fridge temperature exceeded 10°C. Figure 10 provides the QLM response message sent by the fridge at  $t + 3 \times 1800$  that contains

<sup>5</sup><http://dialog.hut.fi>

```

1 <qlmEnvelope xmlns="QLMmi.xsd" version="1.0" ttl="0.0">
2   <response>
3     <result>
4       <return returnCode="200" />
5       <qlmEnvelope version="1.0" ttl="1">
6         <read msgformat="QLMdf.xsd" interval="1800" callback="http://207.46.130.1//QLM_Servlet">
7           <msg>
8             <Objects xmlns="QLMdf.xsd">
9               <Object type="Refrigerator">
10                <id>SmartFridge22334411</id>
11                <InfoItem name="Indoor_temp" />
12              </Object>
13            </Objects>
14          </msg>
15        </read>
16      </qlmEnvelope>
17    </result>
18  </response>
19 </qlmEnvelope>

```

Subscription request (i.e., read – deferred retrieval) piggy backed in the response message

Figure 9: QLM response used to piggy back the subscription request performed by the service provider (see arrow denoted by “2+3” in Figure 5(b))

```

1 <qlmEnvelope xmlns="QLMmi.xsd" version="1.0" ttl="0.0">
2   <response>
3     <result msgformat="QLMdf.xsd">
4       <return returnCode="200" />
5       <requestId>SUB654534</requestId>
6       <Objects xmlns="QLMdf.xsd">
7         <Object type="Refrigerator">
8           <id>SmartFridge22334411</id>
9           <InfoItem name="Indoor_temp">
10            <value>13</value>
11          </InfoItem>
12        </Object>
13      </Objects>
14    </result>
15  </response>
16 </qlmEnvelope>

```

Figure 10: Response sent by the fridge to service provider (arrow “6”)

the ID of the subscription (see row 5: SUB654534), the InfoItem name (see row 9) and its value equal to 13°C at that time (see row 10).

The arrow denoted by “12” in Figure 5(b) illustrates the action undertaken by the user when accessing the fridge temperature evolution through the HTTP web page hosted by the service provider. An overview of such a web page is given in Figure 11, where collected real-time information and other events that have been subscribed beforehand using the QLM piggy backing functionality are displayed (the power consumption evolution is displayed here). As for the SMS, this action does not require QLM for such an access.

When the user wants to stop using Service\_A22, he can deactivate it via the fridge’s touch screen, which automatically sends a QLM write request to the service provider (see arrow denoted by “14” in Figure 5(b)). The QLM write message is similar to the one sent when activating the service (cf. Figure 6), except that the value of InfoItem is now equal to *Deactivate* and not *Activate* (cf. row 8 in Figure 6). After receiving the write request, the service provider automatically generates a QLM response by piggy backing a cancel QLM request in order to unsubscribe to Indoor\_temp to the fridge (see arrow denoted by “15+16” in Figure 5(b)). This piggy backed QLM message is given in Figure 12, in which the Cancel request is piggy backed from row 5 to 9. The subscription ID (see row 7) is required by the fridge (by the embedded DIALOG middleware) to know which subscription has to be cancelled.

It is important to note that the QLM piggy backing property is valid for any type of firewall. In our scenario, it is a simple port blocking firewall, but any other firewall configuration could be considered (e.g., service or domain blocking).

## 5.2. Car diagnostics

In a state-of-the-art car, the diagnostics notifications are only for the driver to notice and act upon. The effectiveness of on-board diagnostics could be enhanced by enabling the notifications to pass to the repair company directly,

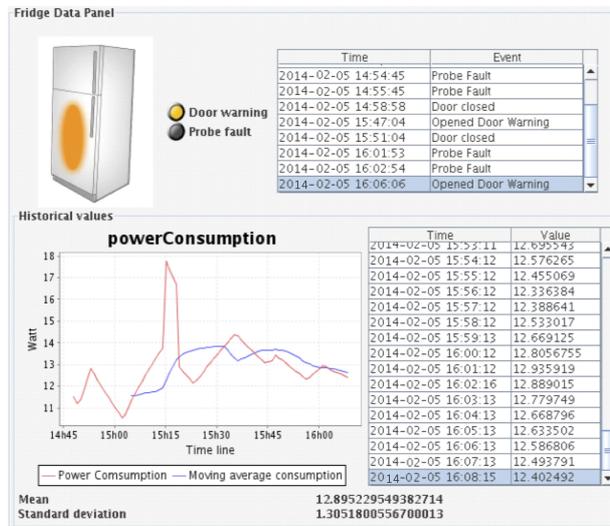


Figure 11: User interface hosted by the service provider showing collected real-time information and events

```

1 <qlmEnvelope xmlns="QLMmi.xsd" version="1.0" ttl="0.0">
2   <response>
3     <result>
4       <return returnCode="200" />
5       <qlmEnvelope version="1.0" ttl="0.0">
6         <cancel msgformat="QLMdf.xsd">
7           <requestId>SUB654534</requestId>
8         </cancel>
9       </qlmEnvelope>
10    </result>
11  </response>
12 </qlmEnvelope>

```

Figure 12: Piggy backing of the QLM cancel request (arrow "15+16")

for instance via an ordinary mobile phone with a suitable application. In our platform, we have implemented such an application on a mobile phone by a Java MIDP program capable of acting as a QLM node, and to send QLM messages over the mobile network with data downloaded from the car's Engine Control Unit (ECU). The connection between the mobile phone and the car's ECU was implemented using a commercially available OBD-II protocol converter [50] connected to the mobile phone via Bluetooth, as illustrated in Figure 13. Figure 14 provides a preliminary user interface on the mobile phone for accessing information from car's ECU.

The complete scenario is detailed in Figure 13, in which a warning display notifies the car user of the presence of deficiencies (see the LED and arrow denoted by "1"). The user therefore solicits the car's ECU to obtain further information, and particularly the Diagnostics Trouble Code (DTC) (see arrow denoted by "2"). Table 3 lists some of the DTC codes defined by OBD-II along with a brief description<sup>6</sup>. In our scenario, the car's ECU returns the DTC code P0172 (see arrow denoted by "3" and Table 3). Accordingly, the user contacts the repair company to further investigate the problem. This is achieved using QLM messaging and not OBD-II protocol. To be more concrete, the user sends a QLM write request to the repair company by including the DTC code and the Vehicle Identification Number (VIN); see arrow denoted by "4" in Figure 13. This request is given in Figure 15, in which the Object "id" corresponds to the VIN (see row 6), the Infoltem name is "DTC", and its value corresponds to the DTC code P0172 (see rows 7 and 8 respectively).

To aid in further problem determination, scheduling a time for service, ordering needed spare parts, or taking some other proactive actions, the repair company would like to monitor specific sensors embedded in the car. As for

<sup>6</sup>There are over 400 DTCs defined in OBD-II.

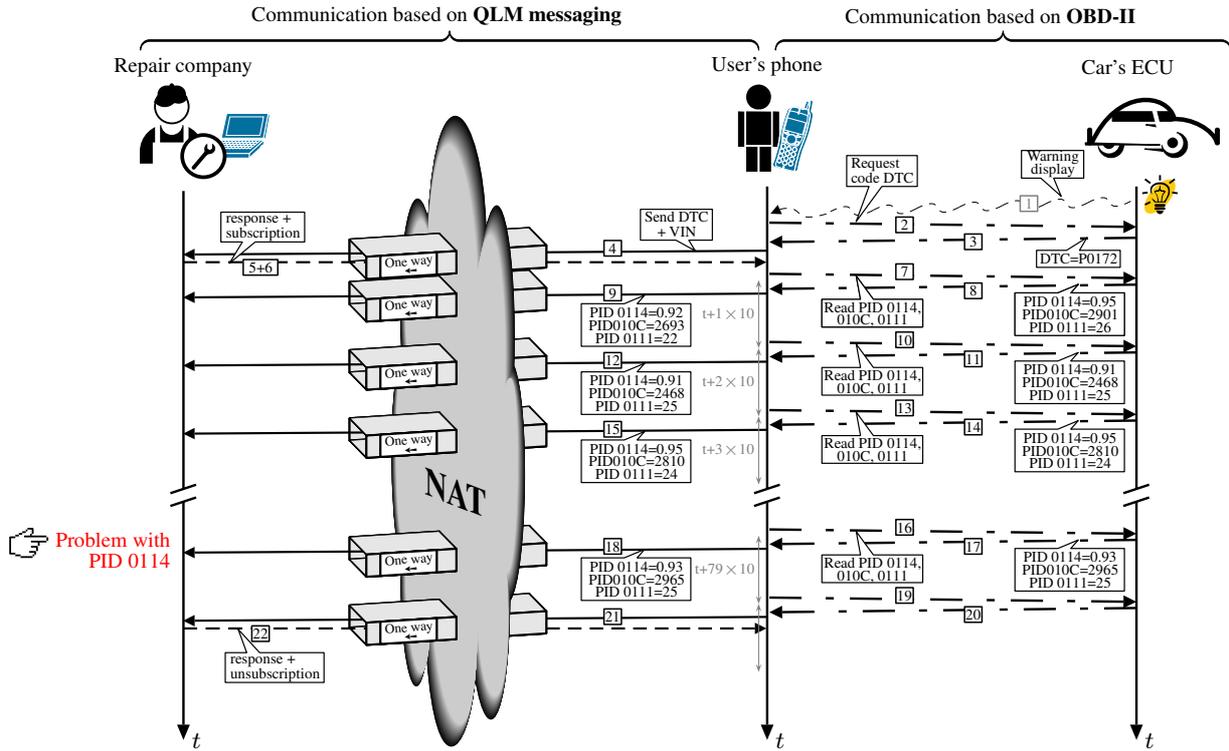


Figure 13: Sequence diagram related to the car automation scenario

DTC codes, OBD-II defines over 80 Parameter IDs (PIDs) that can be read, some of which are listed in Table 3. The company repairer would like to access values of PID 0114, 010C, and 0111 over a period of time of 40min with an interval of 10s. However, at that time, the only way for the repair company to address a new request to the car user is to piggy back the request with a QLM response (see arrow denoted by “5+6” in Figure 13). Indeed, in our scenario, there is no HTTP server embedded on the mobile phone and it is usually not possible to contact it directly using its IP address due to NAT or to access restrictions imposed by the phone operator company. The QLM piggy backed message is given in Figure 16, in which the subscription request is included from row 5 to 18; row 5 contains the TTL value (2400s = 40min), and row 6 contains both the interval (10s) and the callback address to which PID values shall be pushed (it corresponds to a server of the repair company). The set of PIDs to be subscribed to are defined using Infoltems in rows 11, 12, and 13.

When the mobile phone receives the piggy backed message, it initiates an OBD-II communication with the car’s ECU to poll every 10s the respective values of PID 0114, 010C, and 0111, as depicted in Figure 13 through arrows “7”, “10”, “13”, “16”, and “19”. These values are then parsed into QLM responses that are forwarded to the company repair server (see arrows denoted by “9”, “12”, “15”, “18”, and “21”). After 15min, equivalent to 78 collected values (78 intervals × 10s = 780s = 15min), the repair company concludes that the problem is related to PID 0114 because the values returned at the different intervals remain above 0.9, whereas it should constantly jump between values close to zero and values close to one<sup>7</sup>. Based on this observation, the repair company no longer requires information from the car’s ECU and, accordingly, sends a QLM cancel to stop the three existing subscriptions before they expire (i.e., before reaching 40min). Again, this is made possible by piggy backing the QLM cancel with a response to an earlier request (see arrow denoted by “22”).

It is worth pointing out that the collected information could also potentially be transmitted to the car manufacturer. If the car manufacturer could collect such real-use information from a sufficient amount of cars, it could lead to

<sup>7</sup>This sensor measures the amount of oxygen in the exhaust gas. The ECU continuously adjusts the air/fuel mix in order to keep it optimal based on this sensor and other parameters of the engine.

Code	Description
DTC	P0100 Mass or Volume Air Flow Circuit Malfunction
	P0112 Intake Air Temperature Circuit Low Input
	P0172 System too Rich (Bank 1)
	P0173 Fuel Trim Malfunction (Bank 2)
	...
PID	010C Engine RPM
	0111 Absolute Throttle Position
	0114 O2 Sensor 1, Bank 1
	011E Power Take-Off Status
	011F Time Since Engine Start
...	...



Figure 14: Preliminary user interface to access data from car's ECU

improved maintenance scheduling, product design and manufacturing procedures. More generally, the flexibility of both QLM-DF and QLM-MI makes QLM messaging complete to support the various applications in which a product may evolve throughout its lifecycle, and to support the different types of services that might be required by users [10].

## 6. Conclusion

New challenges and opportunities arise with the so-called IoT, in which objects of the real world are linked with the virtual world, thus enabling connectivity anywhere, anytime and for anything. Nonetheless, based on our experience with the IoT and the different messaging and communication standards related to it, as well as our experience from creating numerous IoT implementations in different domains, we claim that there exists a real need for a sufficiently generic and generally applicable application-level IoT messaging standard.

To address this challenge, we propose the QLM data format (QLM-DF) and interface (QLM-MI) specifications presented here as candidates for becoming that standard. A major purpose of this paper is to promote QLM standards. The importance of this standardization work for both academic and commercial purposes should not be under-estimated because the lack of a satisfactory application-level messaging standard is still a great obstacle for

```

1 <qlmEnvelope xmlns="QLMmi.xsd" version="1.0" ttl="0.0">
2   <write msgformat="QLMdf.xsd">
3     <msg>
4       <Objects xmlns="QLMdf.xsd">
5         <Object type="Car.VIN">
6           <id>1HGK782JXMN113456</id>
7           <InfoItem name="DTC">
8             <value>P0172</value>
9           </InfoItem>
10          </Object>
11        </Objects>
12      </msg>
13    </write>
14  </qlmEnvelope>

```

Figure 15: QLM write message sent by the car user to the repair company (see arrow denoted by “4” in Figure 13)

```

1 <qlmEnvelope xmlns="QLMmi.xsd" version="1.0" ttl="0.0">
2   <response>
3     <result>
4       <return returnCode="200" />
5       <qlmEnvelope version="1.0" ttl="2400">
6         <read msgformat="QLMdf.xsd" interval="10" callback="http://207.46.130.1//Repairer_server">
7           <msg>
8             <Objects xmlns="QLMdf.xsd">
9               <Object type="Car.VIN">
10                <id>1HGK782JXMN113456</id>
11                <InfoItem name="PID-0114" />
12                <InfoItem name="PID-010C" />
13                <InfoItem name="PID-0111" />
14              </Object>
15            </Objects>
16          </msg>
17        </read>
18      </qlmEnvelope>
19    </result>
20  </response>
21 </qlmEnvelope>

```

QLM-MI response { 1-2  
 QLM-DF response { 3-4  
 QLM-MI read { 5-6  
 QLM-DF read { 7-14  
 QLM-MI read { 15-16  
 QLM-MI response { 17-18  
 QLM-MI response { 19-21

Subscription request (i.e., read – deferred retrieval) piggy backed in the response message

Figure 16: QLM response used to piggy back the subscription request performed by the repair company (see arrow denoted by “5+6” in Figure 13)

realizing the IoT. Official QLM messaging specifications will be made public by the QLM workgroup during 2014. However, several companies and academic organizations are already using the newest specifications for implementing both academic and commercial-level systems. These standards provide a solid foundation for supporting the various IoT applications, and they are more than necessary for investigating and integrating existing standards, concepts and techniques. Too often, applications are designed to be domain-specific (e.g., using private technologies or adding new software codes), which limits both their interoperability and extendibility throughout the product lifecycle. QLM messaging standards will enable to properly consider other issues in the IoT, e.g. in properly supporting the development of context-aware services and systems [51, 52]. Indeed, as stated in [8, 53], standardized formats and protocols are important for enhancing context-aware systems with flexible context-based services.

In addition to promoting QLM messaging, this paper provides a proof-of-concept of a fundamental QLM property that enables to switch from asynchronous messaging to instant messaging when one of the communicating systems is behind a firewall, NAT, or similar. This property is based on the *piggy backing* model that enables two-way communications through a firewall that is useful, e.g., for real-time control/maintenance or to deal with mobile environments in which it is difficult to provide the product with a permanent IP address. Two case studies are presented in this paper that show, first, how important this property is in diversified real-life IoT applications (i.e., facing diversified firewall and mobility policies) and, second, how the generic information hierarchy defined in QLM-DF can be personalized in accordance with the user and application requirements.

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