Abstract—The Future Internet vision is tightly linked to the transition from a passive system in which users initiate activities to a proactive environment in which software agents find, organize and display information and services on behalf of users. Such applications must be highly proactive and support real-time contextualizations and dynamic situation sensing, processing and reaction. In this paper we discuss situation management as a framework especially useful in domains in which there is the need to automatically and continuously identify and act on complex, often incomplete and unpredictable, dynamic situations. We focus on applying situation management methods in demand response, an element of the emerging smart power grid. We outline an intelligent situation management approach and present an event-based software architecture for supporting demand response aspects of the smart grid.

Situation Management; Web Services; Context-aware services; Smart grids.

I. INTRODUCTION

The Future Internet (FI) vision is tightly linked to applications which dynamically support the operations of businesses organizations as well as the everyday life of citizens in a seamless and natural fashion [1]. The realization of such a vision would require the transition from a passive system in which users initiate activities to an active environment in which software agents find, organize and display information and services on behalf of users. Hence FI applications must be highly responsive, in the sense that they will be able to sense the changes in their context and respond correspondingly [2].

FI applications have been compared to living sense-response systems that connect on demand every possible data and service source, integrate data with other information in real time and distribute results to every interested actor, including business processes that can be changed accordingly in order to enable prompt reactions on emerging situations. However, related research shows that for FI applications to be successful a number of critical functionalities must be supported: dynamic subscriptions, automatic publishing, real-time contextualization, and dynamic situation sensing, processing and reaction [3]. This last point refers to the discovery, representation and management of situations of interest. The ultimate challenge is to support the detection of interesting situations before they appear and the generation of appropriate actions in a proactive manner [4].

Situation awareness and situation management (SM) is an active research field with research on the dynamic, temporal, semantic and logical aspects of situations, and on the situational behavior of humans, systems, and organizations, with input from diverse areas such as artificial intelligence, human–computer interactions and data fusion [5]. SM is critical in domains in which there is the need to automatically and continuously identify and act on complex, often incomplete and unpredictable, dynamic situations [5]. It comprises a variety of tasks such as situation sensing, situation perception and recognition, situation learning and prediction, as well as reasoning and recommending or triggering appropriate responses. Examples of SM applications are found in domains such as real-time fault and configuration management in telecommunication companies, mobile ad hoc and sensor networks, etc.

In this paper we focus on applying SM methods in a emerging domain, the smart power grid. The vision of the smart grid has recently attracted much interest from governments, power companies, and research institutes [6]. It has been argued that the smart grid can be a truly revolutionary advance, akin to the disruptive impact of the World Wide Web, if we treat it not as an advance in power systems, but as the arrival of a massively interconnected information processing system [7]. To this end, informatics tools and techniques have a critical role to play in translating the ability to collect fine grained power usage data into a decision support system for managing the smart power grid [8]. In our approach we aim to exploit the power of using semantics and complex event processing as basic components of the overall information architecture [9] [10].

Here we propose a conceptual architecture for situation management in the smart grid. We show how the use of linked open data can be integrated within an ontology-based situation management architecture. We present an application scenario for proactive situation management in the domain of demand response in the smart power grid.

The rest of the paper is organized as follows. Section II discusses related work on situation management, while Section III outlines the issues of the smart grid and the case of Demand Response (DR). Section IV presents our proposed architecture and Section V closes giving some relevant conclusions.
II. RELATED WORK ON SITUATION MANAGEMENT

Situation awareness was introduced by Mica Endsley whose definition of situation awareness is a generally accepted one: “Situation Awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” [11], [12]. Historically, the first formal specification of a situation was given by McCarthy and Hayes [13] in their Situation Calculus, where they used first order logic expressions to define a situation as a snapshot of a complete world state at a particular time. Since it was computationally inefficient to consider a situation as a complete state of the world, Pirri and Reiter [14] defined a situation as a sequence of actions enabling calculation of the current state knowing the initial state and the sequence of actions transforming the initial state.

Since these original works a lot of situation-related research has been carried out and has become a critical issue in domains in which there is the need to automatically and continuously identify and act on complex, often incomplete and unpredictable, dynamic situations; as a result, effective methods of situation recognition, prediction, reasoning, and control are required — operations collectively identifiable as situation management (SM) [5]. SM is considered a synergistic goal-directed process of (a) sensing and information collection, (b) perceiving and recognizing situations, (c) analyzing past situations and predicting future situations, and (d) reasoning, planning and implementing actions so that desired goal situation is reached within some pre-defined constraints [15] (see Fig. 1).

Following [16] we identify three basic types of SM: investigative; control; and predictive. The investigative situation management is concerned with a retrospective analysis of causal situations, which determine why a certain situation happened. The control type aims to change or keep the current situation, while the predictive type aims to project possible future situations. For example, finding a root of a packet transmission failure in a telecommunication network is an example of an investigative SM; moving a tank unit from the area of direct hostile fire is a control type SM; and a projection of a potential terrorist attack on a critical infrastructure element is an example of a predictive SM [16].

The other dimensions of SM that should be mentioned are: situation awareness, resolution, acquisition, and learning. Situation awareness is based upon the steps of sensing and perception, aimed towards building an understanding of a current operational situation. Situation resolution is based on the steps of action planning and implementing the actions to close the situation control loop. Situation acquisition and learning, being off the timeline of direct SM processes, are the main sources of building knowledge structures required for the SM processes.

Different situation representation approaches have been recently proposed, ranging from event-based approaches [17] to ontology-based ones. The SAWA approach (Situation Awareness Assistant) [18] is based on an upper ontology for situation awareness.

The situation ontology by Yau et. al. [19] incorporates situations as well as contexts and classifies situations into atomic and composite ones. The core SAW ontology of [20] represents a situation as a collection of situation objects, including objects, relations and other situations. It introduces the concept of spatio-temporal primitive relations between observed real-world objects and serves as an extension point for domain ontologies.

III. THE SMART POWER GRID AND DEMAND RESPONSE

A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies [21]. One of the main goals of Smart Grid is to achieve Demand Response (DR). DR can be defined as the changes in electricity usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time. Further, DR can be also defined as the incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized [22]. There are various types of DR, according to the arrangements made between retail or wholesale entities and their retail or wholesale customers. Examples of these arrangements include: direct load control, real-time pricing and emergency DR [23].

Fig. 2 depicts the domains and actors of the NIST Smart Grid Framework [6], which are more relevant to the concept of DR. Each one of the four relevant domains (Operations, Service Providers, Distribution and Customer) is a high-level grouping of organizations, buildings, individuals, systems, devices or other actors that have similar objectives and that rely on - or participate in - similar types of applications.

To enable the DR functionality in the smart grid, actors from various domains interact. Actors can be devices, computer systems, software programs, or individuals or organizations that participate in the Smart Grid. DR-related communications cover interactions between wholesale markets and retail utilities and aggregators, as well as between these entities and the end customers.
The latter reduce demand in response to grid reliability or price signals. Wholesale markets are out of the scope of this paper; therefore are not depicted in Fig. 2.

DR-related information flows back and forth between the utility and the customer. Pricing, electricity usage, critical peak period signals and other DR-related information is communicated through the Meter and the Energy Services Interface (ESI), which together, provide the interface from the smart grid to the Customer Domain. Bidirectional communications between the actors of the Operations and Customer domains allow collection of meter data and load management, including load analysis and control and DR. Existing or new actors of the Service Providers domain are also involved in the DR-related information flows, by providing demand response aggregation functionalities or contextual information allowing situation-aware DR (see section IV).

Managing DR-related information originating from - and information flows between - different actors spanning across various domains, raises the need to automatically and continuously identify and act on complex, often incomplete and unpredictable, dynamic situations.

IV. THE PROPOSED ARCHITECTURE

Proactive situation management requires an architecture that is dynamic, flexible and accessible to/from all participants [21]. The guiding principles of our conceptual framework that supports these requirements are as below.

**SOA (Service Oriented Architecture):** As already discussed, the provision of services in the smart grid (e.g. a DR service), involve the interaction of actors across a variety of domains. SOA provides the necessary infrastructure for integrating services in a flexible way, while it is considered an inherent principle of smart grid architectures, see [24].

**Linked Open Data:** We follow the “linked data” principles [25], i.e. a) use URIs as names for the various grid actors, b) use HTTP URIs so that actors can look up those names, c) when an actor looks up a URI, provide useful information using RDF. In this way it is possible to connect information flows and data originating from various heterogeneous information sources, to existing knowledge represented in different ontologies. Semantic reasoning over the data and the existing or emerging “linked data” can lead to deduction of new knowledge to be taken into account for situation-aware DR.

**Pub/sub Paradigm:** The Web is still inherently based on the request-response paradigm. Instead, the smart grid information space involves real-time information streams that are pushed to the various actors rather than being pulled. Current Linked Data principles apply to static sources but could be extended to include streaming sources as well [26]. This implies a paradigm shift from information pull to information push; or from request-response-based to event-driven web services. Our architecture is based on a publish-subscribe protocol for real time communication.

A. Conceptual Architecture for Situation-Aware DR

Based on the guiding principles described in the previous section and on the architecture described in [27], we propose a conceptual software architecture for situation-aware DR in the smart grid, which is depicted in Fig. 3. It consists of one vertical and four horizontal layers (L1-L4).

**Layer 1** consists of the Real Time Sensor & Instrument Data and other Data Sources. Real time Sensor & Instrument Data represents real time information streams continuously arriving from smart meters, sensors and appliances of the smart grid. These streams carry information such as electricity usage and appliance information. Other Data Sources that contribute to the information space of the future smart grid may include 3rd party service providers giving real-time information (through online services in a SOA setting) with respect to the traffic flow in a city, the current and future weather conditions, the location of EVs and DR customers, as well as the behavior of the latter in the context of social media websites, etc. Static data sources such as customer demographics, energy consumption and DR responsiveness DBs, DBs with historical data from 3rd party service providers etc., fill the smart grid information space.
Layer 2 consists of components for semantic information integration and Complex Event Processing (CEP) [9]. As already discussed, the smart grid information space is broad in terms of data sources and information types. To enable its use and interpretation for situation-aware DR, it should be enriched with semantics. The Semantic Information Integration component is responsible for integrating and enhancing the diverse information space into a semantically enriched one. The real-time part of the smart grid information space can be represented as an event cloud, where events are generated by a wide variety of sources. The CEP component enables accessing, filtering and correlation of these events and provides services to the situation management component for situation identification. CEP is considered as a core component of smart grid software architectures; see e.g. [24].

Layer 3, which is based on the SM lifecycle discussed in section III, lies at the heart of the proposed architecture. The basic functionality provided by this layer is Situation Identification. The identification of the current situation is achieved by exploiting the services of the underlying CEP component and by making use of the ontologies of the Semantic Information Integration component, which provides the vocabulary for defining the situations, situation types, actors, etc. Based on the identified current situation, utility policies, as well as on services of the Situation Mining and Situation Prediction components (see below), the Situation Reasoning component finds out the DR actions that should be taken, while the Situation Execution component executes them. Execution may change the current situation.

The Situation Mining and Situation Prediction components mainly implement investigative and predictive SM, respectively. Situation Mining employs machine learning and data mining techniques on historical data sources residing at Layer 1 of the architecture, as well as on historical SM lifecycles, in order to determine the most effective techniques and actions for DR and provide this knowledge to the Situation Reasoning component. Finally, the Situation Prediction component uses prediction models and - based on the current situation - predicts possible future situations (e.g. a supply-demand mismatch) that may influence DR-related decisions.

Layer 4 is responsible for presenting information to the customer and enabling his/her preferences to be taken into account in DR applications. It consists of customer-focused portals providing access to billing, usage history and available DR programs. Through these portals customers can prioritize possible responses and set parameters related to the control of their appliances and/or distributed generation.

The information space, upon which the proposed architecture is based, contains detailed information about consumers, such as electricity usage, location and behavior in online contexts. Insufficient oversight of such information could lead to unprecedented invasions of consumer privacy, as many intricate details of household life can be gleaned from it. The Data Security and Privacy layer of the architecture encompasses components and functionalities to ensure that information is protected from unauthorized access or malicious attacks. On the other hand, with customers potentially having access to utility-managed information or information from a third party, this layer also encompasses safeguards to prevent access to the utility control systems that manage power grid operations.

B. Use Case for Demand Response on the Smart Grid

In the following we propose an application of our architecture in which the ontology-based situation representation approach of [20] is used. We use a simple DR scenario in the context of the smart grid in order to illustrate how our approach enables situation-aware DR by combining events coming from heterogeneous information sources.

John and Maria live in the same city and their homes are connected to the smart grid through smart meters. Both participate in a DR program, which allows the energy provider to control automatically their appliances at times of peak loads. For example, John has given his permission to the energy provider to increase the thermostat of the refrigerator when wholesale market prices are high and to charge his Electric Vehicle (EV) during a pre-defined time window (at an off-peak time), in return for a lower rate. His preferences are taken into account in the DR program, as he can change parameters related to the control of his appliances and EV charging through a web portal (e.g. he can set price thresholds, change the time window, etc.)

Consider a situation in which consumption at Maria’s home increases 2kW above her base load, while at John’s house drops at his base load, as indicated by the relevant smart meters. At the same time John’s distance from his home is more than 100m and increasing, as indicated by his smartphone’s or car system’s GPS. Finally, an event from the operator signals that the city where John and Maria live is currently under peak load.

In this scenario, data indicate that Maria is consuming more than normally, probably due to an extraordinary occasion (e.g. a party preparation), while John leaves home, probably for the weekend if the current day is Friday or Saturday. The energy provider can respond to these situations e.g., by increasing the refrigerator’s thermostat at John’s home and by suspending the charging of his EV that is plugged in a controlled power socket in the parking lot.

The scenario can be enriched with additional contextual information collected from 3rd party providers indicating e.g., that Maria has sent a lot of invitations to her online friends in social networking sites and her transactions in supermarket were increased compared to her usual shopping patterns. The scenario can be also extended in order to incorporate predictive SM, where the actions taken would aim at avoiding possible undesirable future situations.

Such informally described situations and energy provider’s responses are formalized by means of the rules in Table I. For reasons of brevity, we apply a simplified syntax based on the Semantic Web Rule Language (SWRL) for class membership and relation types.

In the rules isHeavyLoad and isCloseToBaseLoad are functions for calculating the distance between the current consumption and the base load for a customer’s house.
These functions could be realized using web services: both take as input the current consumption of a customer and his/her name and return true if the current consumption is significantly bigger than (or close to) the base load for that customer, respectively.

V. CONCLUSIONS

In this paper we presented an architecture that uses semantics and complex event processing as basic components and exploits the use of linked open data. We also presented an application scenario for proactive situation management in the domain of demand response in the smart power grid.

Our simple example scenario focused only on demand response in the smart power grid; however, we strongly believe that future internet applications may benefit from event-based and ontology-driven situation management for the detection of interesting situations before they appear and the generation of appropriate actions in a proactive manner.

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