Information Mediator for Demand Response in Electrical Grids and Buildings

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Abstract—**Complexity of algorithms and policies in energy systems has increased interactions among heterogeneous systems and information sources. Demand Response (DR) is a representative example where electrical grids and buildings communicate with each other to manage overall electricity demands. There are various industry standards that model the information and the interactions between grids and buildings. However, each building has all the burden of converting information from different models to its information model prior to using it. We envision a system-agnostic information model for these interactions that can reduce information conversion to/from buildings and invigorate the interaction. We propose an integration of ontologies and standards to express DR interactions and open the possibility of connecting other information models. We also suggest an information mediator system that interprets and delivers messages among grids and buildings and can mediate energy usage among buildings based on the system-agnostic model.**

I. INTRODUCTION

Demand-Response (DR) is defined as a method of changing electric usage by demand-side resources in response to changes in the price of electricity or to other incentives [1]. DR has been an essential technology for sustainability due to its capability of reducing outages, diversifying resources, and reducing infrastructure costs [2]. However, Pike Research estimates a worldwide DR participation rate of only 16.8% in 2018 [3]. One of the main reasons for this is a lack of interoperability between electric power distribution grids (grids) and buildings [4]. It implies that reducing the integration hurdle is a key step toward a more sustainable society.

One reason for the lack of interoperability is that grids and buildings have historically been designed independently in each domain and standards bodies sparsely consider interactions between them. A NIST report [5] partitions grids into seven domains as generation, transmission, distribution, operations, markets, service provider and customer. Stakeholders in each of these domains have defined standards such as the IEC TC57 family of standards, including IEC 61850, 61968, 61970 that support distribution, transmission and substation automation, collectively referred to as the Common Information Model (CIM); the OASIS EMIX family of standards including Energy Interoperation [6] and WS-Calendar [7]; and associations such as ASHRAE defining BACNet, and the Facility Smart Grid Information Model (FSGIM). Indeed, the smart grid community's Catalog of Standards [8] only includes some of the emerging standards and already listed 76 standards as of August 2015. The building design and operation communities have been major drivers behind building standards, such as Industry Foundation Classes (IFC) [9] and BACNet [10]. A flexible and adaptable DR requires information exchange among these inherently different perspectives. This requires conversion of information between different information models, which in most cases are not machine processible.

Complicating this situation, DR will require integration of more information into its applications and algorithms to improve flexibility and to optimize grid/building performance and efficiency; tariff schedules and contracts, real-time and forecasted weather [11], standardized time signals, calendars and outages on the grid side, and building use prioritization, weather, calendars, special events, and sensor values such as occupancy sensors [12], on the building side. Operators of grids and buildings need to seamlessly integrate such information into their own systems while preserving their original system design and information models. Information can be modeled and represented in many ways, but the most powerful and maintainable method is to represent information models using ontologies. Ontologies are flexible, extendable, and their repositories are robust to change.

We propose i) a system-agnostic, standards and ontology-based information model for DR between grids and buildings, and ii) an information mediator system that can easily translate different information models based on our system-agnostic model and can adjust different buildings' energy usage.

II. BACKGROUND

A. Smart Grid and Smart Building Standards

1) Grid/Energy: One standard particularly relevant to energy use in buildings is ASHRAE Standard 201, Facility Smart Grid Information Model (FSGIM) [13]. The FSGIM attempts to capture all the information a facility manager needs to know or exchange with energy providers or other outside information sources. The FSGIM is intended to enhance the interoperability of other standards that define technology- and communication protocol-specific implementations. It models electric entities in a facility in terms of four components: Load, Generator, Meter and Energy Manager. However, while FSGIM itself incorporates different standards, it does not provide an actual implementation of the model that can be directly used

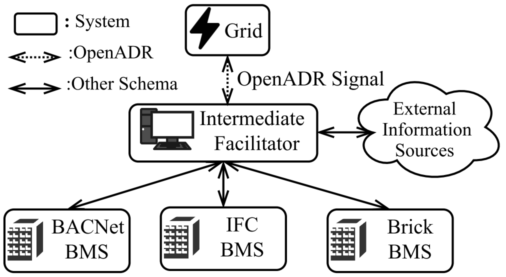

Fig. 1: An information exchange scenario among a grid, an intermediate facilitator and buildings. A grid communicates with a facilitator in OpenADR while the facilitator communicates with buildings with different standards and other information sources for DR processes.

in systems. Rather, it is designed to be implemented through modifications to facility communications protocols such as BACNet.

2) Buildings: Building Management Systems (BMSes) maintain their resources with either a proprietary model or a standard. There are several standards for buildings and each of them covers a specific range of capabilities. BACnet is an information exchange protocol for operations in buildings [10]. It specifies how sensors and actuators send messages to each other for building control and operation. Industry Foundation Classes (IFC) is an information model designed to provide interoperability among different application areas such as architecture and engineering [9]. Recent efforts on building information models, such as Project Haystack [14] and Brick [15], additionally describe resources in buildings and their relationships such as the location of a sensor. However, none of the standards is interoperable with the others, nor do any of them consider interactions with grids or energy management.

B. Demand-Response and OpenADR

DR has two categories of programs: incentive-based and price-based programs. Incentive-based programs give rate incentives under contracts that allow a utility to curtail energy consumption as needed. If a participant cannot satisfy a curtailment request, he/she receives a rate penalty. Price-based programs change prices of electricity per time and participants' usage. Actual pricing events depend on the type of the program and time granularity varies from minutes to days [2].

OpenADR is a standard information exchange protocol for DR [16]. It defines two types of actors: Virtual Top Node (VTN) and Virtual End Node (VEN). A VTN represents an energy provider and can send pricing or incentive event notifications; a VEN represents an energy consumer and can receive and respond to the notifications. Events can contain schedules of prices or load objectives. Fig. 1 shows an information exchange scenario where an energy provider communicates with an intermediate facilitator that manages buildings. It is a common scenario of campuses with many buildings to manage electricity consumption across the entire campus. In the scenario, the grid is a VTN and the facilitator is a VEN, where OpenADR events are communicated from the grid to the facilitator while the facilitator communicates with buildings with/without OpenADR.

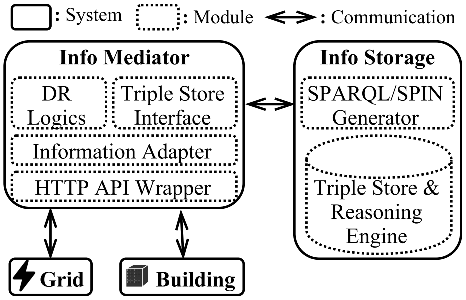

Fig. 2: Suggested Information Mediator Architecture. The information mediator functions as an intermediate facilitator.

In the scenario, the facilitator would adjust the demands of buildings using the buildings' own models in its DR processes. However, it is hard to incorporate OpenADR with the building-specific models directly if their implicit information models are different. The facilitator might also exploit external information sources such as weather or news while OpenADR may not contain all the necessary information.

III. SUGGESTED FRAMEWORK

We envision that interactions among systems with heterogeneous information models mediated by a facilitator are of growing interest in DR and mixed-BMSes. We propose an information mediator system that can interact with heterogeneous client systems and interprets information from them based on an integrated, system-agnostic information model. Client systems such as buildings and grids can interact via this mediator with their own models. The system-agnostic model is easily extended with other information types to provide greater analytical flexibility. Fig. 2 shows the overall architecture. We convert system-specific information models to ours instead of merging them into the model. In the scenario of the intermediate facilitator, it is uncertain what system-specific information needs to be integrated initially and there are numerous system-specific models with different formats.

For example, in DR a campus manager may want to collect energy consumption from all buildings and curtail their loads according to buildings' purposes to meet their contract requirements without penalties. A hospital building might be the last to curtail energy, requiring a rebalancing of other building's loads. In fact, a campus might not consist of buildings with a homogeneous building management system. All buildings' energy consumption information needs to be aligned to a common information model to exploit the information. The same example can be extended to a higher fidelity evaluation if instead of considering a building's load as a constant, a buildings' architecture, use, time of day, outside weather, and other features are taken into account. This broader inclusion of information provides an avenue for better load analysis and efficiency, but also increases the likelihood of information model mismatch across BMSes. Another example integrates weather information. Either a building or a grid may want to use weather information to predict electricity prices.

The system-agnostic model can function as an anchor that various schemata are normalized to and also connects them to the external world more easily if the model is composed of widely-adopted general models. An information mediator converts system-specific information into the system-agnostic model and vice versa. When systems need to interoperate, they must either adopt a shared information model, or they must have adapters that convert models to each kind of system they interoperate with. This can be a time-consuming and risk-prone process since it is never known what the life expectancy of a particular model might be, and downstream changes are costly to accommodate in software. Also, as the number of required interaction types or their complexity increases, the number of adapters that must be developed and maintained grows. The system-agnostic mediator for n different information models needs $O(n)$ converters that offload the burden of information conversion from individual system and each of m systems needs only one adapter for the mediator. The number of necessary total converters is $O(n + m)$ with a system-agnostic mediator. Without a mediator, legacy systems with different information models require the development of an adapter for interaction with each different information model. Each of m systems needs to have $O(n)$ converters for n information models, which are in total $O(nm)$ converters.

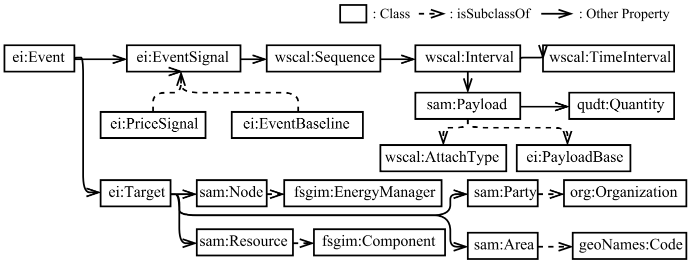

Fig. 3: Core Concepts in Suggested DR Ontology

IV. PRELIMINARY IMPLEMENTATION

A. A System-Agnostic Model

We take price-based DR as an initial application and the framework is easily extended to other use cases. We integrate the information entities necessary for DR pricing from existing standard models and protocols into an ontology. Standard information models used include FSGIM[13] (and by proxy, parts of the Energy Interoperation (EI) [6] model, the eMIX [17] model, the WS-Calendar PIM [7] model and WXXM [18]). Protocols used include OpenADR [16], BACnet [10] and SEP2.0 [19]. Some of these standards are not in OWL format with URIs. We convert them into OWL [20] with URIs so that we can integrate them into a semantic model for the same framework. Fig. 3 shows a model of DR signals shown in the integration – class names are in italic in the following text. We use a name space called System-Agnostic Model (SAM) to represent our own entities. The name space contains triples to connect entities in different standards and entities that are subclasses of entities in other standards for renaming without the loss of information and confusion. The *Event* class, from the EI standard, models a DR event, such as a defined period of time when the price of electricity will be higher than normal. We use *Sequence* and *Interval* from WS-Calendar[7] for timeseries data. It models sequential intervals, each of which is dedicated to a time range and can have a *Payload*. *Payload* is a subclass of *AttachType* from WS-Calendar and *PayloadBase* from EI. It contains the pricing information, and is ”attached” to a time range as defined in WS-Calendar. There are several ways to represent prices. A price can be given as an absolute value of price, proportional to a base price or a level indicating a price among predefined levels of prices. Still, each price type is a kind of quantity regardless of the variations. In the absence of a standard information model for quantities, we use the QUDT[1] ontology to model all quantified values in a consistent way. *Event* also has a *Target* which is the intended recipient or the affected resource of a DR notification. Possible *Target* types in OpenADR are virtual end nodes (VEN), resources, parties and areas, each of which is modeled as *EM* (Energy Manager) or a subclass of *ComponentElement* in FSGIM, *Organization* in the Organization Ontology[2] or *Code* in the geoNames ontology. Administrative information also needs to be shared. It includes event identifiers, event priority, test flag, etc., which are omitted in fig. 3. Unlike price information, the administrative information is specific to DR so we adopt relevant entities in EI and eMIX directly as OpenADR specifies.

Concepts from different standards are connected in two ways. If the same concept appears in several different standards, we define a new concept tat is a subclass of the concept in each of those standards. Entities from different standards are also tied together with properties in the standards provided the values do not violate any defined type constrains. For example, a *Payload* in EI could have a value of a QUDT *Quantity*.

B. Mediator System

We implement the suggested mediator architecture in Fig. 2 that converts messages from client systems and can run DR logic. A grid publishes DR messages for targets to the mediator and a building can subscribe to the DR messages by PUSH or PULL mode via HTTP in a consistent way. HTTP is one of the two transport mechanisms together with XMPP that OpenADR supports [16]. It is encouraged to use XMPP for ones who want to implement PUSH over client-initiated sessions.

The architecture includes an Information Adapter composed of multiple converters to normalize information with respect to models and formats, which offloads interpretation of various standards and encoding formats from clients. A client may internally use any format among Turtle, XML, JSON, etc.

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[1] Quantities, Units, Dimensions and Data Types Ontology, http://qudt.org/
[2] The Organization Ontology, https://www.w3.org/TR/vocab-org/

We implement a converter between XML and Turtle for the first implementation as OpenADR uses XML and general ontologies can be represented by Turtle. A DR message may contain tariff and administrative information, and it is converted to the system-agnostic model.

Included models and converted signals are stored in the Information Storage that can store triples and reason over them. The mediator uses predefined HTTP APIs to invoke semantic logic (SPARQL queries, SPIN functions and SPIN rules) on the Information Storage for transferring triples and reasoning over the given information. We use TopBraid Live[3] as a triple store and a reasoning engine.

V. RELATED WORK

Ontology mapping has been extensively studied [21]. The mapping's goal is to achieve interoperability between different ontologies, which is similar to ours. However, we do not propose an automatic ontology mapping but rather focus on what to do if mappings are known in particular for purposes of applications. Regueiro et al. suggest semantic mediation systems for observation datasets with the same philosophy where datasets with different ontologies are integrated with core system-agnostic ontologies [22]. However, the mediation focuses on merging datasets rather than interactions among systems and its system-agnostic model is focused only on sensor description. Wang et al. also propose semantic mediation for dataset integration with a metadata extraction tool [23].

VI. FUTURE WORK

Our current implementation includes one application and it can be extended to other applications. There are various use cases not included here such as adding other information models to predict energy usages of heterogeneous buildings and mediating load curtailment among different buildings based on rules. Additionally we envision that it will enable unified control mechanism for multiple buildings, using system-agnostic control models. We aim to extend our system-agnostic model to cover more cases. System scalability should be considered in the future as our system is intended to interact with grids and buildings in real time.

VII. CONCLUSION

We have proposed an information mediator architecture based on a standards-based system-agnostic model for DR between the electrical grid and buildings. Information about DR pricing events can be transferred from and to the mediator without the loss of information and it can be translated per the client's information model. Current implementation for a proof of concept shows that client systems can receive semantic information without changing their current information models. We will continue to cover more use cases and validate the system implementation.

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