Implementation challenges of automatic demand response for households in smart grids

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Implementation Challenges of Automatic Demand Response for Households in Smart Grids

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***Abstract*—Utilities rely on Demand response (DR) systems to balance the supply and demand in the power grid. Traditionally, DR systems are utilized by commercial customers since they consume a great deal of power during peak times. With the introduction of Open Automatic Demand Response (OpenADR), DR systems are increasingly becoming available to households. However, there are many obstacles that hinder the wide adoption of automatic demand response systems in the residential sector. In this paper, we focus on OpenADR implementation challenges in households and discuss technical and non-technical issues related to effectiveness, security, privacy, and scalability properties that must be considered when implementing automatic demand response (ADR) systems in households.**

I. Introduction

Demand Response (DR) is a mechanism used by utilities to stabilize the power grid. Participating customers in DR program receive signals to reduce their electricity usage during peak times or shift that usage to off peak periods. Traditionally, DR process was triggered manually by calling, emailing, or texting electricity customers who consume large amount of power during peak times [1] such as commercial and industrial customers. In order to provide cost effective, reliable, and easy to implement process, the Automatic Demand Response (OpenADR) protocol specification [2] [3] is introduced as an industry standard to provide software interoperability framework. The OpenADR specification describes a suite of functions and capabilities for the utility and the participants to exchange DR information automatically [3] [2]. OpenADR is part of the new Smart Grid technologies such as advanced information, control, and communications technologies [2]. These technologies are designed to help optimize the linkages between electric supply and demand. The goal of the OpenADR protocol is to translate timely and reliable demand response events into load sheds or shifts by the participants without the need for any manual process.

As we move towards full deployment of Advance Metering Infrastructure (AMI), ADR systems are becoming increasingly attractive specifically for households. In households, the OpenADR mechanism is expected to automatically engage several OpenADR-compatible appliances in DR events. Several research studies, such as those in [6]-[9], have shown great potential for ADR systems for residential sector. However, there are many challenges that hinder the wide adoption of ADR such as scalability [18], security [4], privacy [5] and user acceptance issues. With respect to consumers' security and privacy concerns, several scenarios of adversary attacks could jeopardize the DR process as discussed in [6]. For example, an external adversary attack on the communication system might end up controlling the bi-directional messages and initiating illegitimate demand response bids to sabotage the power grid operation. Another example of attack could be a malicious consumer who wants to cheat the OpenADR protocol in order to gain larger rewards by submitting false bids and not reducing the agreed upon amount of energy [6]. Even worse, this consumer could collaborate with an external adversary to inflict devastating damages to the system since the consumer is a legitimate agent in the OpenADR protocol and has access to a set of cryptographic keys required to respond to DR events. Another attack scenario may come from the energy supplier [6]. It is assumed that the supplier follows the OpenADR protocol, but it can breach consumers' privacy by linking several bids to individual consumers and make inferences based on these bids. There are other issues related to the heterogeneity of how consumers go about their energy use lifestyle. It is very costly to determine which appliances to participate in OpenADR events as it is not feasible to contact every consumer and obtain their energy consumption characteristics.

In this paper, we focus on OpenADR implementation challenges in households and discuss technical and non-technical issues related to effectiveness, security, privacy, and scalability properties that must be considered when implementing DR systems in households.

The rest of the paper is organized as follows: In section II, we provide an overview of automatic demand response; specifically we discuss the OpenADR protocol. In section III, we discuss the implementation challenges and the open issues. Finally, in section IV we conclude the paper and provide direction for future work.

II. Overview of Automatic Demand Response Protocol

In this section, we provide an overview of the automatic demand response mechanism. Specifically, we elaborate on the specification of the OpenADR protocol and its deployment in households. We also present some of the ongoing implementation studies in this area.

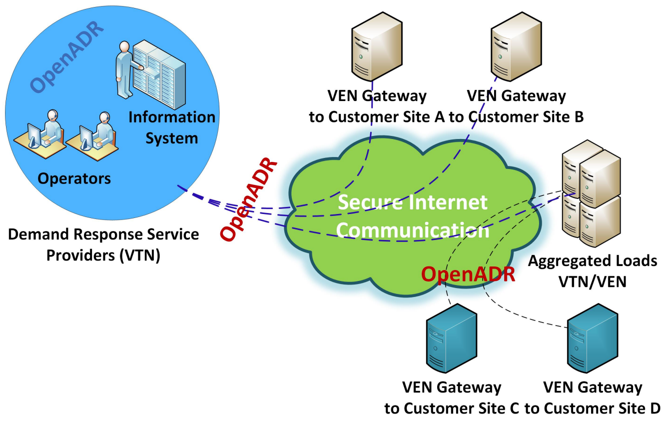

Fig. 1. Overview of VTN and VEN relationship in OpenADR

A. Background on OpenADR

The OpenADR is a data model for communicating events such as DR signals, price schedules, and grid stability, between a DR server, known as Virtual Top Node (VTN), operated by an energy supplier, and DR clients, known as Virtual End Nodes (VENs) [3]. The recent developments have expanded the use of OpenADR to meet diverse market needs such as ancillary services, dynamic prices, intermittent renewable resources, supplement grid-scale storage, electric vehicles, and load as generation [2]. For example, with real-time price information, an automated client within the customer facility can be designed to continuously monitor these prices and translate this information into continuous automated control and response strategies. This process is considered as a fundamental element of Smart Grid interoperability standards, which are developed to improve dynamic optimization of electric supply and demand. The paradigm includes a Demand Response Server (DRAS) through which OpenADR signals are sent to ADR-compatible devices, known as resources, using push or pull notifications. According to the specification of the OpenADR protocol, the energy supplier and the customers access the Demand Response Server (DRAS) over an IP network and utilize encrypted messages for security and privacy. The DR event information are translated to continuous Internet signals to facilitate DR automation. These signals are designed to inter-operate with energy management and control systems, lighting, or other end-use controls. In a residential setting, the VEN acts as a gateway that controls these resources, which are participating in the DR program. In such case, the external signal is designed to initiate automation through the use of pre-programmed DR strategies determined and controlled by the end-use participant.

Figure 1 provides an overview of the VTN and VEN relationships. The VEN is a gateway that controls devices at the customer site. The VEN could be a software embedded in the resource itself and controlled using OpenADR communication protocol. OpenADR nodes are organized in a tree, where the VTN is represented as root node communicating with several VENs via OpenADR messages. All network nodes in OpenADR must have the capabilities to listen and query for events, register themselves, schedule events, and send reports. The VTN node is responsible of publishing and transmitting information about DR events from operators or utilities to VEN nodes which receive the messages and respond to them. It must be noted that VEN nodes communicate with resources using OpenADR protocol or other mean of communication. They may communicate using HTTP in either PUSH mode or in a PULL mode. The VTNs/VENs may also communicate over other transport mechanisms such as XML Messaging and Presence Protocol (XMPP).

The general setup is that the VTN takes the role of a server interacting with VEN clients such that the VTN initiates the DR events and the VENs receive them and respond. The specification of OpenADR left deployment configuration to the designer based on the objectives of the deployment. In this regard, VTNs and VENs can be deployed in any hierarchy, by allowing actors to act as VENs for some interactions and VTNs for others. The exchanged events in either direction can be independent from each other and the OpenADR Alliance does not define how the nodes react to the information. In nodes, which support both the VTN and VEN interfaces (e.g., aggregators) there are no specifications or constraints on how messages arriving at the VEN interface are coupled or translated into any subsequent messages that may be sent from the VTN interface and vice versa. Next, we discuss the benefit of ADR and then provide a review of current OpenADR implementation and research within residential sector.

B. OpenADR Benefits

There are several benefits of deploying automatic demand response and they are embodied with the OpenADR standard, these benefits can be summarized as follows:

- **Customer control**. Legacy demand response programs give the utility company full control over appliances inside buildings through mechanisms known as Direct Load Control(DLC). With OpenADR, the consumer can respond to the demand response signal by adjusting the level of comfort, opting out and in, ignoring the signal, and also decide on the number of intervention by the utility or the aggregator.
- **Supporting curtailment through aggregation**. For households, it is not feasible to directly participate with the utility in DR programs as the amount of consumed energy is small compared to commercial and industrial companies. However, energy curtailment for houses can happen through cooperation or aggregations [7]. With OpenADR, households can participate in the marketplace with various types of aggregators that can serve as gateways to house-based energy loads [11].
- **Diversified signaling**. Demand shaping is a dynamic process, which could vary according to any given situation. With ADR, the utilities can employ various mechanisms to shape the load profile, by giving incentives to shift load to desired time slots. The rewards can take any form

and can include dynamic prices, where customers receive market signals to shave peak use or shift consumption from critical periods [12] . The utility has the mean also to provide the demand needs in advance or in real time irrespective of the price structure; to request decreases as well as increases in consumption; and to target certain loads or appliances at the facility. ADR can be tailored to meet the needs and requirements of both the utility as well as the customer.

- **Supporting ancillary services**. This is one of the great potentials of ADR as a means of supporting ancillary services such as frequency regulation. This service can only be accomplished via real-time signaling because it requires fast response, often two-to-four seconds. One main example is vehicle-to-grid concepts, where many connected battery-powered cars and trucks to the grid, can provide frequency regulation through charging and discharging to and from the power grid [14].
- **Supporting integration of renewable energy sources**. Recently, the deployment of renewable energy sources such as solar and wind turbines has increased dramatically. Integrating such renewable into the power grid is not a trivial task since the power supplied from these sources is intermittent. The only possible way to have these renewable integrated is through automatic operations while keeping the grid operation stable. ADR provides a mechanism for grid operators to integrate such resources which cost less and more responsive compared to costly power plants.

C. Current Implementations

Recently, several research studies such as those in [8] [9] and [10] have proposed methods of implementing automatic demand response for households in the smart grid. In [8],the authors studied the potential for non-disruptive DR in the residential sector in Denmark. They provided an order of magnitude estimates of the technical potential for DR from households. The result of their study shows that the total controllable load from typical resources such as washing machines, clothes dryers, and dishwaters are each nearly 1 GW by 2030. The study concluded that there is visibility of applying ADR mechanisms in households. Similar to [8], the work in [9] provided potential analysis of introducing of ADR for residential houses in Austria, the authors found that there are a great potential of shedding MWs using ADR, but they also found a great deal of variability and uncertainty that needs to be addressed. The work presented in [10] propose network integration for exchange of DR signals between the utility operator and home users who want to participate in DR services at various locations. The authors introduced automated residential DR model based on OpenADR, they have embedded the control capabilities of VEN inside the smart meter and perform simulation and demonstration tests to proof their compliance with the OpenADR specification.

OpenADR is also implemented in the work provided by [15] to communicate electricity prices and adjust controllable loads in building. The authors simulated an intelligent building DC Micro-grid simulation in which the Wind-PV-diesel battery hybrid power system are realized to increase accesses of distributed energy. The authors in [12] propose ADR mechanism to control appliances in homes in response to dynamic price signals to reduce the consumer's electricity bill. The results from different realistic case studies show the effectiveness of automatic DR in minimizing the household's daily electricity bill and preventing the creation of new least-price peaks. In [17], the study presented implementation of ADR for houses equipped with smart appliances, such as washing machine, dishwasher, tumble dryer and electric heating where these appliances can participate in DR programs. The results show that the proposed mechanism has the capability to reduce residential energy use and improve the user's satisfaction.

In parallel to the above studies, different architectures of the OpenADR protocol were examined and analyzed in the work presented by [18]. The study analyze the properties of a number of OpenADR-based architectures that have been proposed for deployment by ADR vendors, in terms of interoperability, scalability, complexity, and security. In [21] an implementation of OpenADR over the Internet and over FM radio is presented, the outcomes of the study shows that utilities can send hourly or sub-hourly electricity pricing information simultaneously to residential, commercial and industrial customers.

III. Implementation Challenges

There is no doubt that OpenADR is an important enabler for deploying DR programs and help stabilizing the power grid. However, as mentioned in the previous sections, the wide acceptance of ADR in residential sectors is yet to take off to the level where utilities and policy makers are hoping for. There are many technical and non-technical challenges that hinder the wide deployment in households. In figure 2, we provide an overview of four major challenges of ADR and the road map for further research.

A. Scalability

One of the major issues facing the wide deployment of automatic demand response systems is scalability. In general, OpenADR systems are designed to operate in client/server architectures, but, as the number of households base increases scalability becomes of large concern. The DR nodes share DR signals through the network, and it has been shown by [18] that event messages from VENs generates approximately 100 TByte traffic per day in the case of one million VENs. This amount of traffic can easily block the network that is connecting the nodes. Also, it has been shown by [18] that the large number of individual messages results in increased latency at the VTN as well. These problems calls for innovative deployment architectures to make sure that DR events reach to the subscribed resources in time. For example, cloud-based deployment is suggested to alleviate the scalability problem as resources are abundant in cloud. However, cloud-based deployment carries additional challenges pertained to security and privacy.

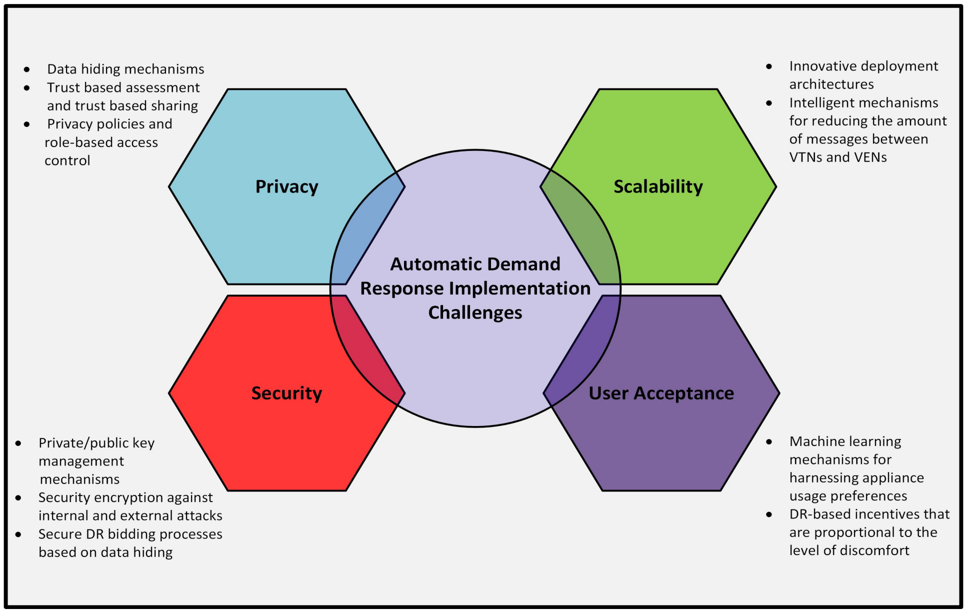

Fig. 2. Implementation Challenges of Automatic Demand Response for Households

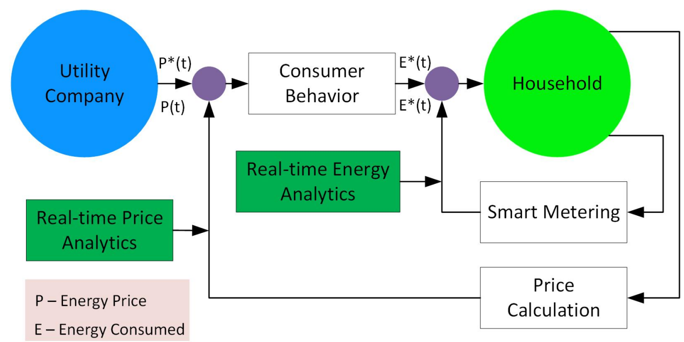

Fig. 3. OpenADR between the utility company and residential consumer (adapted from [19])

Furthermore, the ADR process between the utility and the residential consumer is based on an agreed upon commodity contract where the goal of the automated process is to find an optimum between the time varying energy price negotiated and the corresponding energy amount provided and consumed [19]. There are many constraints to this agreement resulted from day, season, and geo-spatial location changes. The challenge of building an ADR solution is in finding the optimal energy load profile for every point in time all year round. From the consumer side it is not easy to define an energy demand at all times that matches the required supply. This requires real-time analysis of the consumer energy profile and adjustment to the utility price signal. Such price signal also needs to be justified at all times to be charged to the end consumer who is involved in the ADR contract. In order for this loop (see figure 3) to function properly, the ADR approach, must rely on big data forecasting mechanisms that can ingest, manage and analyze highly resolved big data streams in real time. These mechanisms must be capable of correlating the energy and pricing data with the time of day, season, and geo-spatial location constrained. Only in a such a way a match between the supply and the demand can be achieved based on an optimum price that satisfies both the consumer and the utility company [19].

B. Security

The electricity grid is considered a critical infrastructure and hence security is of great importance. The main objective in of security in ADR is to prevent illegitimate entities to participate or intercept the DR signal. In this regard, consumers and demand response management must have the mean to verify the authenticity and integrity of all DR events. Message exchange in OpenADR are carried by the Transport Layer Security (TLS) where client authentication is required for mutual authentication [3] [2]. All nodes are expected to be equipped with public/private key pairs and digital certificates issued by a trusted Certificate Authority (CA). During communication, the peers must be able to verify each other using the digital certificates. One main aspect of security is related to key management [6], this is especially so in the case of having large number of nodes in the system. In cloud-based deployment is that adversaries can target the communication between the utility's system and the DR system on the cloud provider to disrupt operations. While it is not easy to break the underlying cryptographic primitives of the communication link as well as the OpenADR protocol, the security and privacy of the system are still fully dependent on all secret keys being protected from the adversary. Another example of attack could be a malicious consumer who wants to cheat the OpenADR protocol in order to gain larger rewards by submitting false bids and not reducing the agreed upon amount of energy.

Even worse, this consumer could collaborate with an external adversary to inflict devastating damages to the system since the consumer is a legitimate agent in the OpenADR protocol and has access to a set of cryptographic keys required to respond to DR events.

Based on the discussion above, all OpenADR compliant systems must implement at least standard level security in which Transport Layer Security (TLS) with mutual authentication is used to protect the confidentiality and integrity of the communication and authenticate the communicating entities. Some OpenADR systems implement the high security level in which XML signatures are used in addition to TLS to ensure the integrity and authenticity of the messages. In addition to the above goals, the specific hardware elements used in the smart grid might introduce requirements on the security mechanisms, for example, that any cryptographic operations used in the protocol must be achievable on a smart meter with limited computational capabilities.

C. Privacy

As explained in [4], there are three major streams of information in OpenADR systems between household and the demand side manager. These stream contribute for the generation of private information related to billing, demand side management and consumption data. The process of invoking demand response entails the generation of significant amount of private data that could harm the consumer in many ways. The data may reveal information about consumption behavior, billing and financial information, inhabitants demographic, consumers' identity, contact information as well as address of the houses. This information if it gets into the wrong hand can be shared with unauthorized parties [22] or even sold for marketing purposes [23] [20].

The energy consumption may contain data about how households go about their energy consumption and pricing sensitivity and preferences. For residential consumers, the protection of personal or private information is an important requirement in the smart grid. This is illustrated by the significant privacy concerns raised in response to the introduction of smart meters s well as the various research efforts to develop privacy-preserving smart metering protocols. However, despite their importance, these privacy goals are not addressed in the OpenADR specifications. The specifications only call for confidentiality of the communicated messages with respect to an external adversary.

D. User Acceptance

Although many automatic demand response program are accompanied with incentives to encourage consumers to participate, there are still many challenges facing utilities in getting consumers' buy-in. Beside the issues of security and privacy, typical DR actions such as sustained load shedding can directly impact consumers, making some unwilling to participate in DR programs because they care very much about comfort and control [24]. In other words, consumers are not yet into the idea of giving up their appliance operation decision to external entities. Furthermore, demand response traditionally pays little attention to appliance association usage, which is extremely important for consumers as it is related to their comfort and lifestyle. In every house there are many appliances that contribute the energy consumption pattern, some of these appliances are either run sequentially or simultaneously in relation to the activities that the user is performing. Currently, little work has explored the idea of dynamically determining the appliances that should be included together in the demand response event because of their usage association. Such open issue is critical for consumers who are used to perform several home activities at the same time. Disruption such habit leads to discomfort, which in turn rejection of the demand response signal. The main issue here is how to include machine learning mechanisms that uncover consumers' energy consumption behavior to effectively unlock the potential benefits of investing into OpenADR implementations [25] [24].

Another problem is related to scheduling efficiency of demand response algorithms. Because consumers behave differently, their scheduling of appliances should be different; this might not be a trivial as this burden goes to utility companies. They must be able to device different scheduling algorithms for each home to schedule as many appliances as possible at the lowest prices. In addition, automatic demand response might lead to what is known as the rebound peak, i.e., shifting the natural peak period to new time slots. This phonemnun usually happens when homogeneous demand response mechanisms are installed at each house. One possible way to solve this issue is to plan demand response strategies where each home has a limit on the maximum allowable energy that can be shifted from one time slot to another.

IV. Conclusion and Future Work

In this paper, we have discussed the implementation challenges of deploying ADR systems for households in the smart grid. These systems are mainly utilized by commercial and industrial customers. However, the proliferation of OpenADR standard and the AMI infrastructure make it possible to extend ADR service o households. In this paper, we discussed the OpenADR specification and provided an overview of related implementations. We also discussed the benefits of ADR and the challenges related to security, scalability and privacy that hinder the wide acceptance of ADR system in the residential sector. Our future work, is to take a deeper dive into these issues and analyze them and address the practicality of some of the proposed solutions in the literature.

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