A Cloud-Based Open Automated Demand Response Protocol with AMI Support

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***Abstract*— With the increasing number of clients and emerging of renewable energies to the smart grids, maintaining a balance between supply and demand has become a challenge. One of the most important issues in smart grids is the efficient management of demand for energy transfer and distribution networks, especially in electrical grids. The recent studies mostly try to model the clients' usage patterns to use less electricity preferably, particularly during high usage hours. Nowadays demand response is one of the hottest topics in industry and academia as the demand response programs is one of the main solutions in lowering the peak demand and balancing the supply and demand. On the other hand, increasing in the number of clients in demand response programs highlights the importance of process automation of these programs. In recent years OpenADR has been introduced as the international standard for implementation response programs automation. In this paper, we implemented OpenADR in a lab environment, and the demand response server has been deployed in the private cloud. This implementation supports the ability to register clients with all the electrical device information and also automatic reading for each device and the data related to the smart meter. The goal was to combine the advanced metering infrastructures with demand response programs to reduce deployment costs and integration of services. We send useful information like clients cost, minimum and maximum usage and the average usage in the society to the clients through OpenADR to make motivations for them to reform their usage pattern.**

Keywords*——*Smart Grid; OpenADR; automatic demand response; cloud computing; big data

I. INTRODUCTION

Smart Grid and demand response are crucial Topics in Power Industry[1]. Demand response programs, consider as customer power consumption pattern changes due to power pricing changes. By incentive plans in demand response programs, customers encourage to reduce their power usage during peak hours, due to high power price and consequently the grid reliability will increase [2]. The object of demand response programs is to mitigate peak demand by decreasing of load or shifting usage time. Demand response programs are one of the main smart grid services[3]. In some papers, demand response is considered as a solution to confront increasing demand without increase of generation capacity. It also mentions as a way to integrate renewable energy in Smart Grid [4]. Since emerging of renewable energy generation technologies, load balancing between demand and supply becomes more complex. Also by increasing of power consumption and peak demand and power cost, demand response automation attract more attentions [5], which leads to developing OpenADR as an international standard for Auto-Demand Response[6].

Open Automated Demand Response is a data model for communications to automate demand response. Its development begins from 2002 in Lawrence Berkley National Laboratory [7]. OpenADR 2.0 was released in 2013 by OpenADR Community. OpenADR specification specifies the basic interaction between client and server and does not define all deployment scenarios. It leads to grows of various OpenADR deployment architectures [8]. OpenADR is one of the main interoperable standards of smart grid which is aim to improve demand and supply balance. It designs for automation of customer side demand response programs that schedule customer power loads including either shiftable or non-shiftable loads. It also provides continues dynamic pricing signals like hourly day-ahead or day-of-real time pricing and supports various type of demand response programs [9].

On the other hand, the large size of data is collecting from a different kind of Smart Grid equipment every day to perform demand response programs. Exchanged data volume is growing up over time by increasing number of customers, which makes traditional systems unable to manage it. This will lead to leveraging cloud computing environment which is suitable for big data management that guarantees reliability, efficiency [10].

The concept of cloud computing is massive computing and storage capacity in large data centers that are offered by cloud providers. Recently researchers present method for using cloud computing to help smart grid management. Cloud computing is used to increase the reliability, security, and stability in the smart grid. We needed a scalable platform for smart grid applications when the volume of data increased. A cloud platform can provide scalable and shared resources in order to set up a smart grid cloud-based architecture based [11].

All the benefits of the cloud computing can be used in the smart grid. Fig. 1 shows the benefits of cloud computing.

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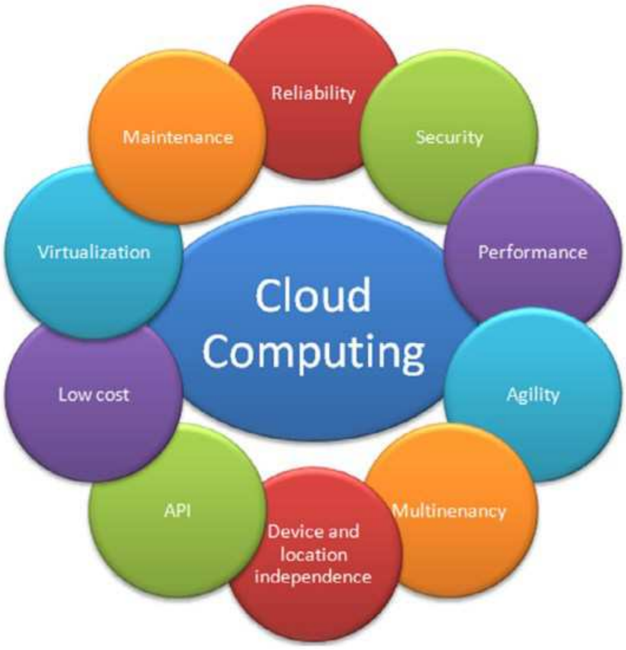

Fig. 1.Cloud Computing Characteristics [13]

The upcoming sections organized as follows: in the second part, we introduced the OpenADR protocol. In the third part is a review of related works. The proposed model is described in section IV. Results and evaluations are shown in section V and finally in section VI summary and conclusions will be presented.

II. OPENADR

OpenADR protocol has several versions (1.0, 2.0a, 2.0b, 2.0c). Version 2.0 designed for demand response management which describes required communication information [6]. OpenADR is an open standard and uses XML for data communication of demand response and pricing signals[14]. Fig. 2 depicts client/server Architecture of OpenADR.

OpenADR provides standards for communication architecture, data model, user programming interface, security policy and so on. OpenADR version 2.0a designed for simple devices like the thermostat whereas version 2.0b designed for energy management in advanced devices which release on 2013.

OpenADR defines a Client/Server communication model which named server as Virtual Top Node (VTN) and client as Virtual End Node (VEN). Nodes are organized in a tree and classified to VTN and VEN. Some nodes like aggregators could have both roles of VEN and VTN at the same time [8]. Transmission mechanisms of OpenADR support HTTP and XMPP. In HTTP mechanism, PULL and PUSH communication modes are defined. Fig. 3 shows a sample interaction of demand response from VTN to VENs in OpenADR architecture.

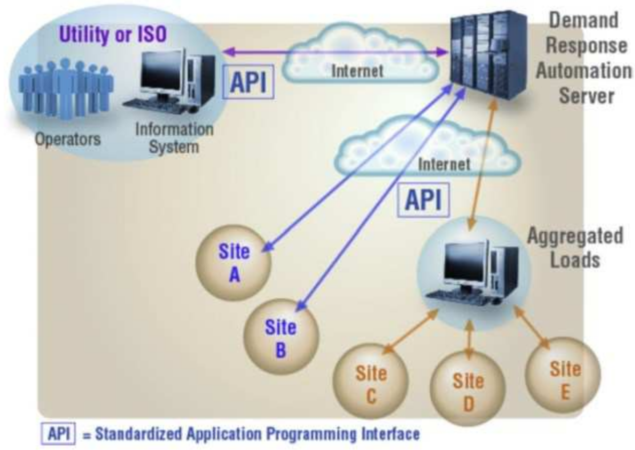

Fig. 2.OpenADR Architecture [15]

OpenADR 2.0 services are listed below:

- Registration (EiRegisterParty): Registration of VENs entities to VTNs.
- Event (EiEvent): Core of DR is Event function and Information model for DR price.Reporting and Feedback(EiReport): capability of information period set or one-time for one source situation
- Opt or Override(EiOpt): Availability short-term Address change for communicating scheduling Opt-in or Opt-out from VEN to VTN

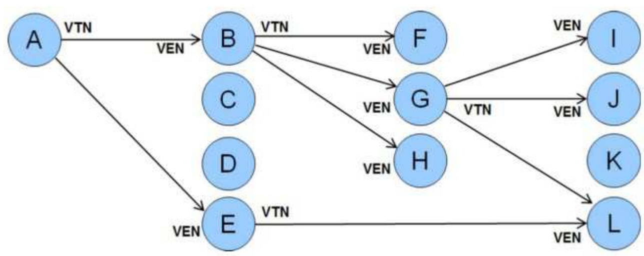

Fig. 3. Sample interactions in OpenADR architecture[16]

III. RELATED WORK

Demand response is a way to reforming the peak load, managing the data and maintaining reliability. With the rise in the number of customers in demand response programs, scalability has become a major issue and enforced them to move to clouds environments. In [17] authors concentrated on systems based on OpenADR 2.0 and discussed the security challenges in migrating to clouds. A mechanism in [4] has proposed in order to have a higher security level for clients using demand response.

In [8] the OpenADR based architectures have been investigated, and it was analyzed with parameters like scalability, complexity, and security. An architecture for automated demand response system introduces which uses OpenADR communication model has been proposed in [3], and the purpose of that is making bidirectional communication between the electrical company and the end client and solve problems such as peak demand, the gap between supply and demand, and managing the power structure.

The topic in [18] is to present a multi-agent system to integrated several IoT devices. The primary goal is to increase efficiency, reduce power consumption and implement demand response in building with the help of OpenADR protocol.

Many papers focus on demand response for industry and commercial areas. Nowadays by increasing of residential areas participation in demand response programs, the researchers make more attention in this area. For example authors in [19] has proposed an automated demand response method for residential areas in advanced metering infrastructure. Also, OpenADR has been used to automate demand response programs completely.

In many papers, cloud computing environment has been used for smart grids. A cloud computing framework in smart grids in [20] has been proposed which creates small integrated energy hubs and real time computing for stored data. It has present a stochastic dynamic programming in cloud computing in order to manage the demand side has been used effectively.

IV. PROPOSED MODEL

Nowadays, Demand Response is one of the most important objectives of research in industry and academia. Due to increasing number of customers and their demands, the importance of the demand response automation appeared stronger than before. Demand response automation can help the system reliability, customer comfortable, costs reduction of utilities and customer. OpenADR communication protocol has become a standard for automated demand response programs in recent years. In this paper, we focus on the implementation of OpenADR in a cloud environment and customize it to achieve out goals. Our proposed architecture is shown in Fig. 4.

In this model, we provide the capability to send customer billing at in real-time and help them to take intelligent decision for their usage pattern. This model also supports sending minimum, maximum and average consumption information from the VTN to the customer. According to the studies [22], this information can affect customer behavior to reduce power consumptions.

By considering the growth of data that should transfer, stored and processed, and movement towards big data we also used the benefits of cloud computing. So we implemented the demand response server on the cloud.

In order to implement the cloud, we used an open source cloud computing platform called OpenStack. OpenStack is used as an Infrastructure as a Service (IaaS) and used for public and private clouds. OpenStack software was installed on Ubuntu operating system. The Newton version of OpenStack was used which is the current stable version at the time of deployment.

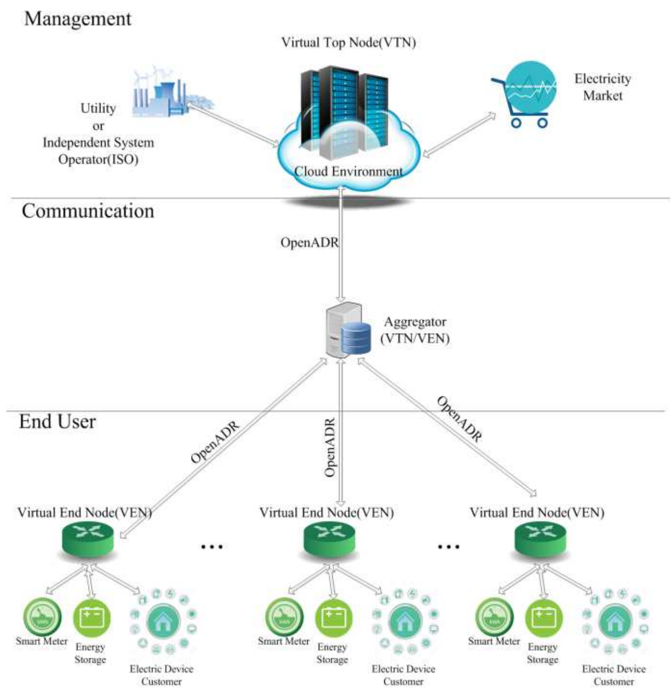

Fig. 4.Proposed architecture

We set up following services of OpenStack:

- Dashboard
- Compute
- Network
- Identity service
- Image service

The KVM supervisor virtual machine was utilized for virtualization. In this paper, we implemented OpenADR 2.0b standard protocol according to its XML schemas in the lab environment. For scalability, we could use horizontal and vertical scalability. We chose horizontal scalability and created four types of flavors for our instances in the cloud which shown in Table 1 and evaluated our implementation on them.

TABLE 1. FLAVORS PROPERTIES

No.	Flavors	vCPU	Disk (in GB)	RAM (in MB)
1	tiny	1	20	1024
2	small	2	20	2048
3	medium	2	20	4096
4	large	4	20	4096

In this implementation, customer registration is done with all electric devices information. It also supports the capability of automatic reading per electric device and the smart meter device. For this project, information of consumers including their consumptions is simulated, and OpenADR protocol utilizes for exchanging data between VEN and VTN server. The metered information is sent automatically every 15 minutes. The diagram of exchanged messages is shown in Fig. 5.

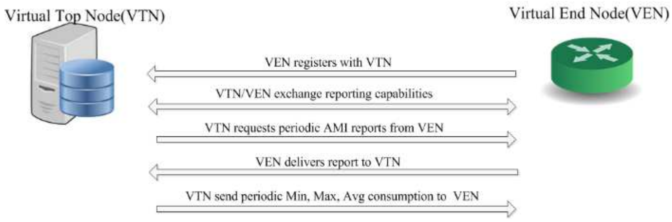

Fig. 5. Message exchange diagram

As indicated in this diagram, after registering of VEN, both VEN and VTN send their reporting capabilities. Then VTN can send its request of periodically automated meter reading to the VEN. Then the VEN start sending periodical messages in specified intervals containing power consumption of the individual device and total power consumption which provided by the smart meter. VTN sends customers total monthly consumption and costs in real-time to the VEN to inform them. Also, the minimum, maximum and average power consumption of society will be sent to let the customers know their position in the community and change their behavior to reduce consumptions.

V. Results

For the evaluation, we measured two parameters according to a number of customers. The first parameter is response time of exchanged messages and the second parameter is the bandwidth it takes. For this purpose, we consider two messages: VEN registration and electric device consumption information. We assume that each customer has five electric devices.

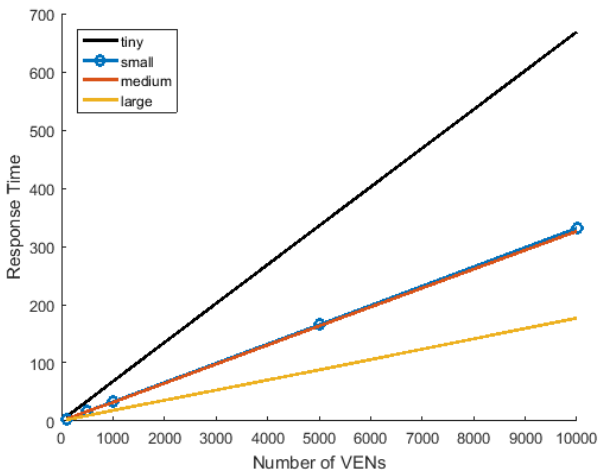

Fig. 6. Response time of VEN registration

Fig. 6 and Fig. 7 shows the response time for registration of VENs and electric device consumptions reading respectively and comparison of four instances. By horizontal scalability and increasing of resources, the response time reduced. The response time of small and medium instances are nearly the same. The amount of RAM is the only difference in these two instances. This indicates that our program is more CPU intensive.

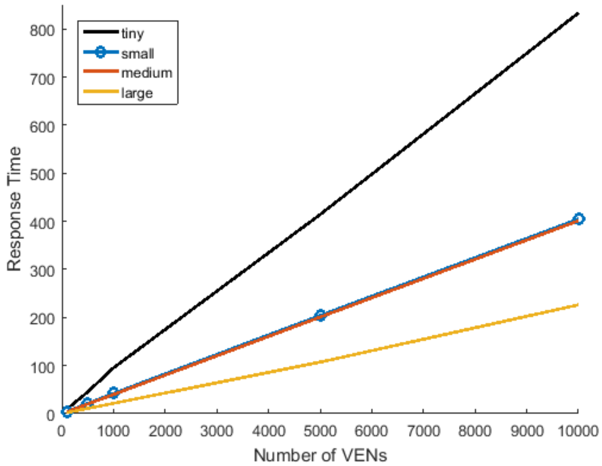

Fig. 7. Response time of electric devices consumptions reading

Bandwidth usage of exchanged data is depicted in Fig. 8 and Fig. 9. The growth of bandwidth is nearly linear. By increasing number of customers, the amount of bandwidth usage is considerable, and it can be a challenge for deploying on a city with millions of customers.

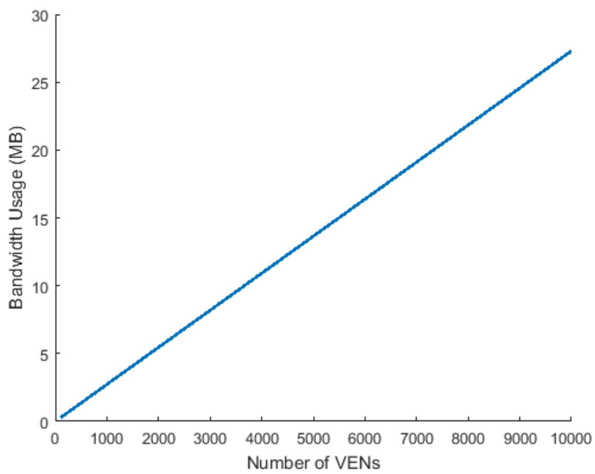

Fig. 8. Bandwidth of VEN registration message exchange

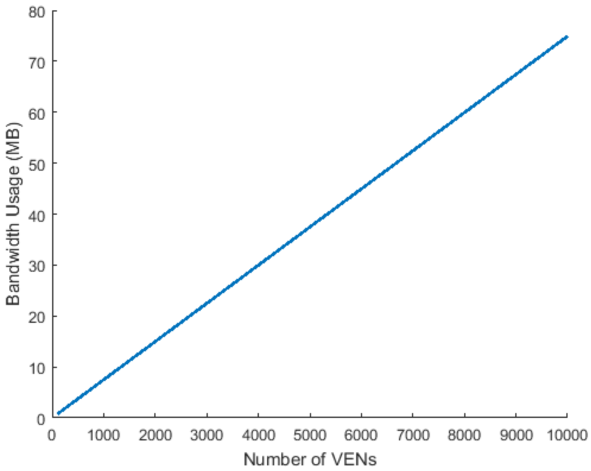

Fig. 9. Bandwidth of electric devices consumptions message exchange

VI. CONCLUSIONS

In this paper, we implemented OpenADR and deploy demand response server on our private cloud in the lab environment. This implementation supports the capability of registering clients with all the electrical device information and also the automatic reading of data for each device and the data related to the smart meter. Our goal was to combine the advanced metering infrastructures with demand response programs to decrease deployment costs and integration of services. This implementation also has the ability to send useful information like clients cost, minimum and maximum usage and the average usage in the society to the clients through OpenADR to make motivations for them to reform their usage pattern. Our results indicate that leveraging cloud computing is a must for smart grid applications due to its unique features such as parallel processing, increasing storage, ubiquitous availability, and flexibility. Utility companies can use our results to estimate their facility and resource requirement to implement automatic demand response and other services which use OpenADR.

Besides all the benefits of utilization of cloud computing in smart grids, there are challenges in terms of security, privacy, performance and reliability that can be considered as opportunities for future research.

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