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Internet-based communication platform for residential DR programmes

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Abstract: The objective of this study is to present the architecture and laboratory experimentation of an Internet-based communication platform to enable residential demand response (DR) programmes that do not rely on the advanced metering infrastructure (smart meters). Technologies and software that serve as the building blocks for the proposed platform, together with the messaging architecture based on the open automated DR protocol, are discussed. Security features necessary to secure DR implementation for a residential sector are also presented. The proposed platform has been implemented in a laboratory environment to showcase how the overall system can function. The proposed Internet-based communication platform is expected to quickly and reliably enable a large number of households to participate in DR programmes without smart meter deployment, while ensuring customer data privacy and comfort.

1 Introduction

With the penetration of renewable energy sources and the expected large-scale introduction of plug-in electric vehicles (EVs), there is a growing need to balance the demand and supply to alleviate grid stress conditions. Demand response (DR) has been envisioned to deal with such unexpected events that can enable customers to react to utility signals, e.g. price or reliability signals [1–3]. Federal Energy Regulatory Commission (FERC) defines the 'DR' term as '*Changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardised*' [4]. FERC also categories DR programmes in two groups: namely, priced-based programmes and incentive-based programmes. The priced-based DR programmes rely on different types of time-varying price signals to encourage customers to reduce electricity demand, while the incentive-based DR programmes rely on some sort of incentive-based payments or contractual arrangements made in advance between utility and customers. Although both commercial and industrial customers play an essential role in DR programmes in today's environment, FERC indicates that the residential sector has the most untapped DR potential. With the advent of smart grid technologies, full DR participation from residential customers is expected to provide roughly half of the total peak demand reduction potential in the USA.

To send DR signals to residential customers, it is typically carried out through smart meters based on advanced metering infrastructure (AMI). However, it may take a long time for smart meters to become ubiquitous in developed countries as the initial investment had faded away (e.g. the American Recovery and Reinvestment Act in the USA) [5], and it may not be economically justifiable in developing countries to invest in smart meters. This is because: (i) two-way communication networks supporting smart meter deployment are expensive to build, maintain and expand [6] and (ii) the major benefit of smart meter deployment which is to reduce labour costs and truck rolls cannot be justified in developing countries where labour costs are fairly inexpensive. Therefore, there is the need for an alternative means to deploy functionalities of the smart grid (i.e. DR) without deploying smart meters. As broadband Internet connection already exists in majority of the households in most industrialised countries and households in major cities in developing world [7], we propose to leverage the existing broadband Internet infrastructure that would enable rapid deployment of automated DR [8].

With respect to web-based solutions for home energy management (HEM) and DR applications, Khan and Mouftah in [9, 10] have proposed an approach to enable interactions between smart homes and utilities via web-services. Batista *et al.* in [11] have presented a method to improve comfort and energy savings in buildings via the Internet. Cheah *et al.* in [12] have developed a web-based consumer energy portal. Authors in [13] have offered a representational state transfer (REST)ful-based web service interface for a building management system. RESTful uses REST architectural style developed as an abstract model of the web architecture.

The main contribution of this paper is to present an alternative Internet-based communication platform for residential DR applications, which allows cost-effective DR programmes that can be rapidly deployed when compared with the AMI that will take time to roll out. The proposed platform is demonstrated in a laboratory environment. The proposed platform relies on the existing infrastructure, i.e. broadband Internet infrastructure, and its messaging format is developed based on RESTful-based web-services and the industry-wide accepted open automated DR (OpenADR) protocol. OpenADR has begun to be developed in 2002 to address the need for an open-standards based communication data model to promote communication exchanges between utility and customers to enable automated DR. It was donated by Lawrence Berkeley Laboratories to the Organisation for the Advancement of Structured Information Standards in 2009 [14] for their development of the Energy Interoperation Standard-Energy Interop™ [15]. At present, majority of OpenADR implementation have been for commercial customers [16]. While an open source solution for OpenADR has becomes available, it has not been widely implemented in a residential space due to the lack of understanding and the lack of hardware/software platform for HEM that can accept OpenADR signals and take actions.

This paper addresses these gaps by providing an insight into an Internet-based communication architecture that supports implementation of DR based on OpenADR standards, as well as presenting a platform that supports this implementation in a residential setting. This option bypasses the need to invest in a costly smart MI, and offers lower deployment risks for an electric utility.

This paper is organised as follows. The proposed Internet-based communication platform including the utility-side architecture, the

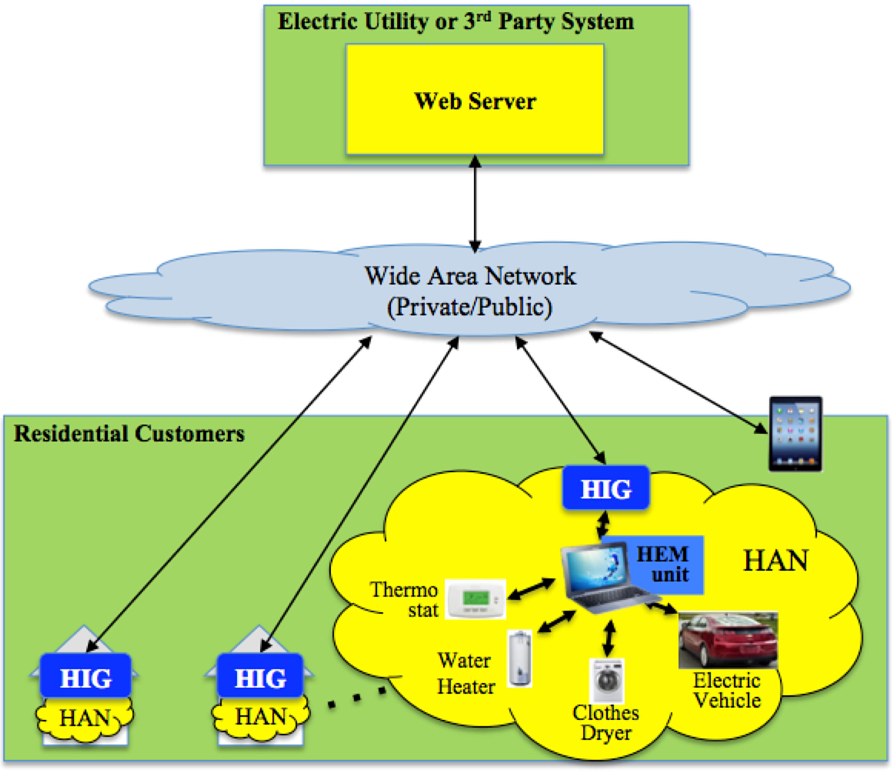


Fig. 1 *Architecture of the proposed Internet-based communication platform*

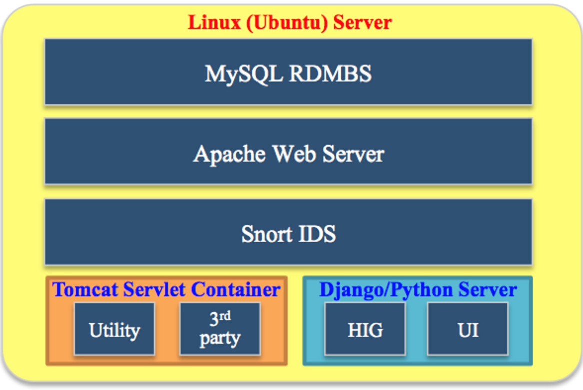


Fig. 2 *Architecture of the proposed WS*

data model for DR event notifications and the customer-side architecture are explained in Section 2. Security measures that have been implemented for the proposed platform are discussed in Section 3. A DR case study in a laboratory environment showcasing the practicability of the proposed platform is presented in Section 4.

2 Architecture of the proposed Internet-based communication platform

The architecture of the proposed Internet-based communication platform is shown in Fig. 1. This system allows an electric utility to send DR signals via the Internet infrastructure, as opposed to AMI.

Building blocks to enable Internet-based DR applications include: (i) a web server (WS) at the electric utility-side and at the customer premises: (ii) HEM system, which comprises a home Internet gateway (HIG), an HEM unit and controllable appliances. Each component is described below.

The WS is responsible for sending DR signals to all households participating in a DR programme. It is also responsible for archiving household electricity usage information (UI) and ensuring customer data privacy with security implementation presented in the later section.

The HIG is located at the customer premises. It serves as a gateway between a utility and a customer premises. HIG is responsible for receiving DR signals from a WS and sending power consumption data from the HEM unit to the WS. This DR signal may comprise a demand limit [kilowatts (kW)] that specifies maximum power consumption of a household, e.g. 6 kW, and a DR event duration that specifies the length of the DR event, e.g. 3 h. Once a DR signal is received, the signal is then passed onto the HEM unit.

The *HEM* unit makes a decision to control appliance status based on customer comfort preference, load priority and a DR signal received. An example of the HEM algorithm that takes into account customer comfort has been proposed in [17, 18]. It is not the focus of this paper to explain the HEM algorithm, but the Internet-based communication architecture for DR implementation based on OpenADR protocol. On the receipt of a DR signal, the HEM unit takes control actions to change appliance status. Appliance-level operations data are stored in the HEM unit, which allows a homeowner to retrieve his/her historical and real-time UI. The home area network (HAN) enables communications within a home, allowing the HEM unit to send commands to specific appliances, and allow data collection from appliances.

Controllable appliances may include heating, ventilation and air conditioning units, electric water heaters, clothes dryers and EVs.

2.1 Utility-side architecture and technologies for the WS

The WS architecture as experimented in this work is illustrated in Fig. 2, showing its components, along with technologies used.

As shown, the WS requires the Ubuntu Linux operating system (OS) with a database server , e.g My Structured Query Language (MySQL), as a regional database management system and an Apache WS to render a user interface (UI). Snort intrusion detection system (IDS) is used to provide further cyber security protection to the WS. It inspects the packets originated from outside of the system or internal network and detects the packets that are intended for some malicious intent. The WS has four interfaces that allow its communications with a utility system, a third party system, as well as an HIG and an UI on user devices. In this work, Tomcat Servlet is implemented to support large-scale web applications offered by a utility or a third party system. The

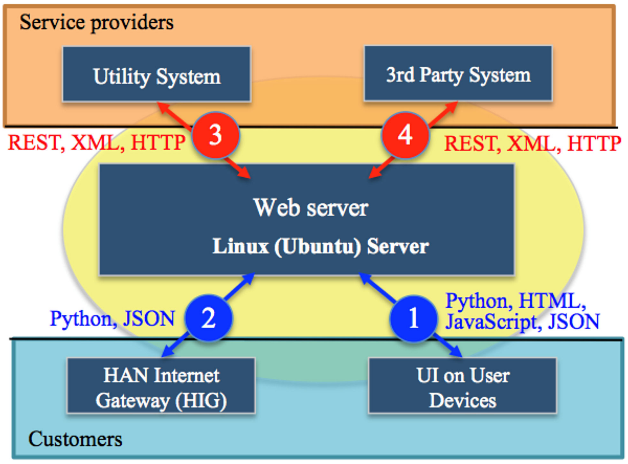


Fig. 3 *Implementation of WS interfaces*

interface with HIG and user devices uses a collection of open source software platforms, and developed primarily in Python using Django web framework.

Fig. 3 depicts connection of the WS to: (i) UI on user devices; (ii) HIG; (iii) a utility system; and (iv) a third party system using the interfaces discussed above.

For *Link 1*, web-services based interaction has been implemented to allow connection between the WS and the UI on user devices. It uses asynchronous JavaScript and extensible markup language (XML) requests in the background to retrieve live data. The web-services UI uses a JavaScript Object Notation (JSON)-based web service protocol. Python is used to deal with JSON-formatted messages including encoding and decoding JSON messages directly.

For *Link 2*, the information about DR event signals is sent to the HIG from the WS. The acknowledged message indicating that the DR signal has been received by the HIG as well as selected customer UI are sent back from the HIG to the WS. Sent/received data are based on JSON-formatted messages.

Via *Link 3*, an electric utility can send the system-level demand reduction target to the WS and get a response about customer participation.

Link 4 represents a connection between the WS and the third party system, which can be a demand aggregator. Typically, a demand aggregator may store selected customer UI such as household power consumption. Connections between the WS and the utility and/or third party system are realised with REST-style architecture, where information is encoded as XML) text and transported over the hypertext transfer protocol (HTTP). XML and HTTP are chosen because these are intuitive and facilitate further application development. Another reason to choose XML and HTTP is their ubiquity. HTTP client side implementation is available in web browsers, which also has XML processing capabilities. In addition, REST can employ HTTP's proven security features without introducing any additional layer of vulnerability.

2.2 Energy UI (EUI) data model for utility DR event notifications

With the WS architecture presented in Figs. 2 and 3, a utility company can use the WS to send a DR event signal to initiate DR to a selected group of households. This would be done according to a prior agreement between the customer and his/her utility company. In this experiment, a hypothetical electric utility control centre is used to send a DR event notification to notify the WS of a DR event. The DR event notification has been constructed using an XML schema based on document type definition (DTD). The implemented DTD for utility DR event notifications is illustrated in Fig. 4.

According to Fig. 4, the utility DR event notification contains the following information:

- *EventIdentifier* is a unique identifier, which is used to retrieve information about a particular DR event.
- *ProgramIdentifier* provides information about the DR programme for which the notification is being used.
- *Destination* is used to indicate the target households. Destination is a list of participants or groups.
- *Location* is used to identify households for DR implementation, which can be within a specific neighbourhood or a zip code. Geographical coordinate of grid location identifier can also be used if necessary.
- *EventTiming* contains information about the notification time of a DR event and its start and end times.
- *EventInformation* contains information about the demand limit level of a DR event signal.

Note that the following three parameters (i.e. UtilityDREvent, EventInformation and drasClients) are adapted from the OpenADR schema; and the EUI data model used for this implementation is adopted from the well-known Green Button initiative [19]. The syntax and semantics of the data (structured as XML) are from the class diagram of North American Energy Standards Board's (NAESB) Priority Action Plan 10 (PAP10). The machine-to-machine interface to the NAESB PAP10 [20] information system is also REST-based whose message formats are according to the XML schema made available on the NAESB server [21]. By following the EUI data model and OpenADR protocol, interoperability issues among different actors are addressed.

2.3 Customer-side architecture and technologies for the HEM system

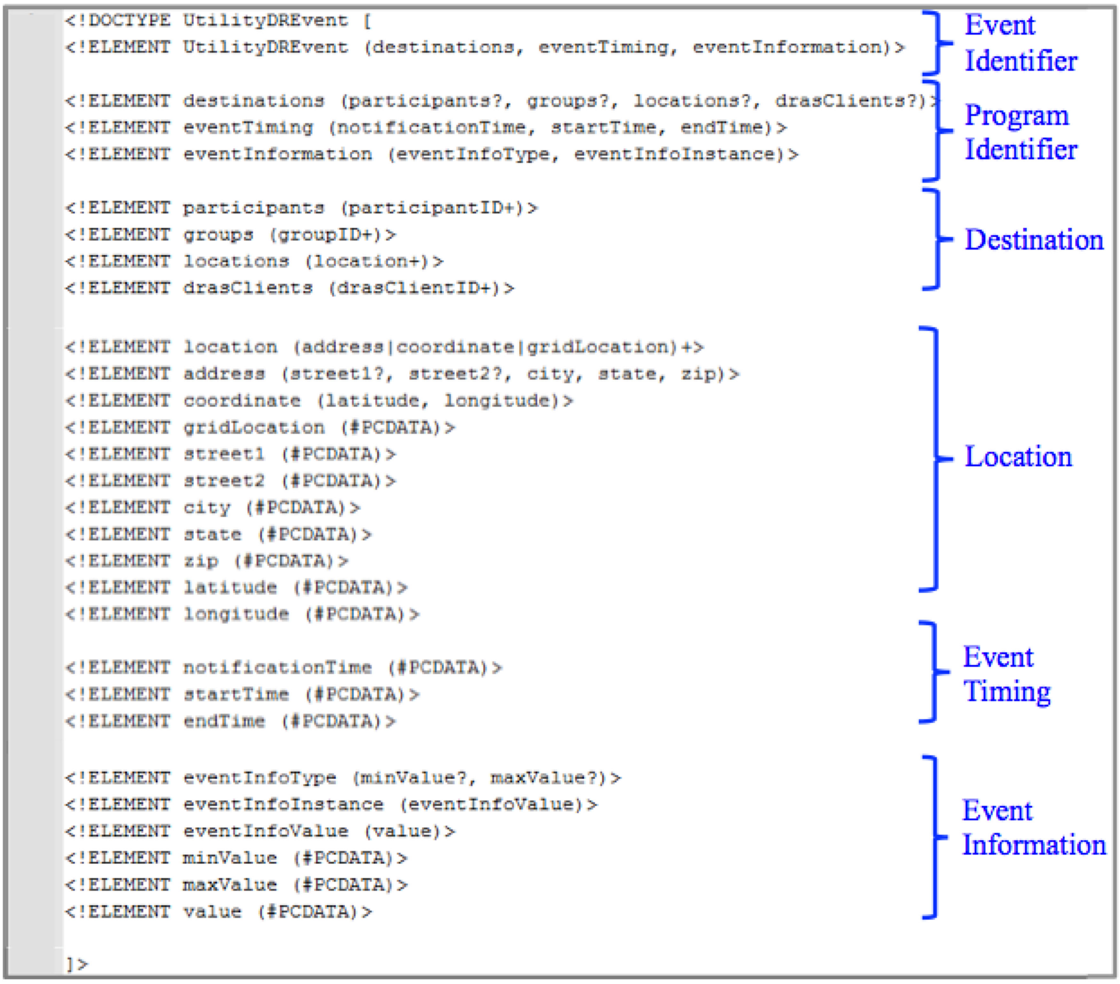
The customer-side HEM architecture is illustrated in Fig. 5. This architecture consists of an HAN IG (HIG), an HEM unit, a ZigBee coordinator and ZigBee-enabled load controllers. HIG and HEM units are explained in Section 2. HIG is connected to the HEM unit, which can be a laptop computer embedded with HEM algorithms in the architecture. ZigBee coordinator is attached to the HEM unit to allow communications with ZigBee-enabled load controllers, which are known as ZigBee end device (ZED).

For the laboratory implementation of the HEM system, ZigBee smart energy (SE) is used as a data exchange format between the HEM unit and ZEDs. In the ZigBee application standards, application data messages are defined using cluster. It is a set of attributes and commands, which define a communications interface between two devices to specify a unique function, service or action, e.g. device ON/OFF control [22]. In this work, the following clusters from ZigBee SE were implemented:

- Network address request/response.
- IEEE address request/response.
- Simple descriptor request/response.
- Active endpoint list request/response.
- Match service descriptor request/response.

The operation of the network address request cluster is shown in Fig. 6. This allows the appliances to be discovered, monitored ,and controlled. By following a set of industry published standards, i.e. ZigBee SE, it is possible for two devices to interact, thus ensuring interoperability. This process includes three steps as follows:

(i) Application programming interface frame is sent to the local ZigBee modem. The modem processor examines the frame and finds its type as *0 × 11-transmit request*; then, sends the frame over a wireless channel.
(ii) A response frame is received from the local ZigBee modem. This frame is called *transmit status (frame type – 0 × 8B)*, which includes the *frame ID: 0 × 48* from the original request, so that high layers can match the response with the request.
(iii) The transmission frame with *frame type – 0 × 91 (Receiver indicator)* is received from a remote device.



```
<!DOCTYPE UtilityDREvent [
<!ELEMENT UtilityDREvent (destinations, eventTiming, eventInformation)>

<!ELEMENT destinations (participants?, groups?, locations?, drasClients?)>
<!ELEMENT eventTiming (notificationTime, startTime, endTime)>
<!ELEMENT eventInformation (eventInfoType, eventInfoInstance)>

<!ELEMENT participants (participantID+)>
<!ELEMENT groups (groupID+)>
<!ELEMENT locations (location+)>
<!ELEMENT drasClients (drasClientID+)>

<!ELEMENT location (address|coordinate|gridLocation)+>
<!ELEMENT address (street1?, street2?, city, state, zip)>
<!ELEMENT coordinate (latitude, longitude)>
<!ELEMENT gridLocation (#PCDATA)>
<!ELEMENT street1 (#PCDATA)>
<!ELEMENT street2 (#PCDATA)>
<!ELEMENT city (#PCDATA)>
<!ELEMENT state (#PCDATA)>
<!ELEMENT zip (#PCDATA)>
<!ELEMENT latitude (#PCDATA)>
<!ELEMENT longitude (#PCDATA)>

<!ELEMENT notificationTime (#PCDATA)>
<!ELEMENT startTime (#PCDATA)>
<!ELEMENT endTime (#PCDATA)>

<!ELEMENT eventInfoType (minValue?, maxValue?)>
<!ELEMENT eventInfoInstance (eventInfoValue)>
<!ELEMENT eventInfoValue (value)>
<!ELEMENT minValue (#PCDATA)>
<!ELEMENT maxValue (#PCDATA)>
<!ELEMENT value (#PCDATA)>

]>
```


Fig. 4 *Designed DTD schema for utility DR event notification*

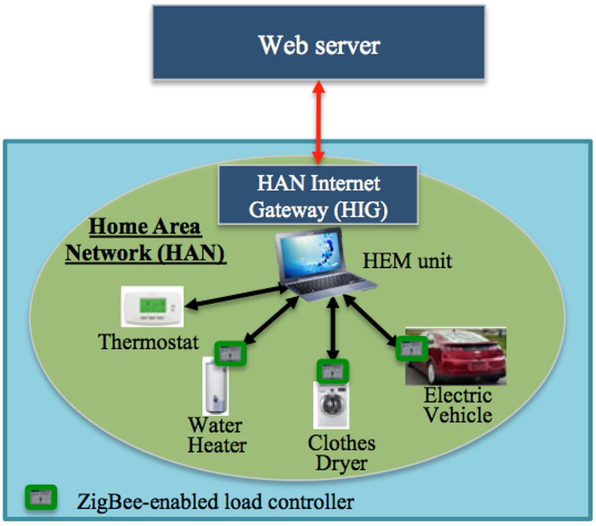


Fig. 5 *HEM architecture*

3 Implemented security measures

Technologies used to secure communication links involved in the proposed system are shown in Fig. 7. The arrows labelled with 1–4 correspond those in Fig. 3. Links labelled as 5–8 represent the wireless communication paths between the HIG/HEM unit and end-use appliances using ZigBee mesh protocol.

Link 1 allows client devices such as laptop or iPad or any other computers to interact with the WS. The secure sockets layer/transport layer security protocol over Hyper-Text Transfer Protocol Secure (HTTP), i.e. HTTPS, is implemented to secure Link 1.

HTTPS is also utilised to secure the communication between the HIG and the WS shown in *Link 2*. In this case, both the client and server mutual authentications based on certificate are performed. The server certificate is stored on the HIG and the client (HIG) certificate is stored during an initial setup on the server, so that one can recognise the other. The access control list (ACL) is applied to filter out all illegitimate requests. The HIG is added to the white list of the ACL.

Links 3 and 4 can be secured by using HTTPS protocol. Both client and server certificate-based mutual authentications are performed over an encrypted session. ACL is implemented for further security.

Links 5–8 are secured by encrypting the messages. About 128 bit advanced encryption algorithm (AES) is used to perform encryption and decryption. Link keys are used to perform the encryption. Each node has a separate link key, which is shared with the coordinator.

HTTPS can prevent attacks such as websocket spoofing, man-in-the-middle and session hijacking. ACL can prevent unauthorised access to the system. AES can prevent network eavesdropping or package sniffing using encryption. In addition to the implemented security method, blocking selected Internet Protocol (IP) addresses at either the firewall level or the Internet service provider (ISP) level can be used to prevent denial-of-service attacks.

4 Laboratory experiment to showcase a DR case study

This section discusses laboratory experiment for DR implementation at customer premises.

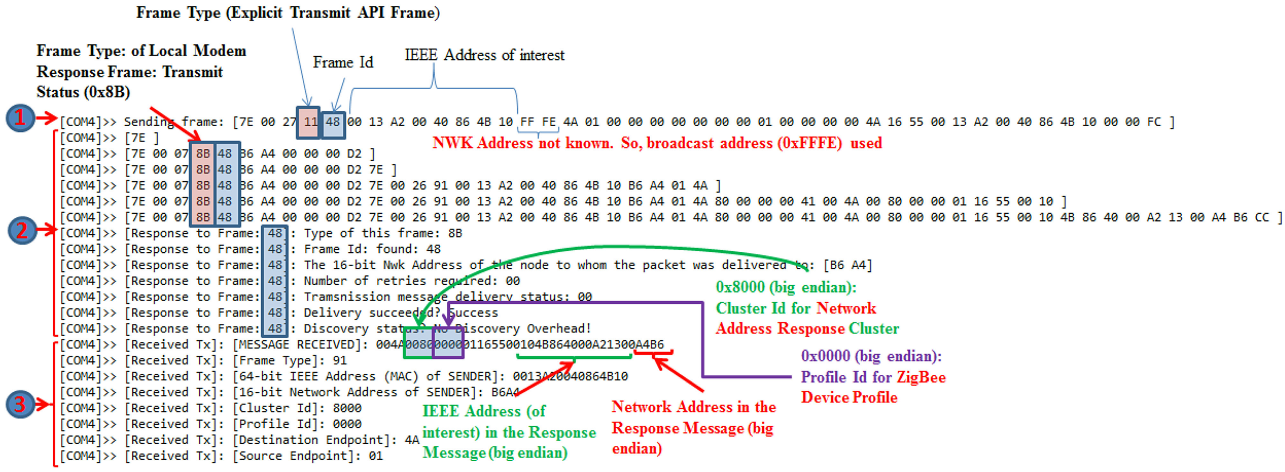


Fig. 6 *Demonstration of the 'network address request/response' clusters*

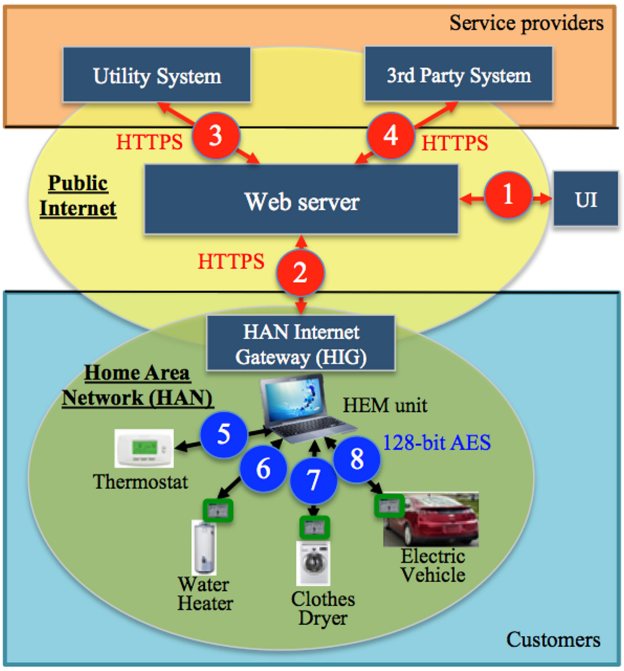


Fig. 7 *Communication paths of the HEM*

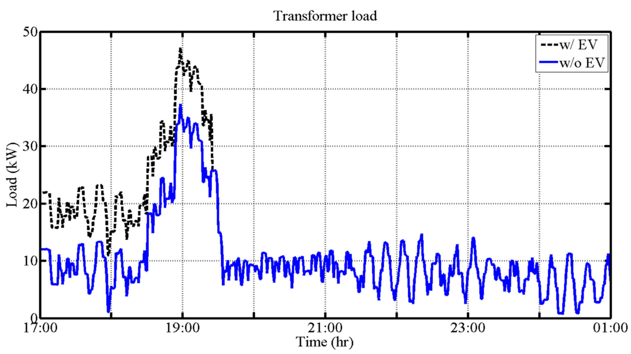


Fig. 8 *Load profiles of a 25 kVA distribution transformer, serving three houses each without EV (solid line) and each with EV (dotted line)*

4.1 Context statement

One benefit of the proposed platform is its ability to enable residential customers to participate in a DR programme especially during a system stress condition. One such example is when there is a high penetration of EVs in a distribution network. With a 25 kVA distribution transformer serving three houses, the total transformer demand could double the transformer rating when each house has an EV (3.3 kW) and all EVs are plugged in during

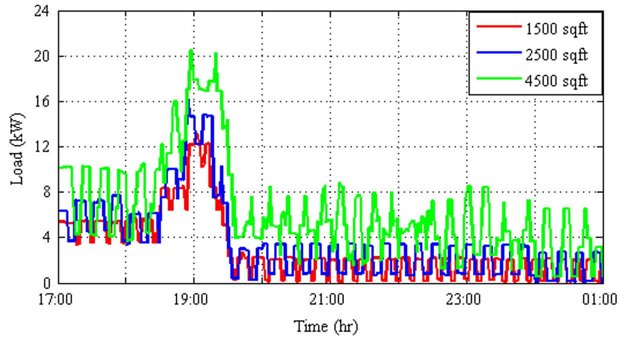


Fig. 9 *Load profiles of three houses of different sizes. Each has one EV*

similar hours. An example is illustrated in Fig. 8 that shows the total transformer load with and without EV. Load profiles of the three houses connected to this 25 kVA transformer are shown in Fig. 9. Please note that the proposed platform is flexible enough to allow the implementation for a number of households that have access to the Internet.

Note that the three houses are of different sizes (1500, 2500 and 4500 ft^2). Each house has an EV plugging in at 5 pm. The dotted black line in Fig. 8 represents the aggregated demand of these three houses. Plots in Figs. 8 and 9 represent simulation results from running the HEM software algorithm presented in [17].

With the proposed platform, a demand limit signal can be sent to each house to ensure that the total transformer demand is limited at its rated capacity (in this case 25 kVA).

4.2 Experiment setup in a laboratory environment

An experiment is set up to showcase how the proposed Internet-based communication platform can be configured and functioned in a laboratory environment. The laboratory setup is shown Fig. 10.

This setup comprises:

(i) A desktop personal computer (PC) that represents the HEM-WS at the utility-side. This PC has been set up according to the HEM-WS architecture as shown in Fig. 2. This is a desktop version of the Ubuntu Linux OS (OS) with an Apache WS, a database server (MySQL) and Snort IDS installed.
(ii) Three laptop computers that represent three HEM units, each located inside each house. Each house has a router, representing the HIG unit that acts as a gateway allowing the HEM unit to communicate with the WS to receive DR signals (see Fig. 5 on how an HEM unit is set up). Each laptop PC is used to simulate household load profiles based on appliance models presented in [23] and run the HEM algorithm specified in [17]. This yields control signals to change appliance status during a DR event. The laptop computer is connected with a ZigBee coordinator that

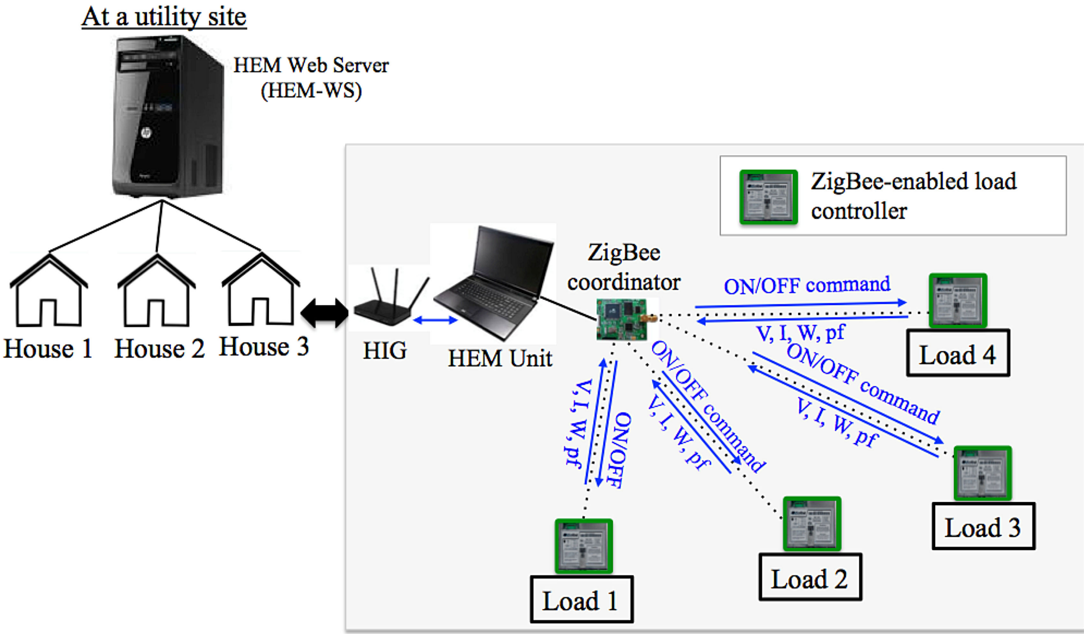


Fig. 10 *Laboratory setup*

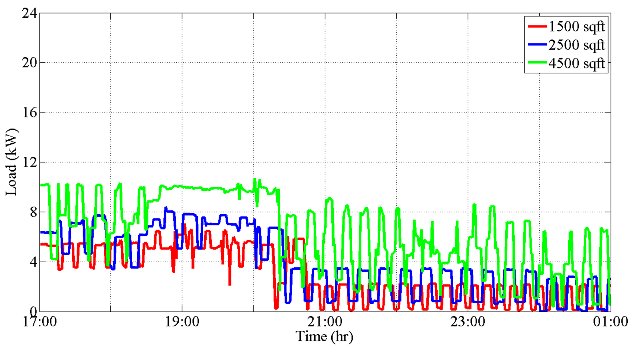


Fig. 11 *Load profiles of three houses with the DR event from 17:00 to 22:00*

forwards these control signals to change status of selected appliances through ZigBee-enabled load controllers.
(iii) A smartphone that represents a utility control centre (not shown in Fig. 10). The smartphone is used to send a DR event notification signal to the WS. Then, the WS distributes this signal among participating houses. The data format as mentioned before (Fig. 4) is used as a basis for DR event notification signals from the WS to each HEM unit.

4.3 Case study results

In this case study, it is assumed that a DR signal, specifying a demand limit target (kW) and duration (hours), is sent to each house such that the total transformer load does not exceed 25 kW. Fig. 11 shows load profiles of the three houses when the following DR signals are imposed on each house from 17:00 to 22:00: 6 kW for the 1500 ft^2 house, 8 kW for the 2500 ft^2 house and 10 kW for the 4500 ft^2 house.

Fig. 12 illustrates the transformer load profiles without DR and with DR to prevent distribution transformer overload.

Experimental results indicate that the proposed platform can perform well in the laboratory experiment.

5 Conclusion

In this paper, an Internet-based communication platform has been designed to enable residential automated DR applications. The architecture of the proposed platform comprises a WS at the utility-side and at the customer premises: an HEM system and controllable appliances. Utility-/customer-side architectures and technologies are discussed together with EUI data model for DR event notifications. The proposed platform allows cost-effective and rapid deployment DR programmes and utilises a general purpose Internet connection instead of hierarchical traditional AMI-based communications. This enables residential consumers to automatically manage their electricity consumption and maintain privacy without exposing their high-resolution consumption data through smart meters. Industry published open architecture standards such as OpenADR, XML schema and ZigBee SE profile have been implemented and demonstrated in a laboratory environment to justify its interoperability with a utility or a third party system. This architecture also provides a path to scalability. In addition, selected security features were implemented for the proposed Internet-based platform. Overall, the proposed approach can facilitate broad customer participation in DR programmes. For the future work, the proposed platform can be improved as a cloud-based open architecture platform to implement DR activities for a large number of households and to allow multiple residential buildings to synergistically collaborate to reduce peak demand during grid stress conditions.

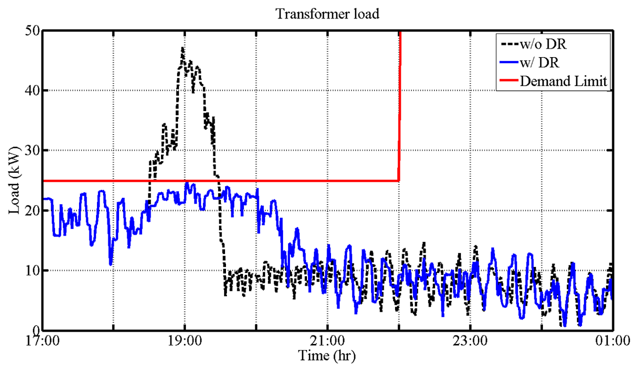


Fig. 12 *Load profiles of a 25 kVA distribution transformer without DR and with DR*

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