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An Implementation for Transforming a Home Energy Management System to a Multi-agent System

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ABSTRACT

In the United States, 41% of produced energy is consumed by the building sector, i.e. residential and commercial buildings (Building Energy Data Book, Buildings Sector, US Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Office, 2012. n.d.). The anticipation is that Home Energy Management Systems (HEMS) will support energy efficiency gains through control of the devices in an optimal fashion. New opportunities are offering the ability to integrate grid type controls and the most suitable way to perform these controls is through a multi-agent system (MAS). In this paper, approaches on supporting a HEMS and MAS integration are discussed.

KEYWORDS

Home energy management system; home automation; multi- agent systems; demand response; smart grid; smart home; smart systems; internet of things; energy saving; interoperability; reusable mechanisms; system engineering; middleware

INTRODUCTION

Home Energy Management Systems (HEMS) today are consumer electronic devices that provide a home owner the option to monitor and control different end-use devices such as heating, ventilation, and air-conditioning (HVAC) systems, water heaters, and lighting to name a few, to support energy efficiency. For the most part, these systems have primarily focused on simple scheduling, control, and linkages (methods) such as IFFT (if this then that) that allow one device or application's output to trigger another. However, these systems are seeing rapid evolvement into a vision of smart homes that can support the smart grid with load and resource flexibility (Karlin et al. 2015). This evolvement is spawning potential grid supporting use cases that support the adoption of home owner HVAC, water heaters, energy storage, and photovoltaic (PV).

Significant research regarding HEMS has been actively pursued with several open-source and proprietary HEMS available (Lobaccaro, Carlucci, and Lofstrom 2016)(Aman, Simmhan, and Prasanna 2013)(Asare-Bediako, Kling, and Ribeiro 2012)(Helia Zandi, Teja Kuruganti, Edward Vineyard 2017). These HEMS typically support a specific suite of devices and methods from partnered vendors with communication protocols such as Wi-Fi, ZigBee (ZigBee. Retrieved from http://www.zigbee.org/ n.d.), and Z-Wave (Z-Wave. Retrieved from http://www.z-wave.com/ n.d.). As a result, interoperability across these devices is a key challenge as each of these devices has unique protocols, interfaces, and control functionality.

Hence, control flexibility from grid to devices through a HEMS has been a difficult proposition.

Multi-agent system (MAS) architectures have been proven as means to provide the necessary infrastructure for HEMS to achieve control goals (Asare-Bediako, Kling, and Ribeiro 2013). A MAS consists of agents that can communicate, and coordinate behaviour based on the overall system goals and status of other agents. By this transformation, the hardware and software components represented by agents can be grouped to collaborate to satisfy a main objective such as minimizing energy cost within the bounds of comfort. By utilizing a MAS architecture, the control strategies are distributed between agents that facilitates increased flexibility, less complexity, and better performance. In this paper, a general framework for integrating HEMS into a MAS using two general interfacing approaches is presented. This allows for a rapid development of new use options for load management and control to support the electric grid, which is also discussed.

METHODS

In this paper, the focus is not specifically on the development of an agent-based system, but on the integration of this type of system with a HEMS. Hence, an open-source distributed agent based platform, VOLTTRON™, was used and will be referenced here forth in tandem with MAS (Haack et al. 2013). Also in this paper, a Home Assistants (HASS), which is an open-source home automation platform is chosen to represent the HEMS (Home Assistant n.d.). However, the architecture developed supports any general MAS and HEMS integration.

The first approach to adopting a MAS into HEMS is the potential utilization of a RESTful API (application programming interface) developed by the HEMS manufacturer as shown in Figure 1. This type of interface often exists in the cloud with direct access control and cyber security measures such as bearer tokens leading to a more seamless integration (Fielding 2000). For adopting the MAS, an agent (represented as HASS driver) is needed to communicate with the HEMS API and receive information about the devices for publishing on a local message bus for sharing with other agents. The agent also can send actuation commands to the devices using the HEMS API. An example is shown in Figure 1, and explanations is provided in Table I and Table II. While vendors may support the utilization of these APIs, these can be proprietary often reducing the ability to integrate with a MAS.

In the case where an API is not supported, the adoption can be performed by using a MQTT machine-to-machine communication protocol. In this case, a MQTT broker is needed as a communication median, represented by mosquito (an open-source broker (Mosquitto Broker n.d.)) in Figure 1. The broker provides the interface between a HEMS and MAS. An agent performing MQTT communications is required to bridge the data from the MQTT stream to a message bus. Also, a MQTT client is needed to publish the information about the devices supported by the HEMS to the broker. This client can also receive actuation commands from the HEMS MQTT Agent. An example along with description is provided in Table I and Table II.

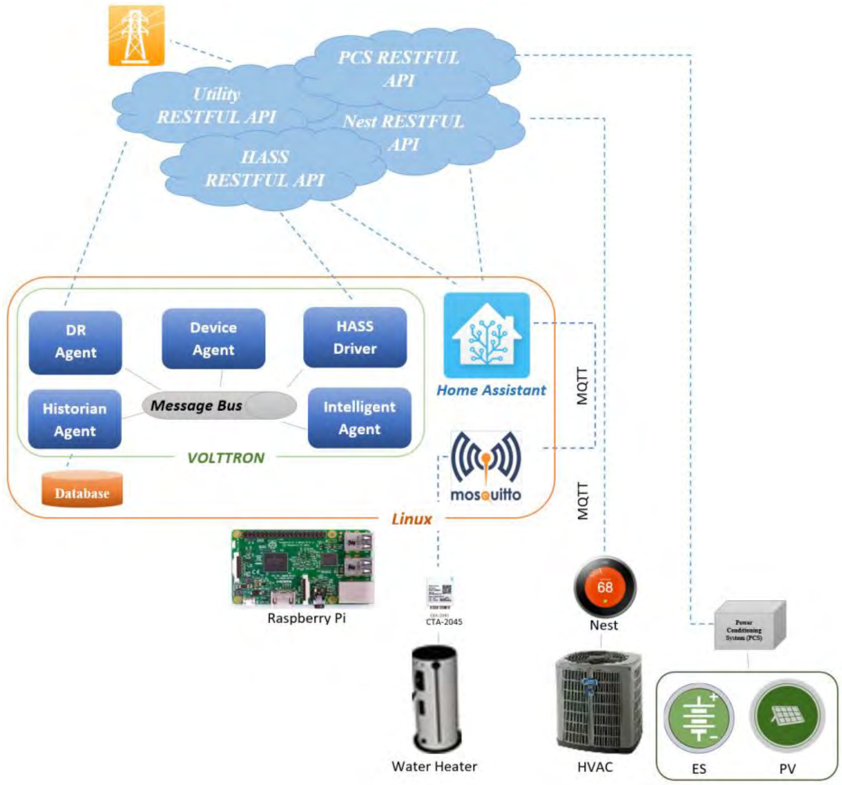

Figure 1- Integrating Home- Assistant with VOLTTRON USING RESTful API

Table I. Communication between HEMS and Devices

	MQTT	API
Communication to Device	1. Water Heater interfaces with a device that communicates via CTA-2045 2. Home Assistant reads CTA-045 data	1. HVAC utilizing a NEST thermostat with available vendor API (NEST RESTful) 2. Home Assistant reads HVAC data from API (NEST RESTful)

Table II. Communication between HEMS and MAS

	MQTT	API
Communication to MAS	1. Mosquito is the MQTT broker 2. Home Assistant MQTT client sends messages to broker and receives control messages 3. VOLTTRON MQTT agent subscribes to HASS messages on the broker and publishes them on message bus for decision making 4. MQTT Agent sends control messages to the broker	1. Home Assistant provides RESTful API. 2. MAS HASS Agent extracts device and provides control requests 3. HASS Agent publishes messages on VOLTTRON message bus for decision making

IMPLEMENTATION

In this section, the hardware and software components used in the system for the transformation are described. The code used for this integration is also openly available on github (Zandi n.d.). The software is installed on a Unix based Raspberry Pi (Raspberry Pi n.d.). Different agents are implemented and running using VOLTTRON as a platform such as Device Agent, Historian Agent, etc. Each of these agents provides various services and can coordinate its decision based on other agents. Device Agent is responsible for monitoring and controlling devices running different communication protocol such as Wi-Fi, CTA- 2045 (CTA- 2045 n.d.), etc. An intelligent agent is responsible for goal-based scheduling and notifying appropriate devices. DR agent is responsible for communicating with the utility and Historian Agent is responsible for data storage and retrieval. Each agent can publish information on the message bus or subscribe to specific topics of its interests published by others (See Figure 1).

The HEMS location is dependent on the mechanism used for the transformation. If the HEMS Restful API is used for the integration, then the HEMS can be located anywhere. If the transformation is done using a local MQTT broker, the HEMS should be connected to the same router as the VOLTTRON. Also, the MQTT broker used for the transformation should also be connected to the same router as other software pieces. The result of the HASS-VOLTTRON integration can be seen in Figure 2.

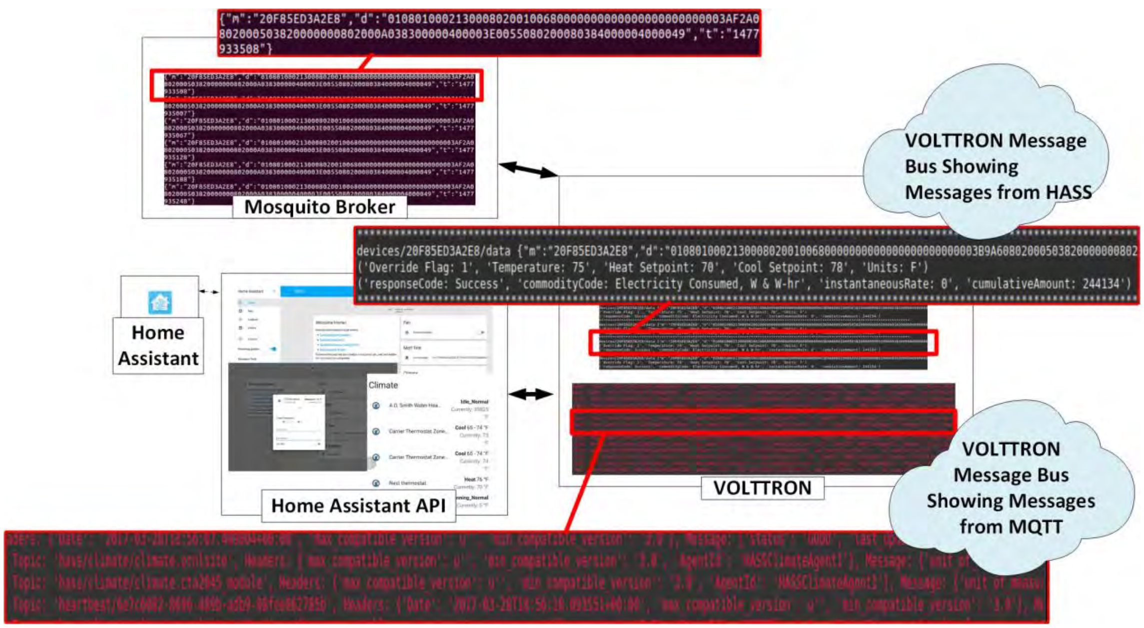

Figure 2- HEMS-VOLTTRON integration information flow

FUTURISTIC USE CASES

While there are a number of opportunities to utilize loads to support traditional demand response load shedding requests, these are already often imbedded in a HEMS without the need of a more sophisticated MAS. MAS offers the ability to implement smart agents to provide more complex optimization and bidding strategies that are not available in todays' HEMS. For example, three different use cases of more advanced grid functions are provided in Table III. These use cases provide a demonstration of more sophisticated functions that require utilities to enable device communications under a common framework. A HEMS supporting MAS has the opportunity to perform the appropriate decision making and control.

Table III. Grid Use Cases

Use Case	Description
1. Reduce Critical Peak Load	Goal: Reduce load during critical price period. Method: Data is collected from each device by separate Device Agents and archived by the Historian Agent. A separate DR Agent assesses the current status of the loads and reports this information to utility distribution management system (DMS). The DMS performs an assessment of the data and estimates the needed overall load reduction. These reductions are issued to the DR Agent which sends control commands to the respective Device Agents and ultimately to the loads.
2. High Penetration of Renewable Energy in Distribution Systems	Goal: Reduce voltage impact by renewable generation. Method Data is collected from each device by separate Device Agents and archived by the Historian Agent. A separate DR Agent assesses the current status of the loads and reports this information to utility distribution management system (DMS). The DMS performs an assessment of the data and estimates the needed overall change in load to support PV. The DMS issues the load change to the DR Agent which sends control commands to the respective Device Agents and ultimately the loads.
3. Residential Resiliency through Islanding.	Goal: Improve residential resiliency with local energy storage and islanding features. Method: Data is collected from each device by separate Device Agents and archived by the Historian Agent. A separate DR Agent assesses the current status of the loads and reports this information to utility distribution management system (DMS). The DMS performs an assessment of the current grid reliability and provides the DR Agent information regarding outage potential. Upon expected outage, the DR Agent issues islanding request to the energy storage Device Agent which is forwarded to the local energy storage system.

CONCLUSIONS

In this paper, a general framework for integrating a multi-agent-system (MAS) into a home energy management system (HEMS) is proposed. MAS offer additional functionalities and decision making that go beyond the IFFT (if this then that) functionalities present with HEMS today. Two different communication methods between the MAS and HEMS are explained. One communication approach utilizes the RESTful API while the other demonstrates a MQTT broker approach. The MQTT local communication approach is demonstrated in the results. These communication schemes can be applied to any existing system regardless of the programming language implemented.

Besides addressing the interoperability challenge by supporting multiple pathways for communications, this work demonstrates a broadening of intelligence into the HEMS. The addition of an agent-based infrastructure provides new pathways and use case functionalities. In this paper, three utility-based use cases utilizing residential assets such as HVAC, water heater, energy storage, and PV are discussed. These use cases include: reduction in critical peak load, high penetration of renewable energy in distribution systems, and residential resiliency through islanding.

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