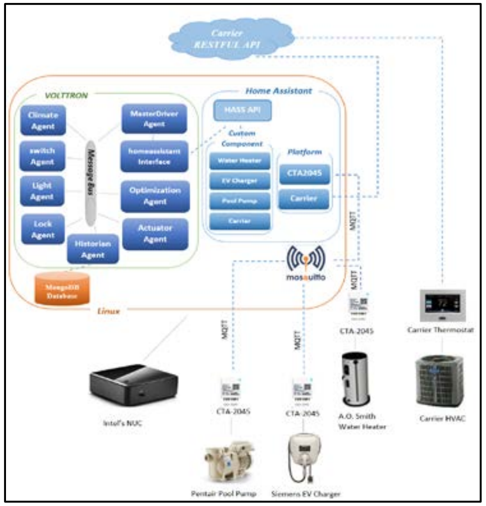
Transactive Whole Homes as Integrated Assets - Connected Homes



Oak Ridge National Laboratory (ORNL)

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Project Summary

Timeline:

Start date: 03/01/2016

Planned end date: 02/28/2019

Key Milestones

1. Develop software and hardware to field evaluate end-to-end integration of open-source HEMS using VOLTTRON platform to control HVAC, EVSE, WH, and pool pump (12/31/2017).
2. Deliver draft report on software framework for VOLTTRON integration of IoT devices at the device-level, aggregator-level, and cloud-level for performing reliable transactive control at-scale (3/31/2018).
3. Deliver final report on the software framework for the VOLTTRON integration of IoT devices to perform reliable transactive control at-scale (9/30/2018).

Budget:

Total Project $ to Date:

- DOE: $1,470,000
- Cost Share: $0

Total Project $:

- DOE: $1,470,000
- Cost Share: $0

Key Partners:

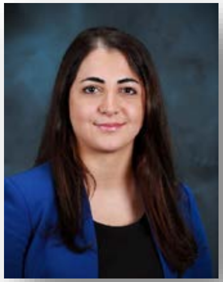
Southern Company	Haier (GE)
SkyCentrics	PNNL
EPRI	A.O. Smith
Emerson	Nat'l Assn of Realtors

Project Outcome:

- An open source home energy management system (HEMS) which can enable load coordination and aggregation to improve energy efficiency, reduce energy costs, reduce peak demand, and improve comfort.
- A general framework for power grid IoT-VOLTTRON™ solutions.

Team

Oak Ridge National Laboratory



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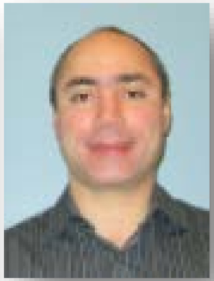

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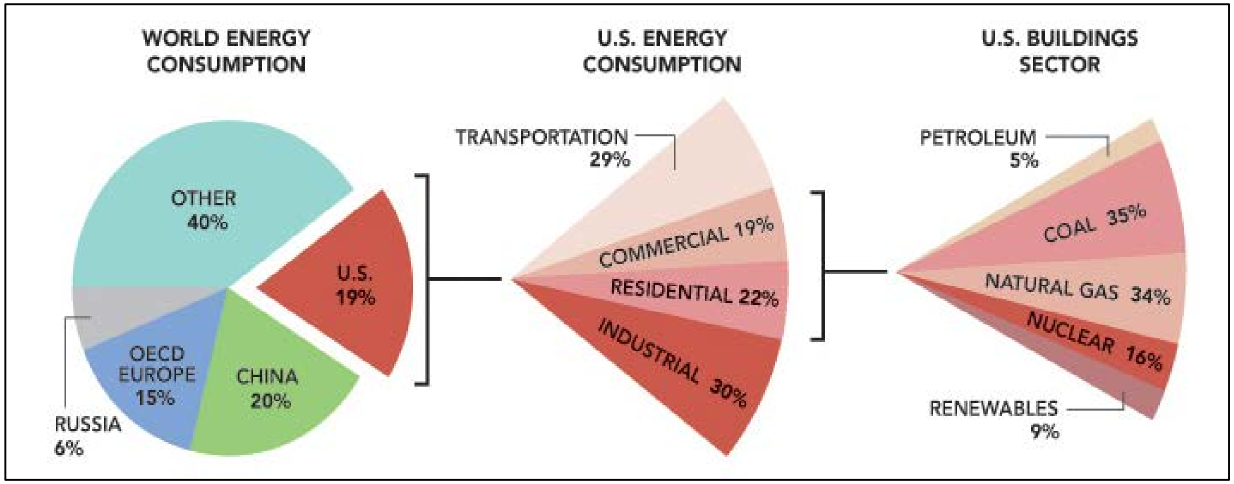
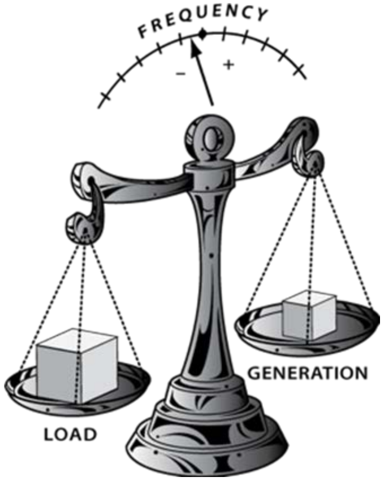
Challenge

Problem Definition:

- Over **20 billion** connected devices predicted to be in use by 2020.
- Over **41%** of the energy consumption in the United States is from buildings.
- Advanced sensing and controls have the potential to save energy in buildings up to **40%.**
- There is an immense need for a building energy management system which can **monitor, control, and coordinate the power use** by these devices to enable load flexibility.
- This management system should also provide **seamless** communication between devices and **enable interoperability.**

Target Market and Audience: Target market is residential buildings, which account for 22% (14.5 Quads primary) of the nation's total energy consumption. Target audience are homeowners and utilities.



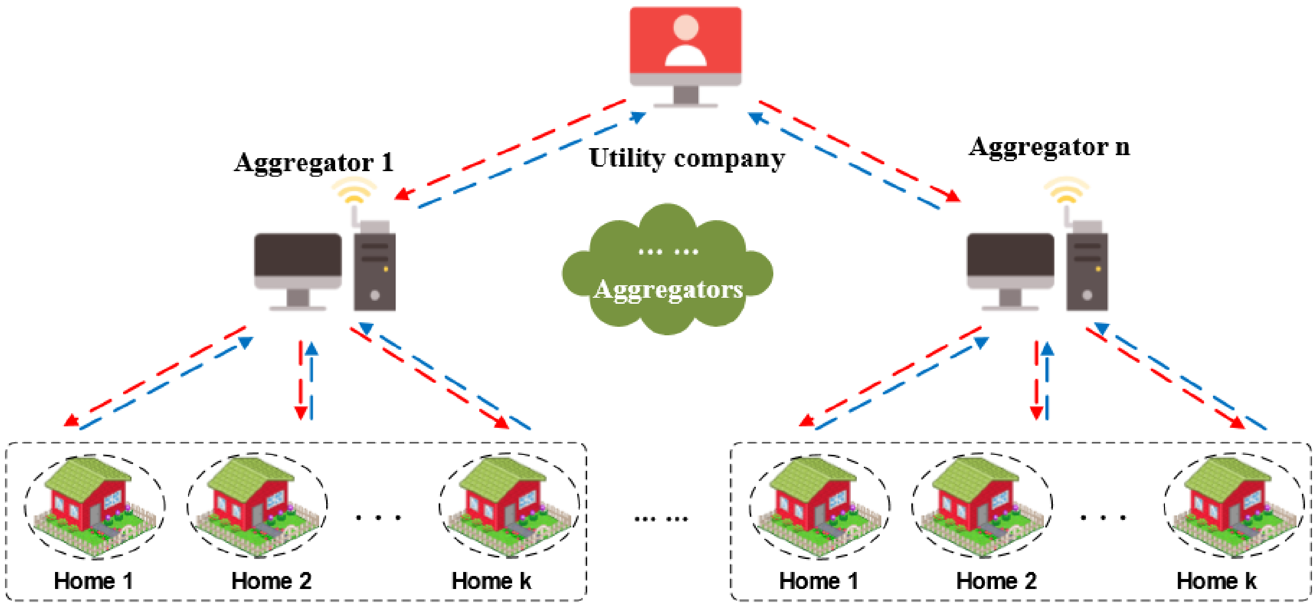


Approach: Project Overview

- Develop Open-Source Home Energy Management System (HEMS) using VOLTTRON™ as a platform.
  - Integrate existing HEMS into VOLTTRON™.
  - Enable supervisory control of different loads.
  - Enables the full potential of connected equipment in residential buildings by increasing the flexibility of loads to achieve improved energy efficiency, reduced energy costs, reduced peak demand, and improved comfort.
  - Enable home-level and neighborhood-level aggregation and coordination.
  - Generate an agent blueprint to bring in variety of devices.
    - Cloud based communication: RESTful API
    - Local communication: CTA- 2045
- Deliver software and hardware for end-to-end demonstration.
  - Yarnell Station research home
  - Southern Company – Connected Neighborhood
- Develop a repeatable implementation of the software framework for VOLTTRON- IoT solutions at device-level, aggregator-level, and cloud-level.

Approach

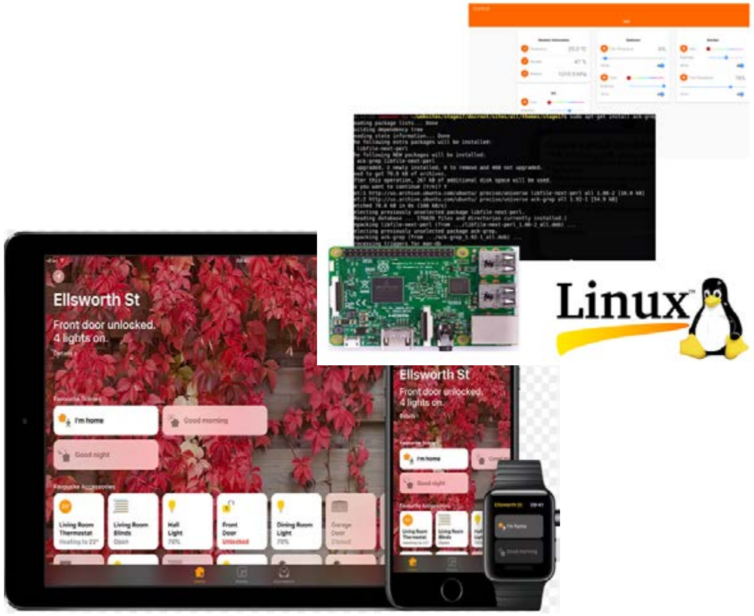
- Assessing the complex issues associated with connected infrastructure.
- Evaluating the main drivers for more widespread deployment of connected residential buildings, appliances, and devices.
- VOLTTRON™-HEMS integration
- Leveraging existing capabilities and focusing on missing functionalities.
- Enable interoperability and load flexibility.
- Developing control algorithms to improve efficiency, improve comfort, and reduce peak demand.
- Introduce general and platform-agnostic approaches for repeatable implementation.

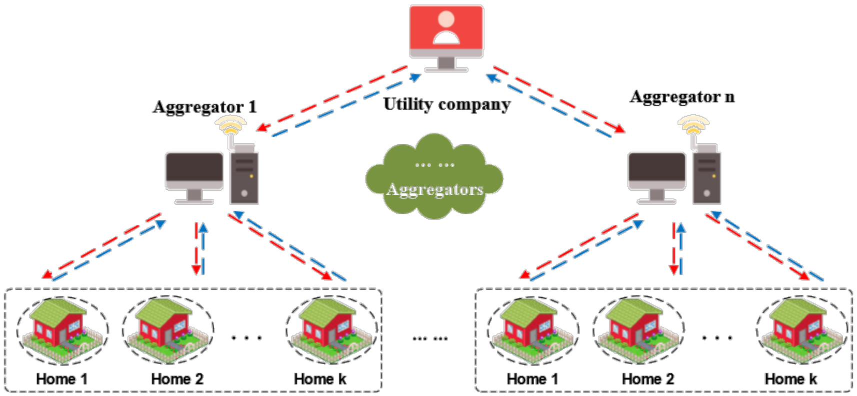


Impact

The methodologies introduced in this project:

- Increase market penetration of HEMS that enable DOE to achieve its goals of reducing energy.
- Accelerate the adoption rate of products to enable intelligent control of devices inside a connected home.
- Develop retrofit control technology, aimed at residential buildings, improves the energy efficiency and reduces peak demand by 40%.
- Facilitates load dispatch of HVAC, appliances, and plug loads in residential buildings, contributing towards GMLC goal of 50% decrease in the net integration cost of distributed energy resources by 2025.



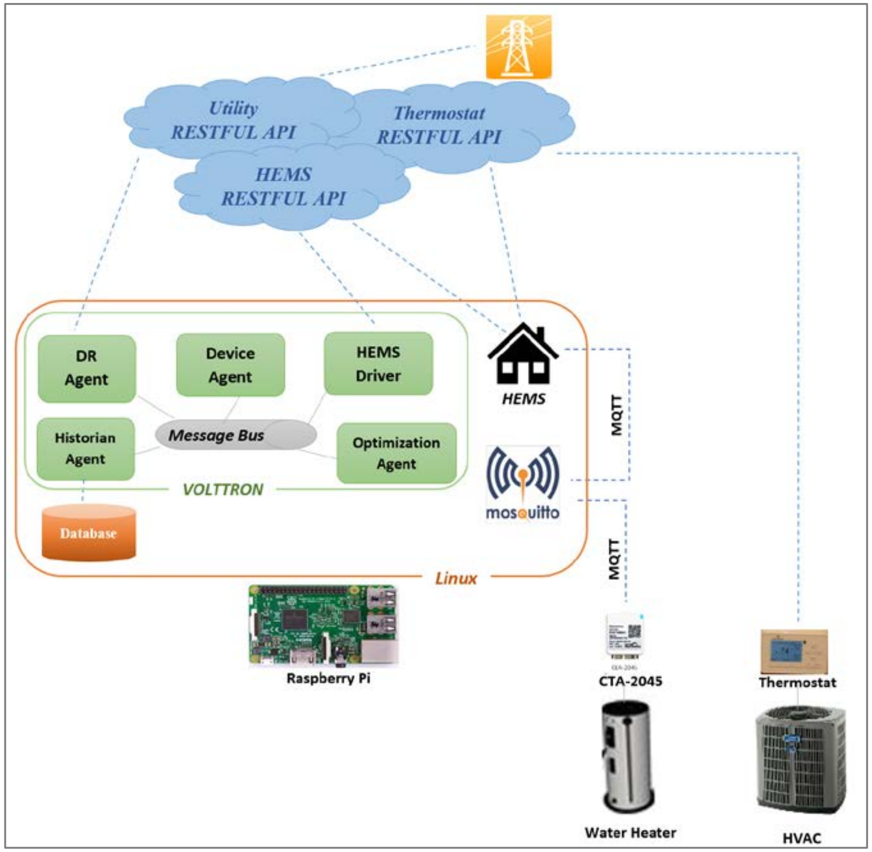


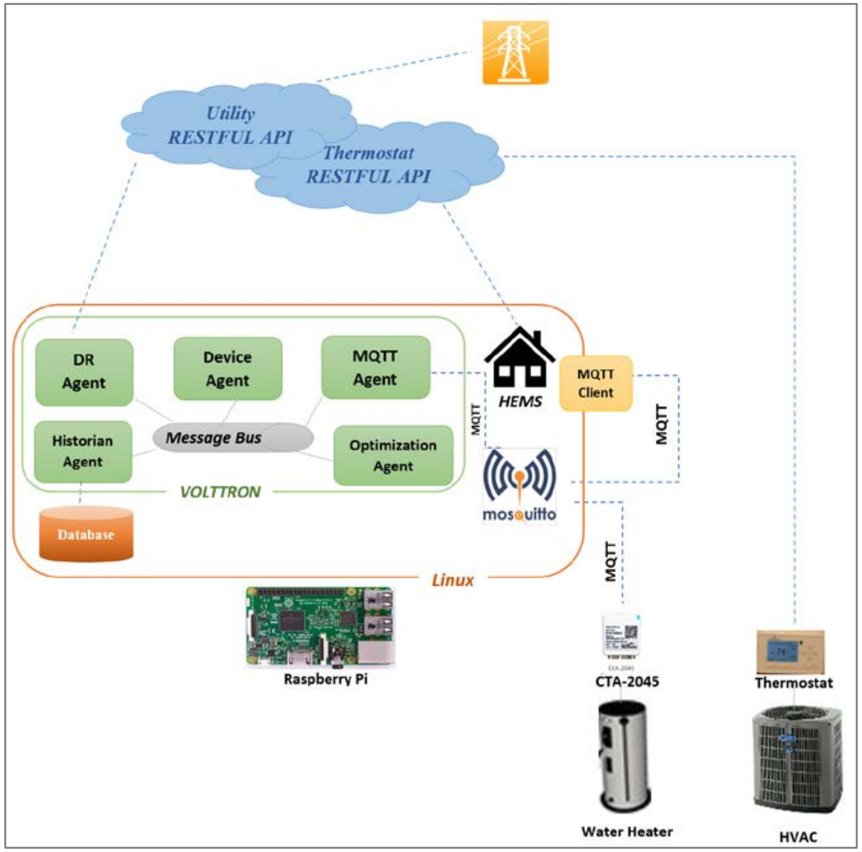
Approach: HEMS-VOLTTRON Integration

General method to transform any HEMS to a Multi-Agent system by HEMS-VOLTTRON integration.

If the existing HEMS provides an API, the transformation can be done using the API.

If not, the integration between HEMS and VOLTTRON can be done using the machine- to-machine protocol MQTT.

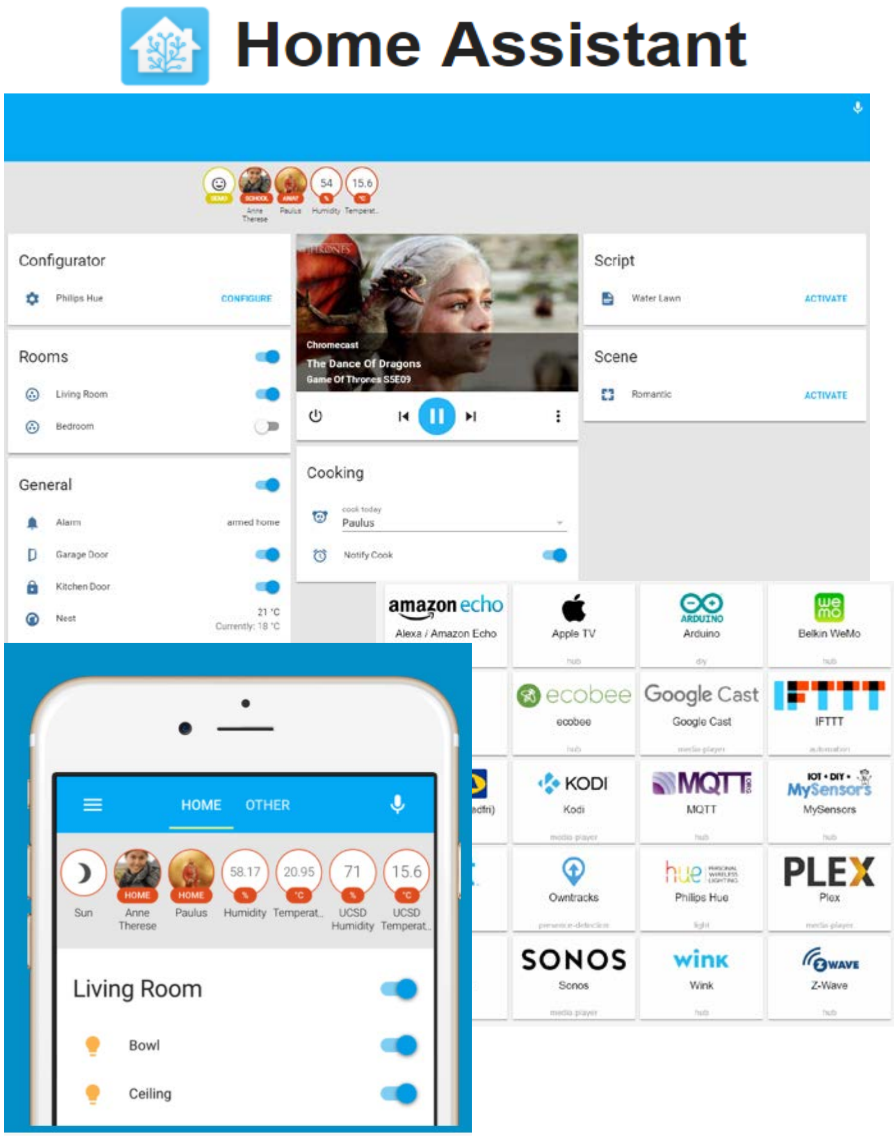




Progress: Home Assistant-VOLTTRON Integration

- Home Assistant (https://home-assistant.io/) is an open- source home automation platform implemented in Python.
- Performed integration using home-assistant API and in a VOLTTRON driver framework.
- Extended home-assistant implementation to add support for more devices.
- Incorporate optimization into the system
- The code is available at :

  https://github.com/VOLTTRON/volttron-applications/tree/master/ornl/HomeAssistant-VOLTTRON-Integration-Agents



Approach: ORNL Yarnell Station Research House

- Approximately 100 instrumentation points
  - Temperature
  - Humidity
  - Water consumption (relevant to water heating)
  - Electricity (Power)
  - Outdoor weather conditions
- Automation for simulated occupancy and hot water consumption.

Yarnell Station house, A 2,400 ft^2 house located in Knoxville, TN

Siemens EV Charger

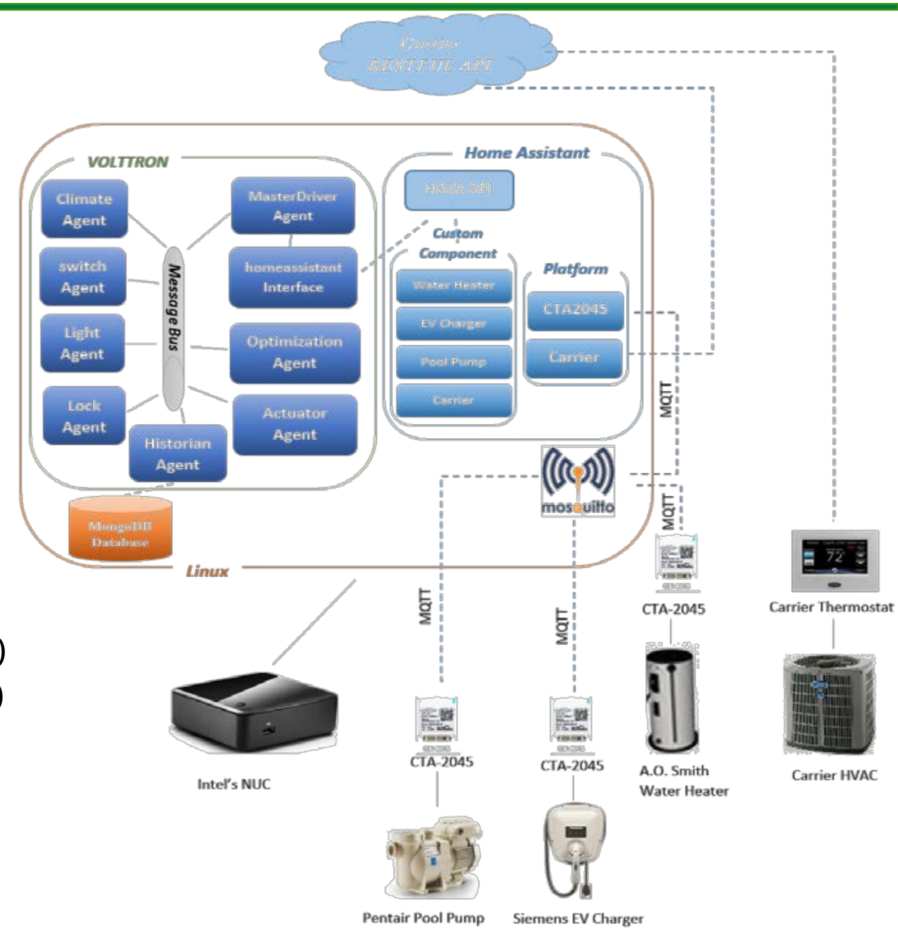
A.O. Smith Water Heater

Pentair Pool Pump

Carrier HVAC

Progress: Field Demonstration

- Demonstrate end-to-end integration of open-source HEMS using VOLTTRON platform to control HVAC, EVSE, WH, and pool pump.
- Optimization is focused on minimizing peak at the house level.



<u>Objective f(x):</u>

$$min\left(W_P \sum_{t=0}^{t} Peak + W_{DW} \sum_{t=0}^{t} D_{WH}(t) + W_{DH} \sum_{t=0}^{t} D_{HVAC}(t)\right)$$

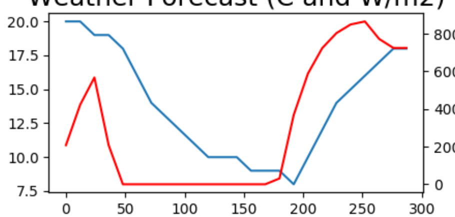
<u>Constraints</u>:

$$D_{WH}(t) \geq T_{WT}(t) - 140$$
$$D_{WH}(t) \geq 120 - T_{WT}(t)$$
$$D_{WH}(t) \geq 0$$

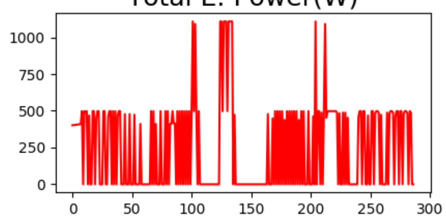
$$D_{HVAC}(t) \geq T_{in}(t) - T_{max}(t)$$
$$D_{HVAC}(t) \geq T_{min}(t) - T_{in}(t)$$
$$D_{HVAC}(t) \geq 0$$

$$Peak > P_{WH}(t) + P_{HVAC}(t)$$

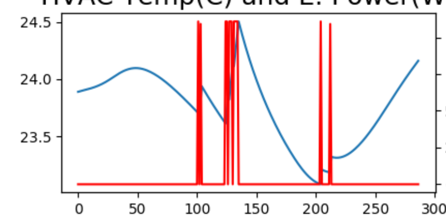
Weather Forecast (C and W/m2)



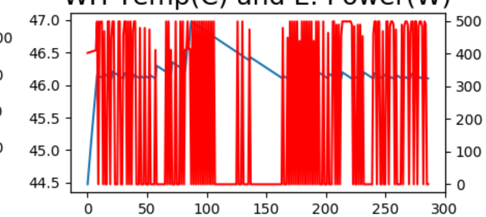
Total E. Power(W)



HVAC Temp(C) and E. Power(W)

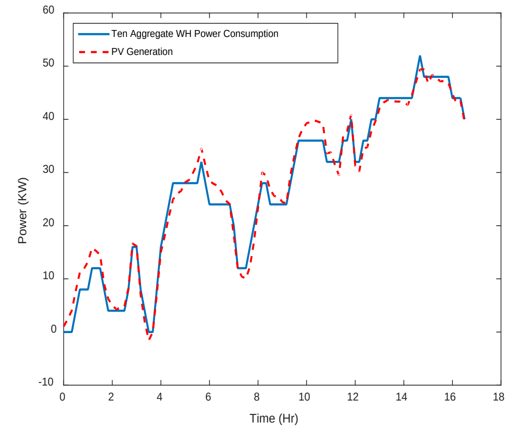


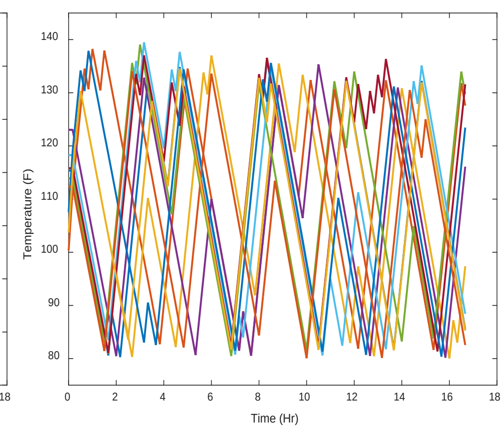
WH Temp(C) and E. Power(W)



Progress: PV-WH Control

- **Rule-based WH Control**
  - Real PV data, 10 WH, permissible temp (80°F – 140°F), time-step 10min
  - If PV > Power consumed by WHs
    - Heat (turn ON) WHs with lowest temp first
  - If PV < Power consumed by WHs
    - Cool (turn OFF) WHs with highest temp. first



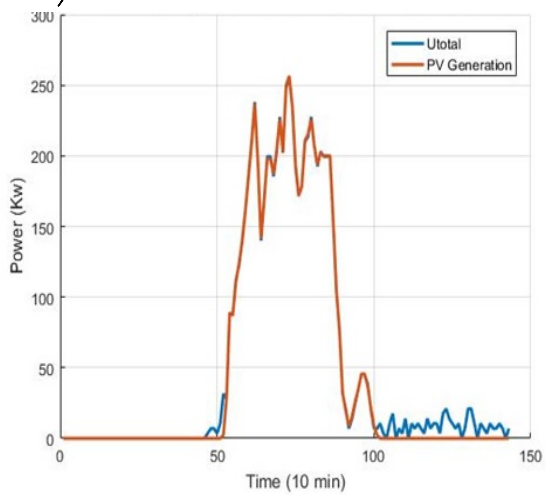


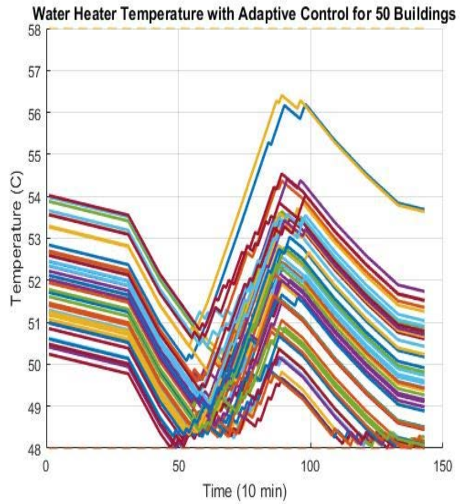
- **Model Predictive WH Control**
  - Real PV data, 50 WH, permissible temp (48°C – 58°C), time-step 10min

$$\min \sum_{k=1}^{K}\left[\left(\sum_{j=1}^{J} u_j(k) - P_{PV}(k)\right)^T R \left(\sum_{j=1}^{J} u_j(k) - P_{PV}(k)\right) + \left(\sum_{j=1}^{J} x_j(k) - x_j^{ref}\right)^T Q \left(\sum_{j=1}^{J} x_j(k) - x_j^{ref}\right)^T\right]$$

subject to

$$u_j(k) \in \{0, 1\}$$
$$x_j^{min}(k) < x_j\ (k) < x_j^{max}(k)$$



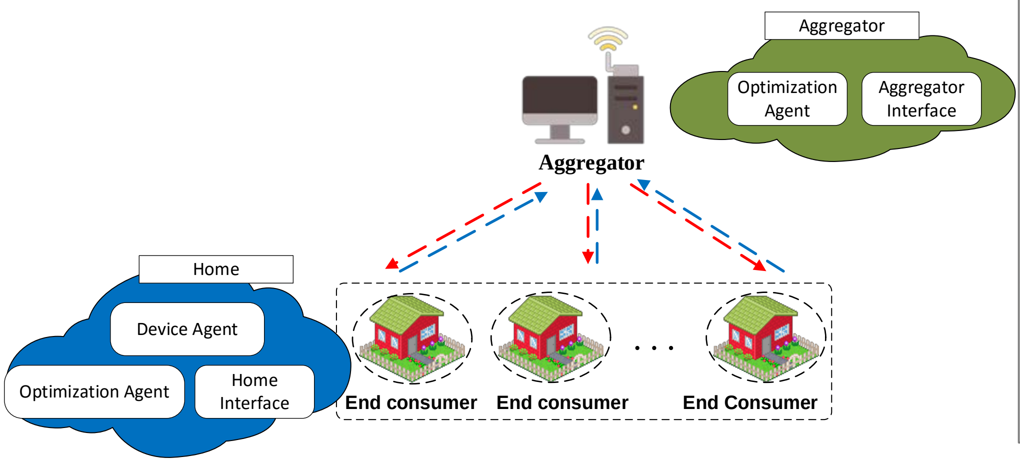


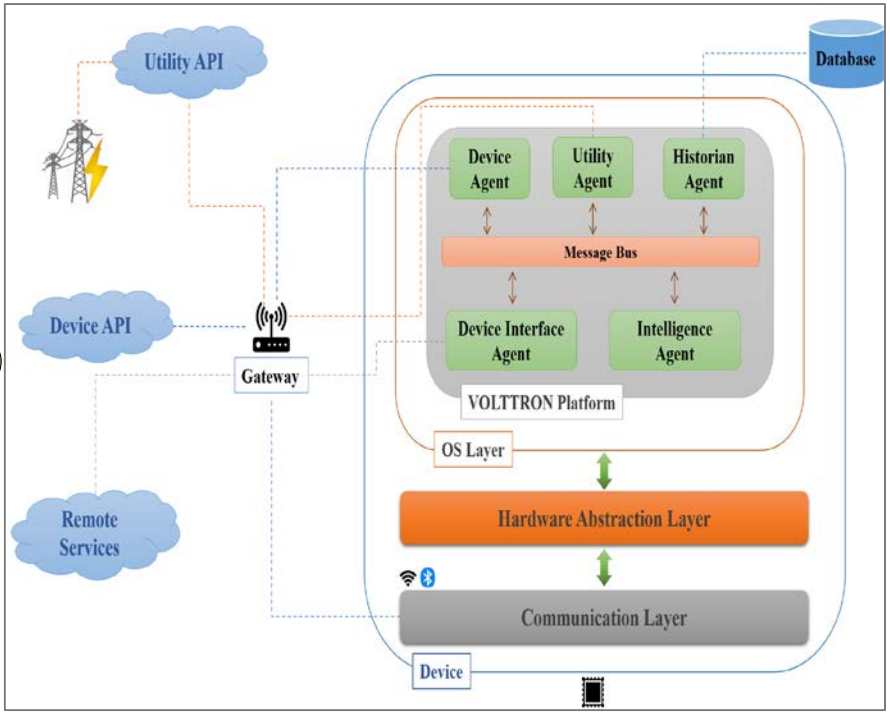
Approach: Grid IoT Solutions

- IoT has revolutionized the way individuals and organizations are exchanging information.
- IoT facilitates communication to different sensors, actuators, and, devices and enables data exchange, collection, and analysis.
- To achieve optimal outcome for variety of stakeholders (buildings, utilities, equipment):
  - **Peer to peer information exchange across nodes/devices**
  - **Distributed decision making**
- Smart grid VOLTTRON-IoT solutions consists of 3 services:
  - Device-level services
  - Aggregator-level
  - Cloud-level
- The system architecture of each of these services has a critical role in stable development of a scalable transactive control system.

Device-level architecture:

- OS
- Hardware Abstraction Layer (HAL) to enable access to hardware features such as serial ports.
- Communication Layer to facilitate communication to the device using Wi-Fi, MQTT, Bluetooth.
- Device API for managing the device remotely.





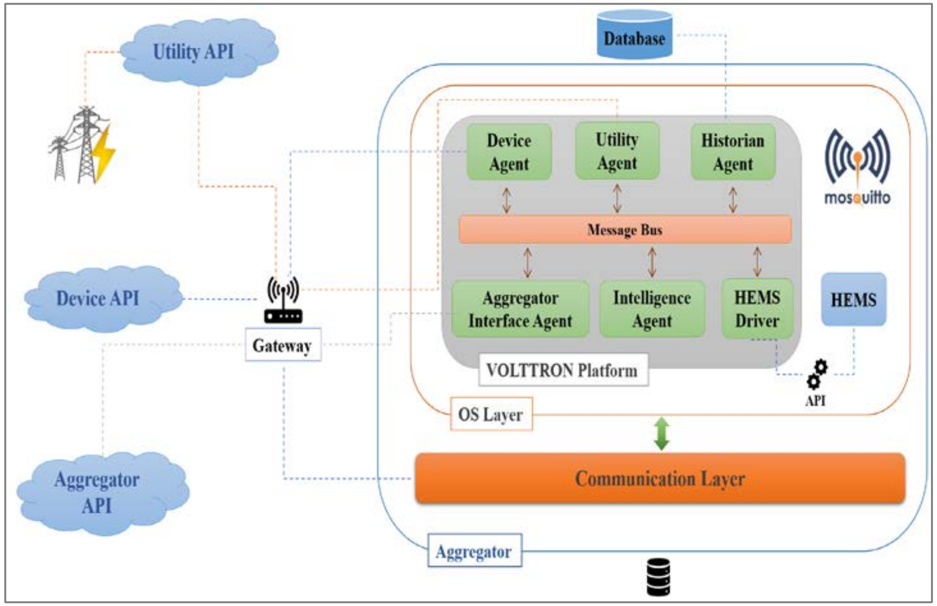
Progress: IoT Solutions Architecture

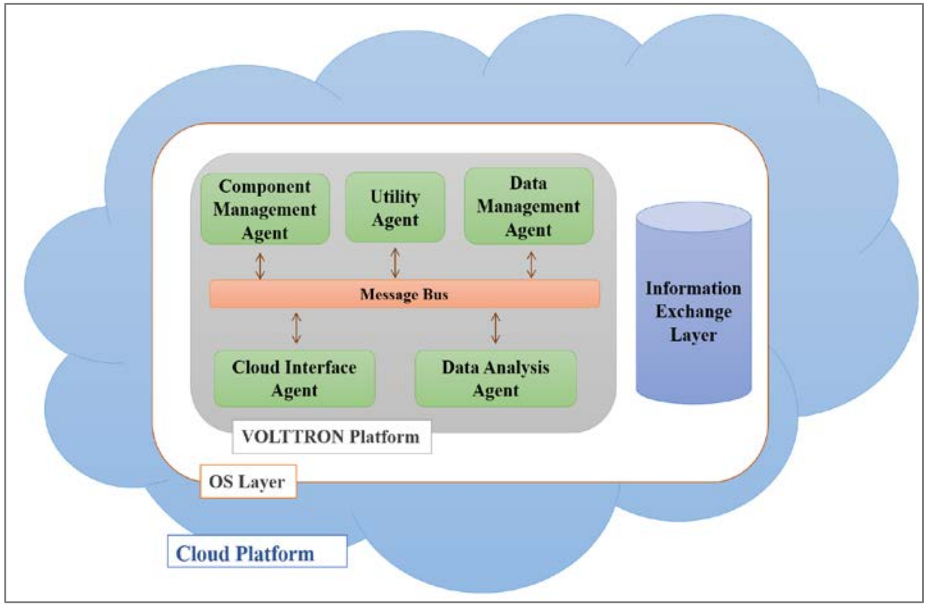
Aggregate-level architecture:

- General-purpose OS
- Communication layer to communicate with different devices running different communication protocols.
- Data management and messaging to support data analysis and exchanging data to local or remote components.
- Aggregator API so it can be managed remotely and to ease the process of integration.

Cloud-level architecture:

- Information Exchange layer to interact with a large number of devices and aggregators.
- Component management to register and identify devices and,
- Data management to support the volume and variety of IoT data.
- Data analysis to facilitate data analysis, creating reports, and dashboards.
- OS layer in which all VOLTTRON-based services are implemented.





Stakeholder Engagement

- Biweekly meetings
- ORNL has demonstrates and presented the work to Whirlpool, GE, Southern Company, EPRI, PNNL.
- The work has been presented in conferences (3 published papers, 1 submitted, 1 invention disclosure).
- ORNL's work is being leveraged by our collaborators at PNNL for their project.
- ORNL submits Quarterly Progress Report (QPR) to DOE.

Remaining Project Work

- Develop software for IoT integration at the device-level, aggregate-level, and cloud-level using VOLTTRON platform.
- Design a platform technology the seamlessly facilitates the peer to peer information exchange that enables resolution to obtain information of one node or aggregate hundreds of nodes.
- Software engineering approaches to define building systems as software services (architectures, semantics, standards/protocols, data models, service oriented architectures and protocols).
- Build systems and boards, and evaluate local and networked functionality and benchmark performance with standard tools.
- Control execution tied closely with several new techniques (like agent-based control and cooperative control) that provide high degree of functionality at low computational cost.

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: 989K (FY16), 381K (FY17), 100K (FY18)
Variances: Original project budget was $3,000K but reduced scope and budget to $1,470K
Cost to Date: $790K
Additional Funding: none

Budget History					
FY2016 – FY 2017 (past)		FY 2018 (current)		FY 2019 – 2/28/2019 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1370K	$0	$100K	$0	0	$0

Project Plan and Schedule

Project Start: March 2016		Completed Work
Projected End: March 2019		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned)
		Milestone/Deliverable (Actual)

Task	FY2016 Q1 (Oct-Dec)	FY2016 Q2 (Jan-Mar)	FY2016 Q3 (Apr-Jun)	FY2016 Q4 (Jul-Sep)	FY2017 Q1 (Oct-Dec)	FY2017 Q2 (Jan-Mar)	FY2017 Q3 (Apr-Jun)	FY2017 Q4 (Jul-Sep)	FY2018 Q1 (Oct-Dec)	FY2018 Q2 (Jan-Mar)	FY2018 Q3 (Apr-Jun)	FY2018 Q4 (Jul-Sep)
Past Work												
Q1 Milestone: Complete work plan which prioritizes VOLTTRON protocols and service agents needed to support Home Energy Management system												
Q2 Milestone: HEMS-VOLTTRON Integration in a VOLTTON driver framework.												
Q4 Milestone: Draft report on the connected homes projec												
Q1 Milestone: Develop software and hardware to field evaluation end-to-end integration of open-source HEMS using VOLTTRON platform to control HVAC, EVSE, WH, and pool pump												
Q2 Milestone: Deliver draft report on VOLTTRON-IoT solutions at the device-level, aggregator-level, and cloud-level for performing reliable transactive control at-scale												
Current/Future Work												
Q4 Milestone:Deliver final report on the software framework for the VOLTTRON integration of IoT devices to perform reliable transactive control at-scale												