Makahiki+WattDepot: An open source software stack for next generation energy research and education

[Extended Abstract]

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1. INTRODUCTION

Several characteristics of the traditional electrical energy infrastructure of industrial societies have remained unchanged for almost 100 years. First, energy production has been centralized in power plants using "firm" energy sources such as coal, oil, nuclear, or hydro. Second, centralized production has promoted centralized control of the grid, typically through a single or small number of utilities with public regulation over their policies and rates. Third, centralized production and control has led to the predominence of "macro-grids", or grid infrastructures designed to service hundreds of thousands to millions of consumers. Finally, traditional grids have been designed to minimize the information about energy required by consumers to utilize the service. The typical consumer needs to know almost nothing more than how to plug an appliance into an outlet, and can assume that this exceedingly simple "user interface" will provide virtually unlimited amounts of high quality energy at any time for a relatively small cost.

Unfortunately, the accelerating world-wide growth in demand for energy is leading to a breakdown in this approach to electrical energy infrastructure. Petroleum products such as coal and oil are nonrenewable, are no longer reliably inexpensive, and have been found to have a variety of adverse environmental effects. Nuclear energy, while low in emissions, has risks that have caused countries such as Japan and Germany to reevaluate this approach to energy generation.

Addressing these emergent problems has led to the conceptualization of a "smart grid", where a variety of decentralized, intermittent, renewable energy sources (for example, wind, solar, and wave) would provide most or all of the power required by small-scale "micro-grids" servicing hundreds to thousands of consumers. Such a smart grid will require consumers to transition from passive to active participation in maintaining efficient and effective use of the grid's electrical capabilities. For example, these "smart consumers" should be able to tailor their use of electrical energy to the types and amount of energy available in the grid at any point in time; minimizing the overall use of non-renewable resources as well as peak loads on the grid.

Satisfying the radically different requirements and operating assumptions of this next generation grid requires new kinds of software that enable research and experimentation into the ways that electrical energy production and consumption can be collected, analyzed, visualized, and provided to consumers in a way that enables a transition from passive to active participation. Since 2009, we have been designing, implementing, and evaluating an open source software "stack" to facilitate this research. This software stack consists of two custom systems called WattDepot[1] and Makahiki[2], along with the open source components they rely upon (Java, Restlet, Postgres, Python, Django, Memcache).

In the full version of this paper, we will detail the novel features of WattDepot and Makahiki, our experiences using them for research and education, and additional ways they can be used for next generation energy research and education. The remainder of this extended abstract briefly introduces WattDepot and Makahiki and our research experiences to date.

2. WATTDEPOT IN BRIEF

Software for energy collection, storage, and analysis tends to come in two flavors that support two ends of the scalability spectrum. At one end are utility-scale SCADA sys-

[1]http://wattdepot.googlecode.com
[2]http://github.com/csdl/makahiki

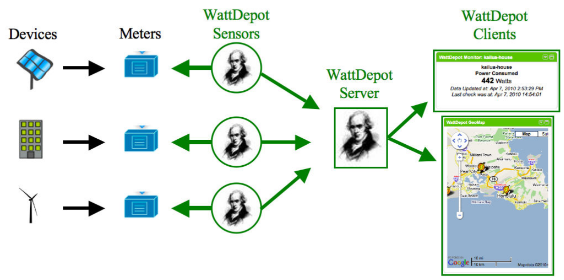

Figure 1: Architecture of WattDepot

tems and protocols which are intended to manage macro-grid data [1–3]. At the other end are "personal scale" systems such as those provided by energy meter or solar panel manufacturers which are intended to manage information about single households [4, 5]. We designed WattDepot to support a middle ground that we refer to as "enterprise-level" energy management, in which data concerning energy production and consumption of hundreds to thousands of households can be usefully managed. Figure 1 illustrates the architecture of the system, where WattDepot sensors send data from meters attached to energy devices to a server, which can then be queried by clients to provide visualizations and analyses.

Our use of WattDepot has led to a novel set of capabilities to support this middle ground.

First, unlike personal-scale systems that are typically tied to a particular manufacturer's product, WattDepot is agnostic about the kinds of meters used to monitor energy production and consumption data, and whether the data is personal-scale or utility-scale. It provides a REST protocol for data transmission that can be used to implement clients for a wide variety of devices; the major constraint is that these devices need to have network access. WattDepot clients can be written in any language that supports the HTTP protocol. We provide a high-level client libraries for Java and JavaScript.

Second, WattDepot can represent aggregations of power sources. For example, a building might have multiple meters monitoring energy consumption, one per floor. WattDepot can represent the power consumed by individual floors, as well as an aggregate source representing the building as a whole. Aggregations can be nested, so that floors can be aggregated into buildings, buildings into neighborhoods, and neighborhoods into cities.

Third, WattDepot automatically performs data interpolation when necessary. For example, a meter might provide a snapshot of energy usage once per hour for a given device. Clients can request the power consumed by this device at any time instant, and WattDepot will automatically provide interpolation when the requested time does not match a time for which actual sensor data is available.

Fourth, WattDepot is architecturally decoupled from the underlying data storage technology. This supports experimentation with both traditional relational as well as NoSQL technologies, and facilitates scalability. Currently, WattDepot implements support for Derby, Postgres, and BerkeleyDB storage systems.

Fifth, WattDepot is designed to support both Platform-as-a-Service (PaaS) and local installation. We have successfully deployed WattDepot to the Heroku cloud-based hosting service.

Sixth, WattDepot implements support for "ephemeral" data. In some application scenarios, it is useful to send energy data to the WattDepot server quite frequently (i.e. every few seconds) so that clients can monitor current energy consumption with low latency. However, that rate of data sampling is not necessary for historical analyses, which may only require energy data sampling at the rate of every few minutes. WattDepot supports this situation through ephemeral data, which creates an in-memory window during which all recently received energy data is available for retrieval, but stored in the repository only at a much lower sampling rate.

Finally, WattDepot can be effectively used for simulation and what-if scenario development, as well as for management of live energy data. This makes it appropriate as a kind of technological "scaffolding" for smart grid applications, where WattDepot can provide clients with simulated production and consumption data early in development, with the simulated data transitioning to live data as these sources go online later in development.

3. MAKAHIKI IN BRIEF

The feature set of WattDepot creates attractive infrastructure for management of energy data, but research suggests that effective participation of consumers in a next generation smart grid requires more than simple feedback to consumers about their consumption, particularly given the passive nature of their involvement for the past 100 years.

The second component of our open source software stack, Makahiki, represents research intended to create synergy between the need to create knowledge and engagement regarding energy and the ability of so-called "serious game" techniques and/or energy feedback to create participation and engagement [6–9]. In Makahiki, online game mechanics are employed with the goal of affecting real-world energy behaviors. The ultimate goal is to not just affect energy behaviors during the course of the game, but to produce long lasting, sustained change in energy behaviors and outlooks by participants. Figure 2 illustrates the architecture of Makahiki.

Makahiki consists of a configurable game engine that can be customized to the needs of different organizations. It includes a library of pre-built game "widgets" that implement a variety of game mechanics. Using the widgets, an organization can create a custom energy challenge in which players can compete individually and/or in teams to earn the most points by reducing their energy consumption as well as by learning about energy concepts in general. Some of the pre-built widgets include:

The *Smart Grid Game widget* is the primary place players go to learn about energy issues and earn points. The Smart

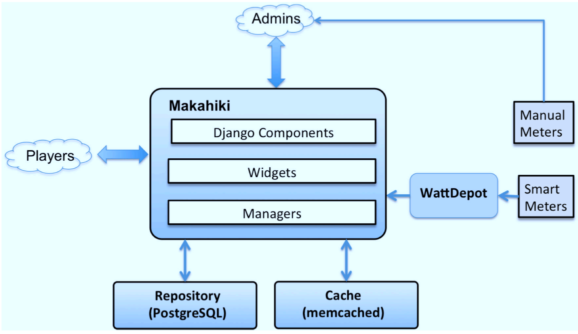

Figure 2: Architecture of Makahiki

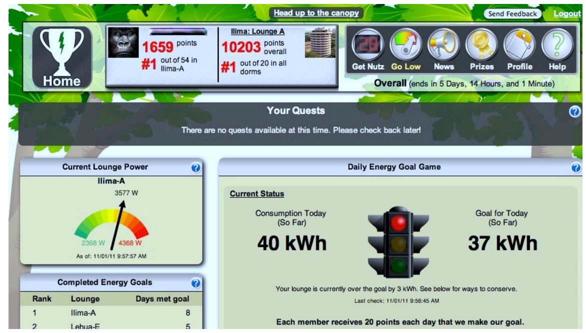

Figure 3: An energy challenge implemented in Makahiki that visualizes WattDepot data

Grid Game supports four different kinds of actions: activities, commitments, events, and excursions.

The *Daily Energy Goal Game widget* provides a way for players to earn points by reducing their current consumption from a baseline that is typically determined prior to the challenge. Both the historical baseline data and the current consumption is typically provided by API calls from Makahiki to an underlying WattDepot server.

The *Raffle Game widget* provides a way to incentivize participation from all individuals, even those who are not in the running for a top prize. For every 25 points a player earns, they receive one virtual raffle ticket. Players can dynamically allocate their tickets to any raffle prizes they are interested in at any time, up to the end of the raffle.

The *Social and Referral Bonus widgets* provide game mechanics that help encourage participation by providing additional points to players who participate in activities with other players and/or facilitate the entry of new players into an energy challenge.

4. EXPERIENCES IN BRIEF

As a preliminary assessment of the Makahiki+WattDepot software stack, we designed and implemented an energy challenge called the "Kukui Cup" for over 1,000 first year students living in the residence halls at the University of Hawaii in Fall, 2011. We installed 40 Shark 200-S meters throughout the residence halls, and used the ModBus WattDepot sensors to gather instantaneous power and cumulative energy every 15 seconds. Figure 3 shows a portion of the Go Low page, which contains two widgets (Power Meter and Daily Energy Goal Game) that are based upon WattDepot data.

Response to this initial challenge was very positive. Over 400 students participated, for an adoption rate of approximately 40%. In a survey of those participating students conducted near the end of the challenge, over 90% of them said they would play the game if it were offered next year. 60% of participants said "ease of use" was the thing they liked best about the website. 40% responded "Nothing" when asked what was confusing about the website, and 32% responded "Nothing" when asked what they would change about the website. The survey did yield insights into what could be improved, including the ability to introduce new games at points during the challenge, to provide better access to other player data, and simplify navigation.

The full version of this paper will go into more detail on our experiences as well as the changes and enhancements we have made to the Makahiki+WattDepot software stack in preparation for three energy challenges by different organizations to be held in Fall, 2012.

5. REFERENCES

[1] "Smart energy 2.0," http://www.zigbee.org/SmartEnergy.

[2] "Open Source Home Area Network (OSHAN)," http://sourceforge.net/projects/oshan/.

[3] "Open Phasor Data Concentrator (OpenPDC)," http://openpdc.codeplex.com/.

[4] "The Energy Detective (TED) Home Energy Meter)," http://www.theenergydetective.com/.

[5] "Control4 EMS 100," http://news.cnet.com/8301-11128_3-20000731-54.html.

[6] S. Deterding, D. Dixon, R. Khaled, and L. Nacke, "From game design elements to gamefulness: Defining "gamification"," in *Proceedings of MindTrek*, 2011.

[7] S. Darby, "The effectiveness of feedback on energy consumption," Environmental Change Institute, University of Oxford, Tech. Rep., 2006.

[8] A. Faruqui, S. Sergici, and A. Sharif, "The impact of informational feedback on energy consumption–a survey of the experimental evidence," *Energy*, vol. 35, no. 4, pp. 1598–1608, 2010. [Online]. Available: http://www.sciencedirect.com/science/article/B6V2S-4XP8T48-1/2/a3e827a4c0be61380d4fbb0480c3dbe3

[9] J. E. Petersen, V. Shunturov, K. Janda, G. Platt, and K. Weinberger, "Dormitory residents reduce electricity consumption when exposed to real-time visual feedback and incentives," *International Journal of Sustainability in Higher Education*, vol. 8, no. 1, pp. 16–33, 2007.