Demo Abstract: Creating Greener Homes with IP-Based Wireless AC Energy Monitors

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ABSTRACT

A home where every major appliance can be monitored for energy consumption and individually controlled wirelessly has long been a dream of gadgeteers and the green-conscious alike. Research has shown that real-time, per-appliance electricity usage feedback can induce behavior changes that lead to 10% to 20% reduction in usage [2].

We present ACME (AC Meter): an IP-based wireless device that provides real time energy usage measurement and control for AC devices. This device fills the gap between inexpensive watt-meters and expensive networked enterprise energy monitors. We show that ACME provides accurate measurement of active, reactive, and apparent energy from milliamps to tens of amps. We also demonstrate its ability to remotely switch the connected appliance.

In this demo, we will present a complete home monitoring system that integrates a set of ACMEs with an 802.15.4-to-802.11 router and a web server. Energy measurements will be pushed directly into a database by the ACMEs via UDP and retrieved by the web server continuously or on-demand to generate real-time graphs.

Categories and Subject Descriptors

B.0 [**Hardware**]: General; B.4 [**Hardware**]: Input/Output & Data Communication; J.4 [**Computer Applications**]: Social and Behavior Sciences

General Terms

Design, Experimentation, Performance, Measurement

Keywords

Architecture, AC, Meter, Green, Energy, Power, Platform, Wireless, Sensor Network, Mote, Measurement

1. HARDWARE ARCHITECTURE

Wireless energy and power monitoring is not new. It has been used in many industrial and commercial settings to monitor heavy-duty or mission critical equipment. Wireless is often a much needed convenience, since adding a wired metering network to pre-existing infrastructure is often difficult or expensive. However, such systems are designed for commercial environments and are often ill-suited for homes. Green conscious home owners are left with only a few options, such as the budget-priced kill-a-watt meters [1], a simple meter with an LCD interface.

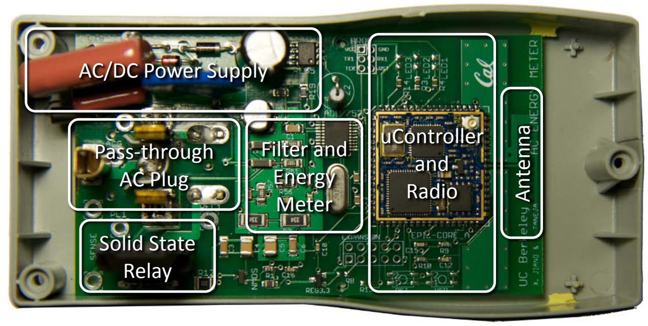

Figure 1: An ACME consists of four main sections: power supply, signal filtering and energy metering, micro-controller and radio, and solid state relay

Our hardware consists of four main sections: power supply, input filtering and energy metering, micro-controller and radio, and solid state relay, as shown in Figure 1, and described below.

The power supply performs AC to DC conversion and provides the rest of the circuit with a stable DC power source. We chose to use a simple half-wave rectifier with cut-off diodes that directly connects to the AC line. This avoids using a transformer and reduces cost and size.

We use a pass-through design in which the ACME plugs into the electric outlet and the appliance under measurement is plugged into the AC receptacles on the other side of ACME. Between the male AC plugs and the female receptacles is a sub-$m\Omega$ current sensing resistor. This adds an insignificantly small voltage drop between the supply and the load, but enough to be amplified and measured by the energy measurement circuit. A set of filters conditions this small differential voltage and feeds it directly into the current channel of the energy meter chip; a separate filter connects the voltage channel of the energy chip to the hot and neutral lines of AC to provide voltage measurements.

We use ADE7753 as our energy meter because it provides

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ACM 978-1-59593-990-6/08/11.

a comprehensive set of measurements such as real, active, and reactive power via both voltage and current channels. Energy measurements are internally stored in registers and are accessed by the Epic Core [3] mote via SPI bus.

Epic acts as a router that receives energy readings from ADE7753 and sends them to the appropriate destinations wirelessly via the onboard 802.15.4 radio, connected to a printed inverted-F antenna. Because Epic is TinyOS compatible, multiple flavors of routing algorithms can be used to route readings across multiple hops.

To allow remote control of the plug-in appliance, `ACME` includes a solid state relay capable of switching tens of amps. It is controlled directly by Epic.

2. DRIVER

The driver is implemented in TinyOS. The API uses a standard sampled interface which provides the ability to read the energy consumed by the appliance at regular intervals via a *start(interval)* command. `ACME` will signal *sampleDone(energy)* with the energy measurement at intervals specified in *start*. The application can turn on and off the device using *set(state)* command and query the current state via *getState()* command.

3. NETWORK ARCHITECTURE

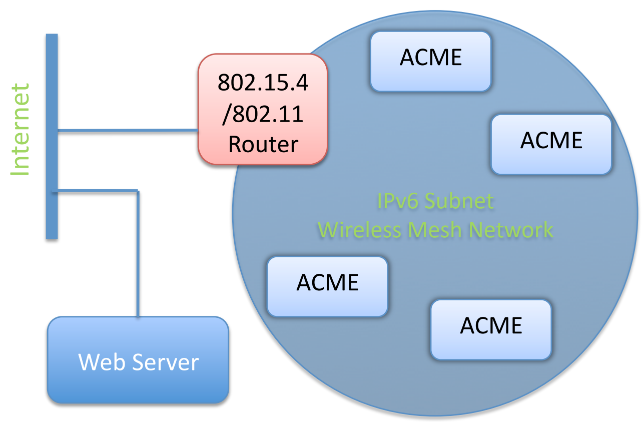

Figure 2: `ACME`s and the 802.11 router forms a mesh network and a logical IPv6 subnet. Energy measurements are routed from `ACME`s to the Internet via the 802.11 bridge can be read anywhere in the Internet.

`ACME` is a generic TinyOS compatible platform and therefore it supports all networking options available in TinyOS. In this demonstration, we use the `b6lowpan` IPv6 stack for connectivity. However, since `ACME` uses 802.15.4 radios, an 802.15.4 to 802.11 or Ethernet bridge is necessary. Several options are avalable, from a PC attached to a mote to a platform we have developed based on an embedded Linux device with integrated mote.

As shown in Figure 3, multiple `ACME`s form a mesh network and route data to and from the 802.11 router, which connects to the rest of the Internet via 802.11 or Ethernet. A set of `ACME`s and 802.11 routers form a logical IPv6 subnet with an 802.11 router as the globally-routable gateway.

4. WEB PORTAL

Energy information embedded in ones and zeros in packets will have little effect in modifying users' behavior unless they are presented effectively. We use a public web interface to present real-time energy and power information via per-device time-series graphs and a pie chart of distribution of energy in the home. Additionally, the user can control all `ACME`s on the subnet. Energy measurements from `ACME`s are pushed to the web server over a UDP socket, where they are inserted into a database for presentation.

5. DEMONSTRATION

We will show a set of `ACME`s monitoring and controlling various AC devices such as laptops, monitors, and lights. Visitors will be able to view real-time graphs of energy information through the web portal. Visitors are encouraged to control the AC device and directly "talk" to `ACME`s via IP-compatible utilities such as netcat or via the web interface.

6. CONCLUSION

We hope that a TinyOS based platform that runs directly off AC electricity will un-tether the TinyOS community from battery based experiments and facilitate indoor deployments. We further hope that a relatively inexpensive wireless AC monitor will facilitate innovation and research in creating greener homes and offices. We plan to use `ACME` as a primitive in combination with other sensors to actively perform on-line energy optimizations.

Please refer to: `http://smote.cs.berkeley.edu:8000/tracenv/wiki/ACME` for current status of this project.

7. REFERENCES

[1] `http://www.p3international.com/products/special/P4400/P4400-CE.html`.

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