Demo Abstract: A Magnetic Field-based Appliance Metering System

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ABSTRACT

In this demonstration, we show an energy measurement system that estimates the energy consumption of individual appliances using a wireless sensor network consisting of contactless electromagnetic field (EMF) sensors deployed near each appliance, and a whole-house power meter [1]. The EMF sensor can detect appliance state transitions within close proximity based on magnetic field fluctuations. Data from these sensors are then relayed back to the main meter using a low-latency wireless sensor networking protocol, where changes in the total power consumption of the house are used to determine the power usage of individual appliances. The sensors are low-cost, easy to deploy and are able to detect current changes associated with the appliance from a few inches away making it possible to externally monitor in-wall wiring to devices like overhead lights or heavy machinery that might operate on multiple phases of the AC distribution system of the building. Appliance-level energy data provide continuous feedback to end users about their consumption patterns and provide building managers accurate information that can be used to target the most effective update and retrofit strategies.

Categories and Subject Descriptors

J.2 [**Physical Sciences and Engineering**]: Miscellaneous

Keywords

CPS, Energy Metering, Sensor Networks

1. SYSTEM DESCRIPTION

Figure 1 shows an overview of the general system architecture which consists of a three-phase meter used for overall mains power metering, plug-meter devices used for ground-truth data collection and the EMF event detectors. These components are connected to a networked backend and the real-time results are displayed on an application running on a personal computer (PC). The hardware components and the appliance metering algorithm are described in the following sections.

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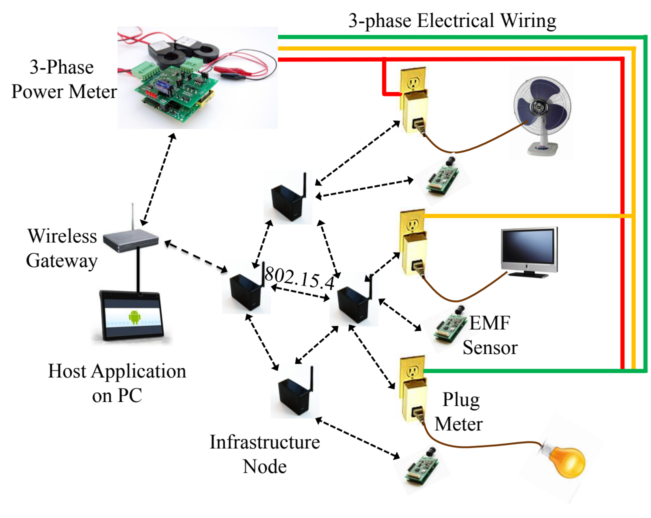

Figure 1: Network Architecture

1.1 Three-Phase Meter

We designed a custom three-phase power meter, shown in Figure 2, which employs the cutting edge ADE7878 energy metering chip from Analog Devices, specifically to collect high resolution data which can be correlated with events from our EMF detectors. Off-the-shelf energy meters often make it difficult to capture high-speed raw waveforms. In contrast, our meter samples both the current and the voltage on each phase at 1KHz, and uses an on-chip DSP to compute true, apparent and reactive power, as well as several other energy metrics. The main board is powered from either 120 or 240 VAC and can sense voltages as large as 600VAC. Current sensing uses split-core current transformers and both voltage and current values are read at 24-bit resolution. The overall range and accuracy values depend on the particular configuration of the current transformer used, but this configuration typically meets the 0.2% accuracy requirements for most utility billing standards.

1.2 Plug Meter

We use the FireFly plug meter [2] for ground-truth validation and for devices that can benefit from remote actuation. Each plug meter, shown in Figure 3 contains the ability to monitor and control two electrical outlets using wireless communication. The meter uses an efficient switching power supply that draws less than 0.1 watts ensuring that it does

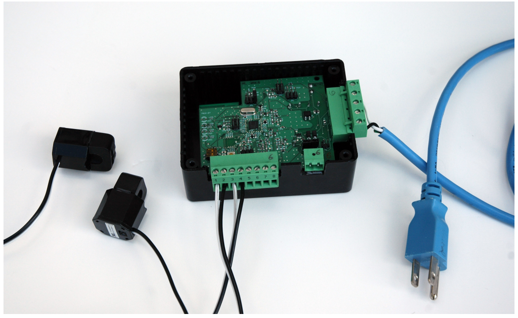

Figure 2: Wireless Three-Phase Circuit-Panel Meter

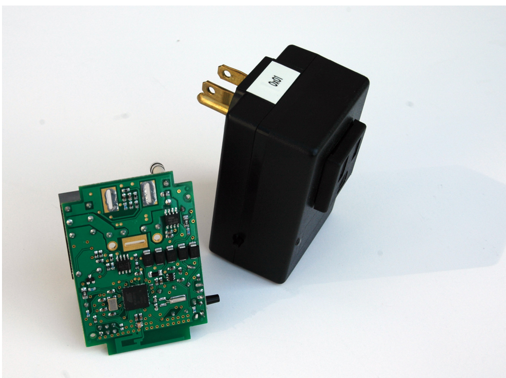

Figure 3: Plug-Level Meter

not unnecessarily increase the building power consumption. The meter measures power and energy consumed by an appliance. We use plug meters solely for ground-truth measurements and hence they would not be required in a real deployment.

1.3 EMF Sensor

The core principle behind the EMF event detector is that an alternating current (AC) flowing through a conductor generates a corresponding magnetic field. The EMF event detector senses an appliance state change (transition between *on* and *off*), by monitoring changes in nearby electromagnetic fields. Typically AC wires run as parallel pairs and hence most of the magnetic fields cancel out. However, imbalances in wires and stray currents flowing on ground lines as well as through appliances produce a significant magnetic field. The amplitude of this field is generally small (millivolts), but if sufficiently amplified, one can reconstruct the original source to a reasonable degree of approximation.

In [3], the authors present ViridiScope which uses indirect sensing of appliances to estimate per-appliance energy consumption. This work suggests using magnetic field sensors to estimate the power consumption of a device. Due to the difficulty in estimating power consumption without device and installation-specific calibration, our EMF event detector shown in Figure 4 focuses on detecting appliance state changes rather than trying to directly measure power. The magnetic field is detected using an instrumentation amplifier (INA) and an inductor. In order to increase robustness on the magnetic field sensing front-end, an MSP430 controller performs continuous automatic-gain adjustment to keep the peak-to-peak range of the signal at approximately $\frac{V_{dd}}{2}$ to avoid clipping while still capturing events of interest. Each EMF sensor transmits its auto-gain value every 640ms. Significant changes in this value would indicate that a nearby appliance has changed its power consumption.

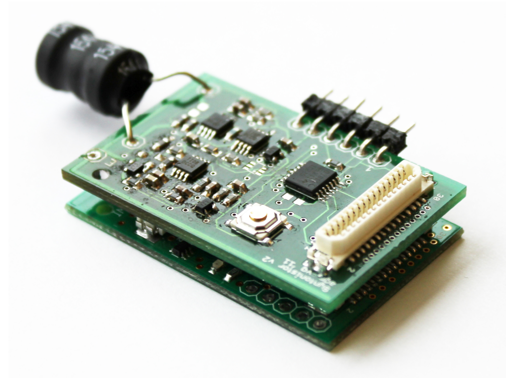

Figure 4: EMF event detector stacked on FireFly3 sensor node.

1.4 Appliance Metering

When the EMF sensor detects an event, it sends a timestamped message to the gateway. Our algorithm then determines the change in power of the three-phase meter across a time window before and after the event. We assume that the power consumption for this appliance remains constant when the appliance is *on*. This constant value is found by averaging the absolute value of the power change during the *off-on* and *on-off* transitions, and the energy is found by integrating the power for the *on* period.

2. DEMONSTRATION

Our demonstration consists of a setup similar to Figure 1. It consists of multiple portable appliances (Example - light bulb, fan, laptop and iron) connected to an electrical outlet, which is monitored by a three-phase energy meter. Each appliance is connected to the outlet through an individual plug-meter. An EMF sensor is placed in the proximity of the electrical cable connected to each appliance. The users can turn *on* and *off* the different appliances. Our real-time results are displayed on a Graphical User Interface on a PC. The results show the dis-aggregation of total energy from the three-phase meter into the energy consumed by the various appliances. The ground-truth, which is provided by the plug meter is shown for validation.

3. REFERENCES

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