Technology | DOI:10.1145/1743546.1743554

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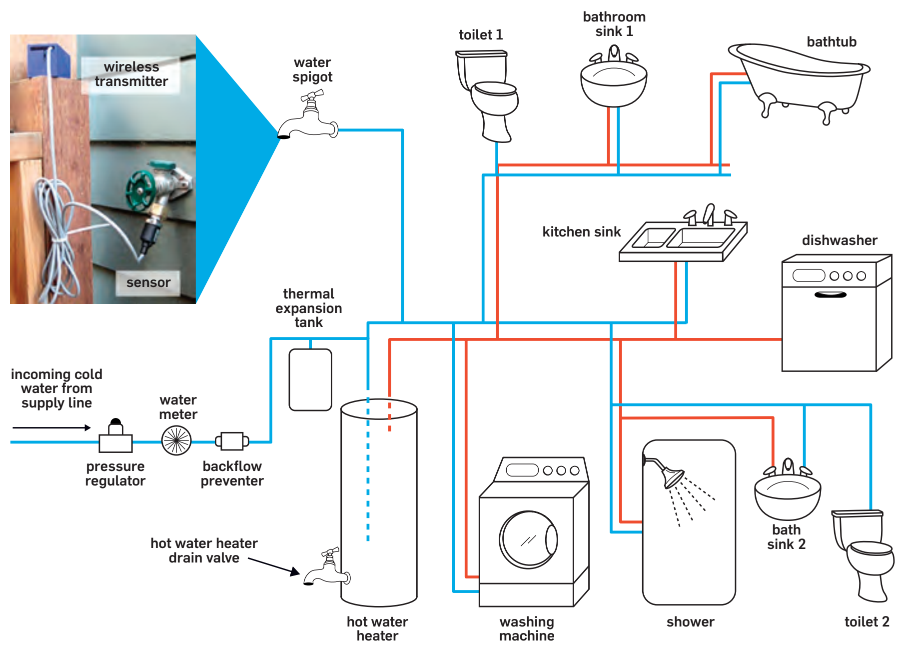
Beyond the Smart Grid

Sensor networks monitor residential and institutional devices, motivating energy conservation.

As president-elect, Barack Obama used the term "smart grid" in his first major speech of 2009, and few phrases have enjoyed as much currency recently. The electrical grid isn't the only utility acquiring intelligence, however, as water and gas meters throughout the U.S. gain radio communication capabilities and other innovations.

But those grids (and their attendant smartness) stop at the residential meter, so consumers never know which household devices are the biggest energy users. Once monitored, these devices would need to communicate—to turn on the ceiling fan and adjust the air conditioner when electricity prices peak, for example. The final ingredient for such a system to be useful to consumers is an easy-to-understand interface for monitoring and controlling the devices.

The solution, like the problem, has three parts. First, monitor each device separately; second, network them together for coordination; third, present the resulting data in an easy-to-use format. As it happens, this solution goes beyond energy conservation to suggest new ways of integrating home automation, safety, security, and entertainment applications with smart grid data.



HydroSense can be installed at any accessible location in a home's water infrastructure, with typical installations at an exterior hose bib, a utility sink spigot, or a water heater drain valve. By continuously sensing water pressure at a single installation point, HydroSense can identify individual fixtures where water is being used and estimate their water usage.

FIGURE FROM HYDROSENSE: INFRASTRUCTURE-MEDIATED SINGLE-POINT SENSING OF WHOLE-HOME WATER ACTIVITY
JON FROEHLICH, ERIC LARSON, TIM CAMPBELL, CONOR HAGGERTY, JAMES FOGARTY, SHWETAK N. PATEL

Your Home's Five Senses

The first key part is the sensors themselves. For utility monitoring, installation has been a major barrier to consumer adoption. Measuring water flow to a specific faucet, for example, required removing a section of pipe. To give a residential consumer the whole picture, this process would have to be repeated for every faucet in the house.

But now work done by Shwetak Patel, an assistant professor in the department of computer science and engineering at University of Washington, and colleagues can extrapolate electrical, water, and gas use of individual devices by measuring the "shock waves" created when consumers turn on the devices that use those utilities.

Patel's HydroSense approach is to attach a single sensor to a spigot and examine differences in pressure created by the water-hammer phenomenon when individual devices are turned on and off. After building a profile of devices in the house, he says, the single sensor can accurately tell each device from the others within a 5% margin of error. The same model works for gas lines as well; for electricity, the single plug-in sensor looks for characteristic noise patterns produced by individual devices over the home's electrical lines.

Patel points out the educational value of this information. "Often peoples' mental model of [utility] consumption is really inaccurate," he says. "Over 30 years of study in environmental psychology has shown that giving people itemized feedback can reduce overall energy use by 15%–20%. But adoption of sensors that will give them that feedback drastically drops off as the installation burden increases. So the question is, How can we build a single sensor that gives them disaggregated information, but doesn't need a professional electrician or plumber to install? If we can build cheap sensors that give consumers effective feedback, they can start to reduce overall consumption in their home."

Even with single-point sensors installed, there's still a place for individual sensors to measure environmental factors. For example, a sensor that measures the oil level in a furnace could switch on electric heating when the oil is running out, but only during times of low electricity demand. Or a combustible-gas sensor could prevent an explosion, when a gas leak is detected, by preventing a gas furnace's ignition from sparking on. Such concepts require a development platform that hosts both sensors and communications hardware.

One such platform is SquidBee and its successor, Waspmote. Both originated at the Spain-based company Libelium, which also produces three types of Waspmote sensor boards. One determines the presence of gases, such as carbon dioxide and methane; the second senses environmental changes, such as vibration, pressure, and moisture; and the third is a prototype board that will host any other sensor types a developer might have. For applications that don't require immediate communication or in situations where immediate communication is impossible, the Waspmote board contains two gigabytes of internal memory for later transmission.

Making Sensors Talk

Both Patel and Libelium's devices require a way to communicate their findings to the outside world. Waspmote uses a variety of methods, including USB, GPS, 802.15.4, and a range of radio frequencies. Patel is agnostic about the communication methods his still-in-development devices will use. "We're innovating on the hardware, aggregation, and signal processing," he says, "but not on the network."

One specification that both plan to use is ZigBee, an extension of the 802.15.4 standard promoted by the nonprofit, industry-based ZigBee Alliance. According to ZigBee Alliance Chairman Bob Heile, ZigBee was designed specifically "to create open, global standards for wireless sensor networks." As such, it prioritizes power consumption and transmission integrity so that the devices—which might be used in difficult-to-access areas—can operate trouble-free for a long period of time. "We're achieving devices that go for five to 10 years on an alkaline battery or 10 to 20 years on lithium-ion," says Heile.

The ZigBee Alliance also prioritized scalability well beyond the residential needs. Heile says the ARIA Resort & Casino in the new CityCenter development in Las Vegas has more than 90,000 ZigBee-compliant devices to control both common-area and guest-room environments. On the other hand, ZigBee largely ignores issues of bandwidth and quality of service, as would be needed for a telephony or video application.

Oberlin College hosts an annual dorm energy competition, with prizes for the dorm that achieves the greatest energy reduction.

The ZigBee specifications cover all seven layers of the Open Systems Interconnection model, in three parts. The bottom two—the physical and data-link layers—are the 802.15.4 standard, with no changes. Layers three to six comprise the "ZigBee stack," including algorithms for organization among nodes, error routing, and AES-128 security. (As a wireless technology, the security portion is especially important to prevent outside tampering that could cause unpredictable device behavior.) When layers one through six are implemented according to the ZigBee specification, it qualifies for ZigBee platform compliance certification. ZigBee-certified products also implement layer seven, which is a ZigBee public profile such as smart energy, home automation, or health care.

Acting on Data

Once the data is collected, it needs to be presented in ways that are understandable to humans and to other devices. "We don't want to overwhelm the consumer with a bunch of data," says Patel. "We could provide them with a 'Top Ten Energy Consumers in Your Home' list to give them something to work on. Or if we see that the compressor in their refrigerator is degrading in performance over time, we could give them targeted advice on blowing out the coils."

One example of how such data is being used is found in Oberlin College's campus resource monitoring system. The environmental studies program monitors electricity use in each of the college's dorms, in some cases with multiple sensor points per dorm. Administrators make adjustments to discount nondiscretionary expenditures, such as a kitchen in those dorms with cafeterias, then take a baseline reading to determine typical usage. Data from dorms' current energy use is displayed in three ways: on the Web at oberlin.edu/dormenergy; as building dashboard video displays throughout campus; and as color-changing orbs placed in several campus locations, including the dorms themselves.

Finally, Oberlin College runs an annual dorm energy competition and gives prizes to the dorm with the greatest reduction from baseline use. Henry Bent, sustainable technology research fellow partly responsible for maintaining the Oberlin system, is especially enthusiastic about the orbs. "Numbers and dials and graphs are fantastic, but you want something that you can see very quickly at a glance," Bent says. "I just know when I'm on my way to the bathroom, 'Oh, look, that orb is red, I should turn something off.' " ■

Further Reading

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Wireless Sensor Networks Research Group
http://www.sensor-networks.org.

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