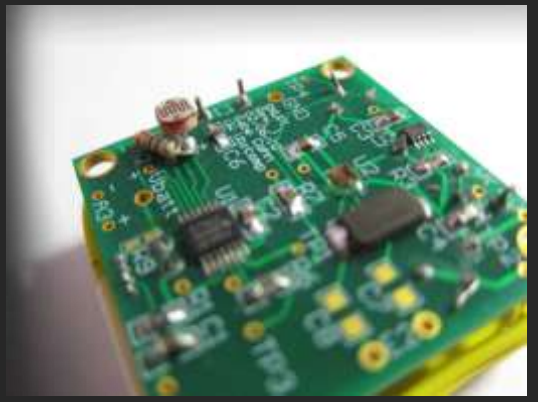
Strategies for Large Scale Deployment of Energy Monitoring and Sensing in the Home

Shwetak N. Patel
University of Washington

http://ubicomplab.cs.washington.edu/

Focus of this talk

- Sensing in the home
  - Resource monitoring
  - Low-power wireless sensing



Living Laboratories

Non-expert deployment of energy monitoring technology

Disaggregated energy use

CITY OF SEATTLE

Seattle Public Utilities Bill

Questions? Call 206-684-3000 or 1-800-862-1181 (out of area calls only)
Write us? 700 5th Avenue, Suite 2777, PO Box 34027, Seattle, WA 98124-4027

C99034
LEAK
32B
CD-0

Summary of charges as of August 18, 2009

Payments received after August 19, 2009 are not reflected.

Previous balance:	317.91
Payments applied - **THANK YOU:**	317.91 CR
Balance:	0.00
Total adjustments:	0.00
Current billing:	2,994.83
TOTAL AMOUNT DUE ON September 08, 2009	**$2,994.83**

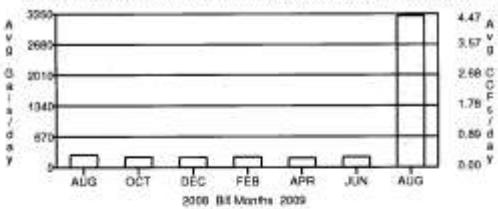
Service address:
5544 ASHWORTH AVE N

SUMMER WATER RATES ARE IN EFFECT FROM MAY 16 THROUGH SEPTEMBER 15. THIS BILL SHOWS HIGH CONSUMPTION. PLEASE READ ENCLOSED BROCHURE FOR INFORMATION.

Moving? *Call us on the day you move if you are reading your own meter. To have us read your meter for a fee, call us at least 3 days in advance of your move.*

Remember: *Account openings and account closings cannot be backdated to a day before you contact us.*

Compare Your Water Usage



This Period
No. of days: 64
Consumption in CCF: 283
Avg consumption/day: 4.42 CCF
Consumption in gals: 211684
Avg consumption/day: 3307.56 gals

Same Period Last Year
No. of days: 62
Consumption in CCF: 23
Avg consumption/day: 0.37 CCF
Consumption in gals: 17204
Avg consumption/day: 277.48 gals

1 CCF = 748 gallons

Seattle Public Utilities Bill

Service address: 5544 ASHWORTH AVE N

DUE DATE: September 08, 2009
AUTOMATIC PAYMENT

5544 ASHWORTH AVE N
SEATTLE, WA 98103-5917

Your account has Automatic Bank Payment. $2,994.83 will be deducted from your bank account on the payment due date.

0000000908090200108434701547710000000000299483003

Florida Power & Light Company
PO Box 025576
Miami, FL 33102

/ 27

Please request changes on the back. Notes on the front will not be detected.

The amount enclosed includes the following donation:
FPL Care To Share $ _____

2,3,4,7,8 4118 6
AUTO **CO 4501
116049 Z
BEACH FL 33445-3506

Make check payable to FPL in U.S. fiav and mail along with this coupon to:
FPL
GENERAL MAIL FACILITY
MIAMI FL 33188-0001

Account number	Total amount you owe	New charges due by	Amount enclosed
	$295.43	Jul 16 2008	$

Account number:

Statement date: Jun 25 2008
Next meter reading: Jul 25 2008

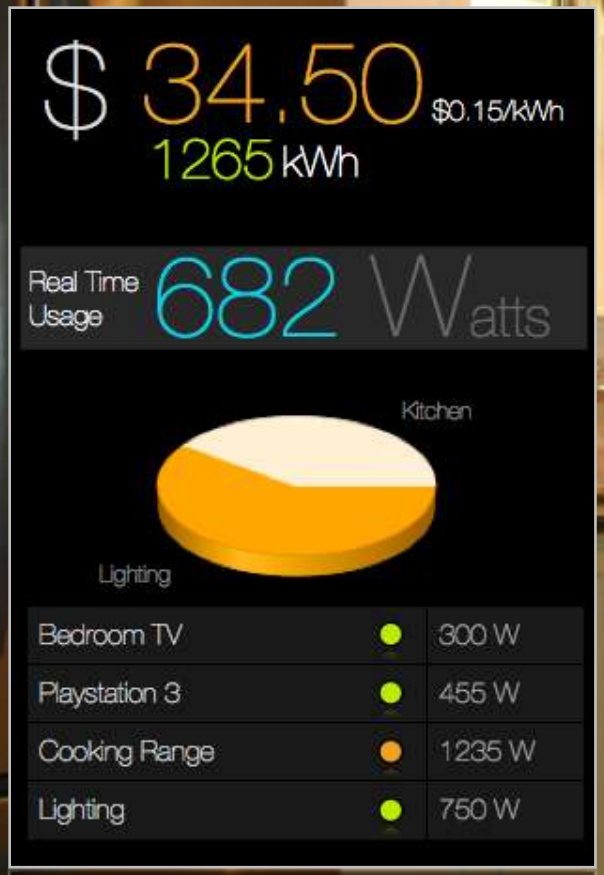
Additional activity (+ or -)	Balance before new charges (=)	New charges (+)	Total amount you owe (=)	New charges due by
0.00	0.00	295.43	$295.43	Jul 16 2008

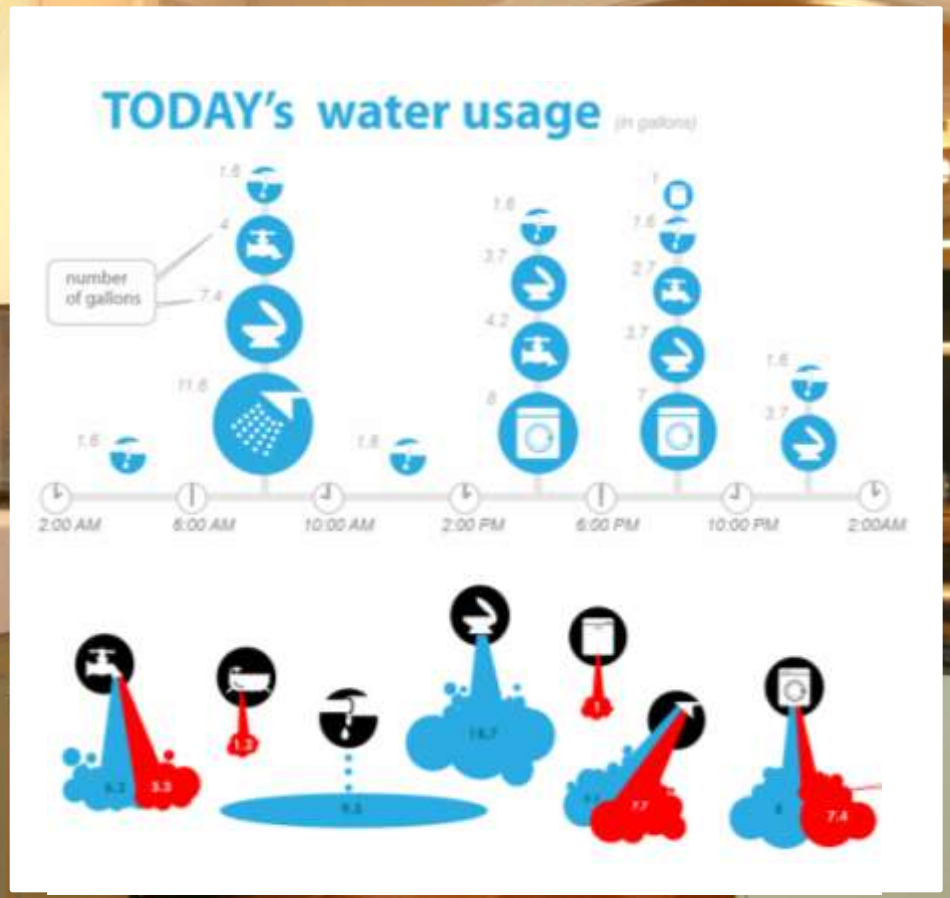
Amount of your last bill	326.10
Payment received - Thank you	326.10C
Balance before new charges	$0.00
New charges (Rate: RS-1 RESIDENTIAL SERVICE)	
Electric service amount	251.15**
Storm charge	2.59
Gross receipts tax	6.51
Franchise charge	18.75
Utility tax	[illegible]
Late payment charge	4.50
Total new charges	$295.43
Total amount you owe	**$295.43**

- A late payment charge of 1.50% will apply if not paid by July 16, 2008, and your account may be subject to being billed an additional deposit.
- Would you like one less bill to think about & help the [illegible] FPL Automatic Bill Pay & your bill is always paid on time. Save time, postage, check writing & paper. Plus, cut fuel consumption of cars & trucks that transport checks. Enroll at FPL.com or see authorization form in this bill.

Please have your account number ready when contacting FPL.
Customer service: (561) 994-8227
Outside Florida: 1-800-226-3545
To report power outages: 1-800-4OUTAGE
Hearing/speech impaired: 711
Online at:

Feedback Interfaces



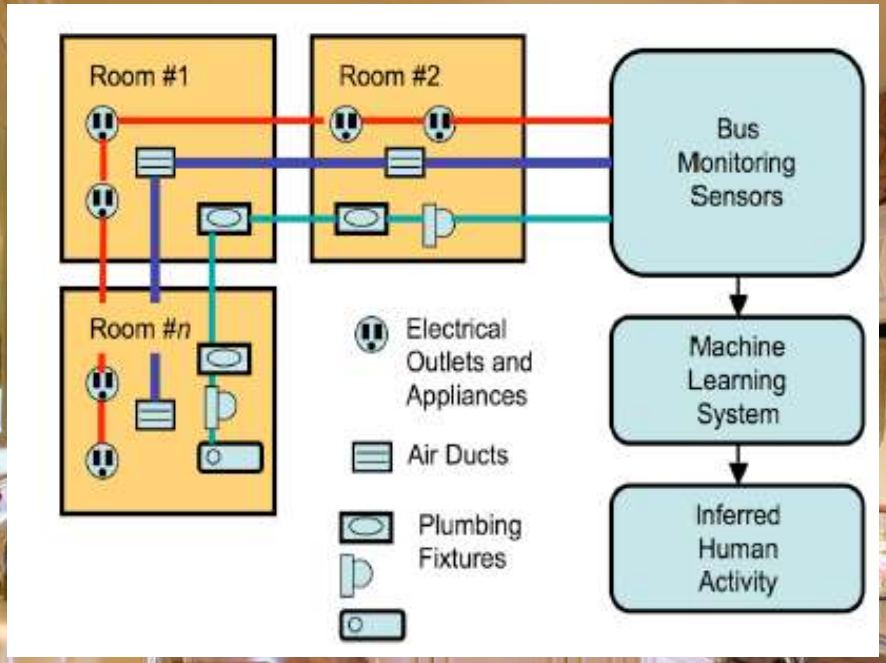


Value for the stakeholders

- Conservation and actionable feedback
- New model for demand response
- Validation and verification of conservation activities
- No truck roll or costly rollouts
- No need to go into the home

Distributed Direct Sensing

Infrastructure Mediated Sensing

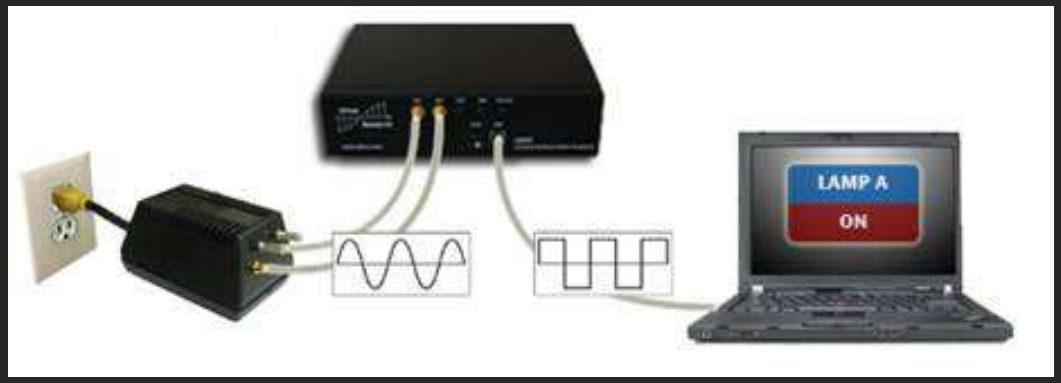


Use the utility infrastructure as the sensor

Ubicomp 2007, Pervasive 2008

PowerLine Event Detection

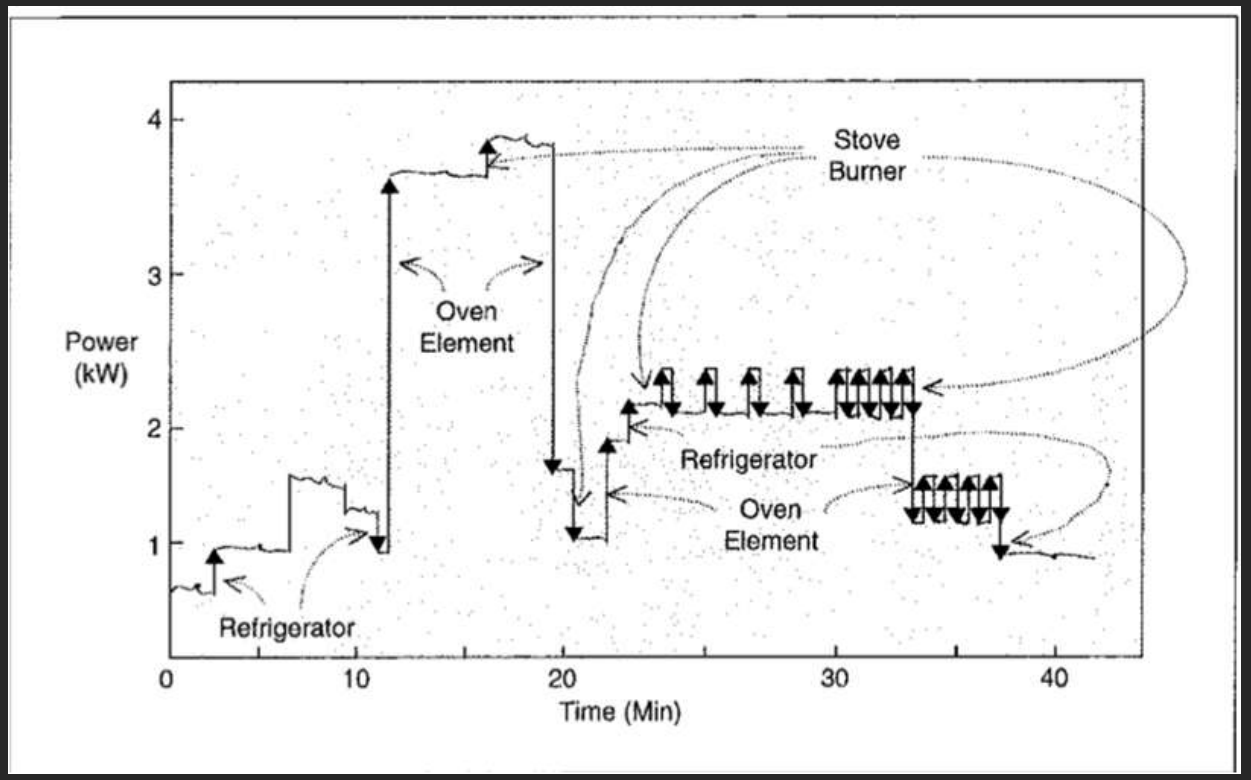
- Single sensor on the power line can detect the use of most electrical devices



Ubicomp 2007, 2010, Pervasive 2011

Existing Approaches

- Past work has looked at the current/voltage relationship (NILM, Hart et al).

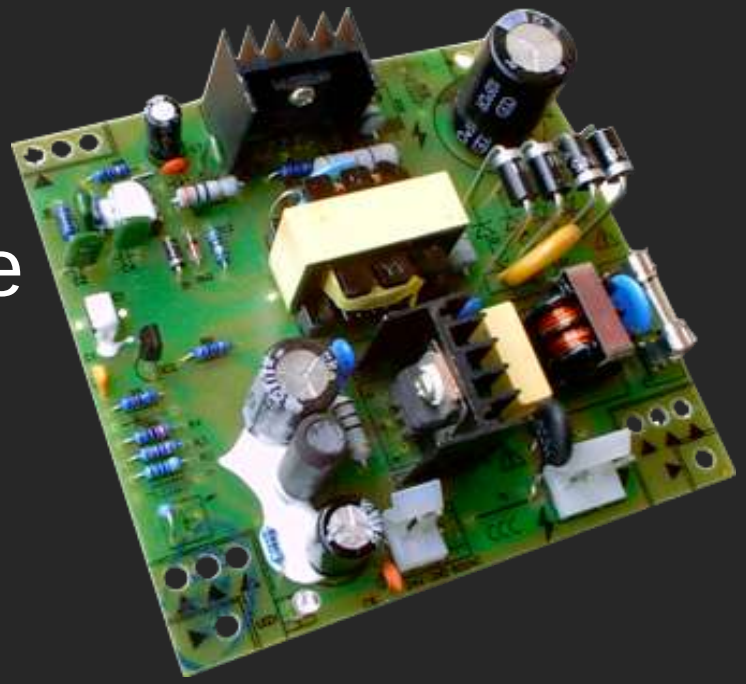


Our Approach: Your noise is my signal

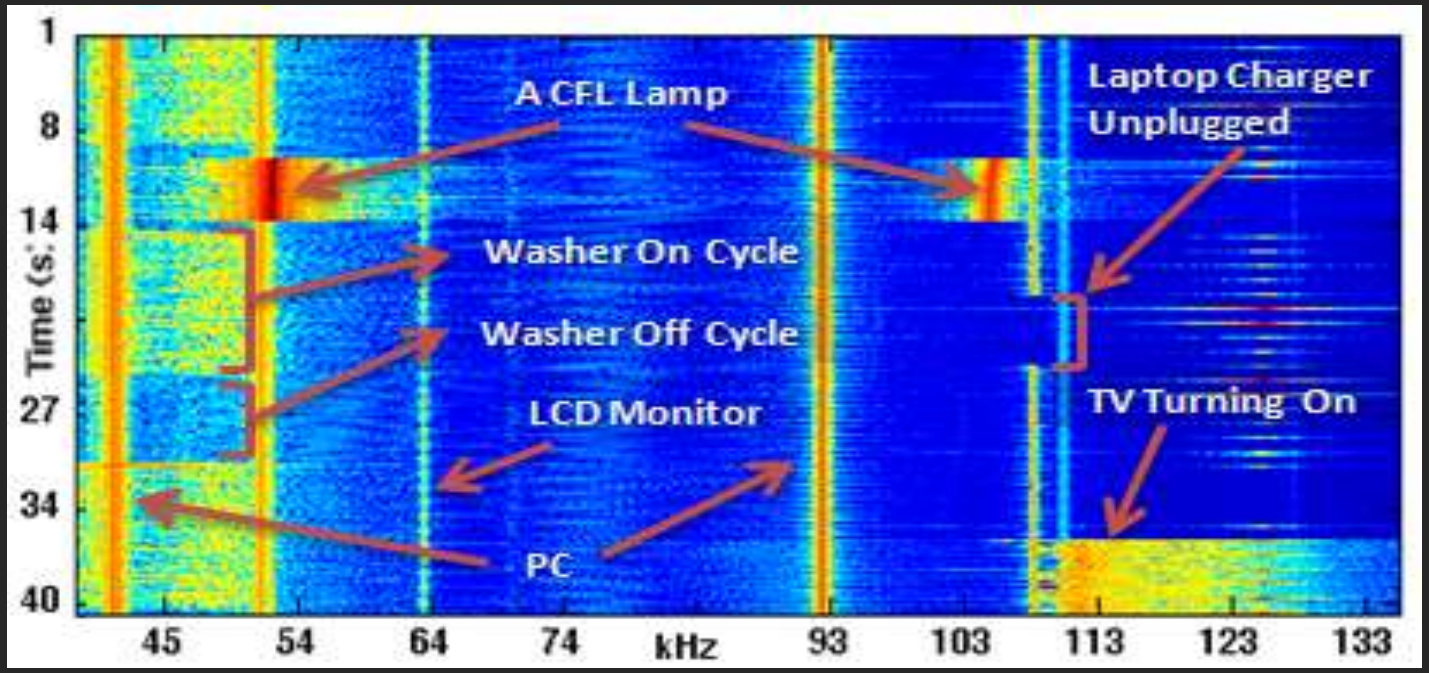
- Instead of just current, sample the voltage at a high rate
  - Only have to sample one location
- Look at electrical noise on the power lines
  - Electronic devices produce noise

Switch Mode Power Supplies (SMPS)

- Small, efficient
- Very popular
- Produce continuous noise



For example…


A CFL Lamp
Laptop Charger Unplugged
Washer On Cycle
Washer Off Cycle
LCD Monitor
TV Turning On
PC
Time (s)
1
8
14
27
34
40
45
54
64
74
kHz
93
103
113
123
133

Whole-House Current Consumption

- Not end-user installable
- Requires an electrician

Contact-Less Whole-House Current Consumption Sensor

- Detects the magnetic field behind the metal
- Within 4% of “true power”
- Also provides additional features for classification

CHI 2010

Detectable Events

- Microwave door
- Microwave
- Coffee maker
- Electric stove
- Refrigerator door
- Refrigerator
- Electric oven
- Electric oven door
- Dishwasher
- Garbage disposal
- Bathroom exhaust fan
- Incandescent lights via a wall switch
- Fluorescent lights via a wall switch
- Lights via a dimmer wall switch
- Garage door opener
- Dryer
- HVAC/Heat Pump
- Ceiling fan
- Laptop power adapter
- Television

Water Sensing

- **Single-point sensor of water usage**
- **Identifies water usage activity down to a fixture level (e.g., toilet)**
- **Provides estimates of flow at each fixture**

hydrosense

Ubicomp 2009, Pervasive 2011, PMC Journal 2011

traditional inline
water meter

water tower

Plumbing System

hose spigot

thermal expansion tank

incoming cold water from supply line

pressure regulator

hot water heater

laundry

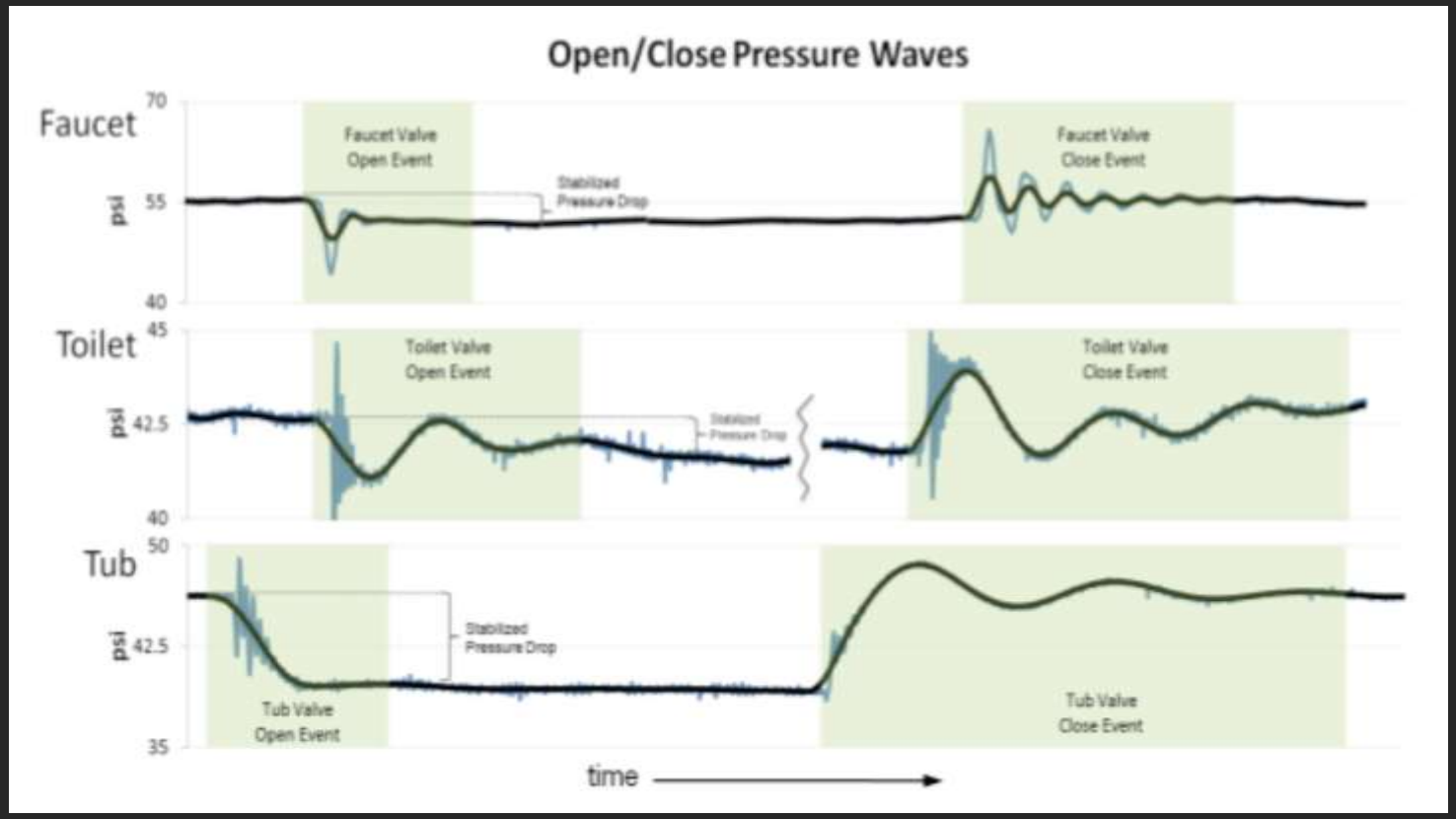
bathroom 1

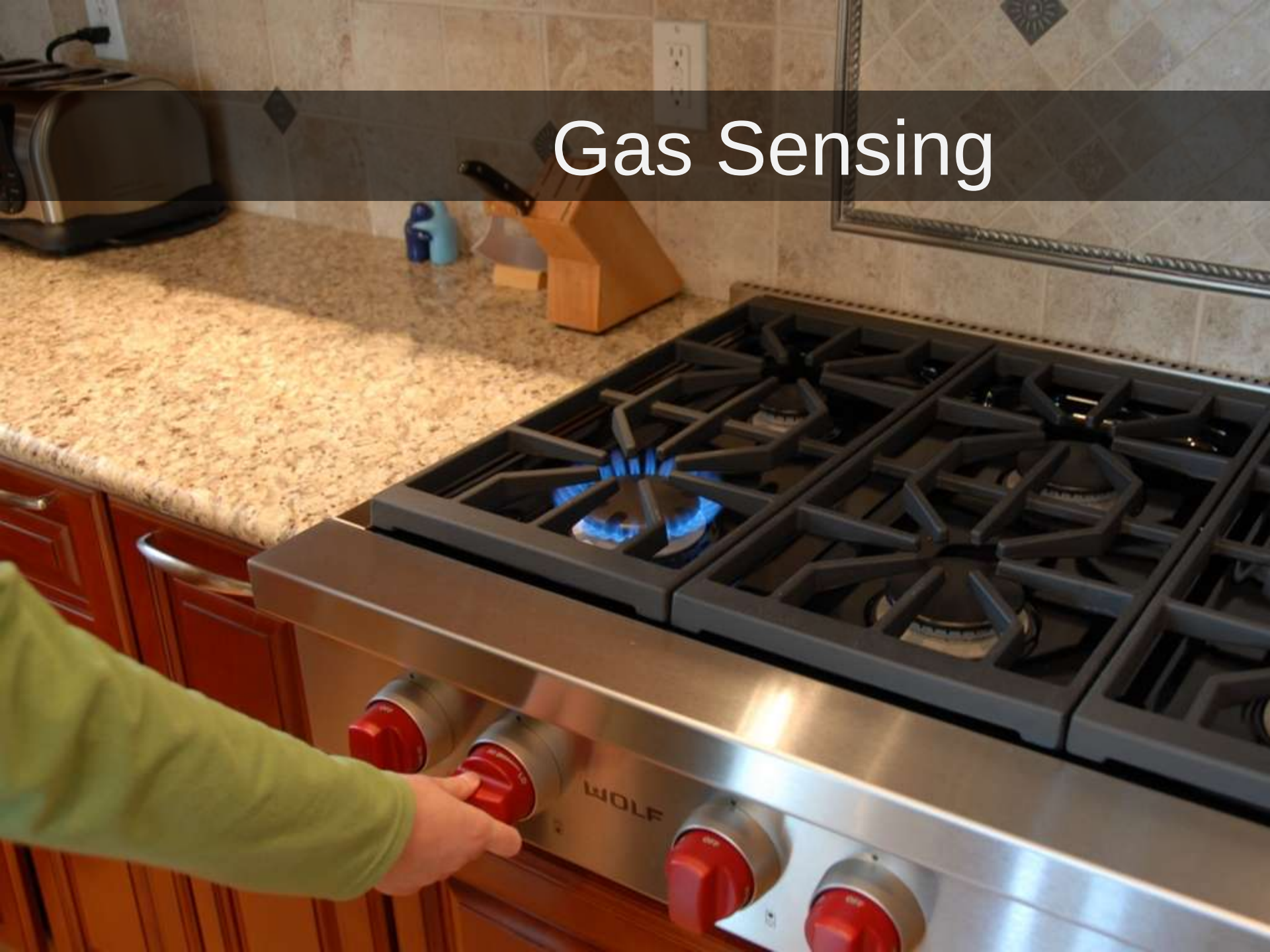
kitchen

dishwasher

bathroom 2

Fixture-level Event Detection



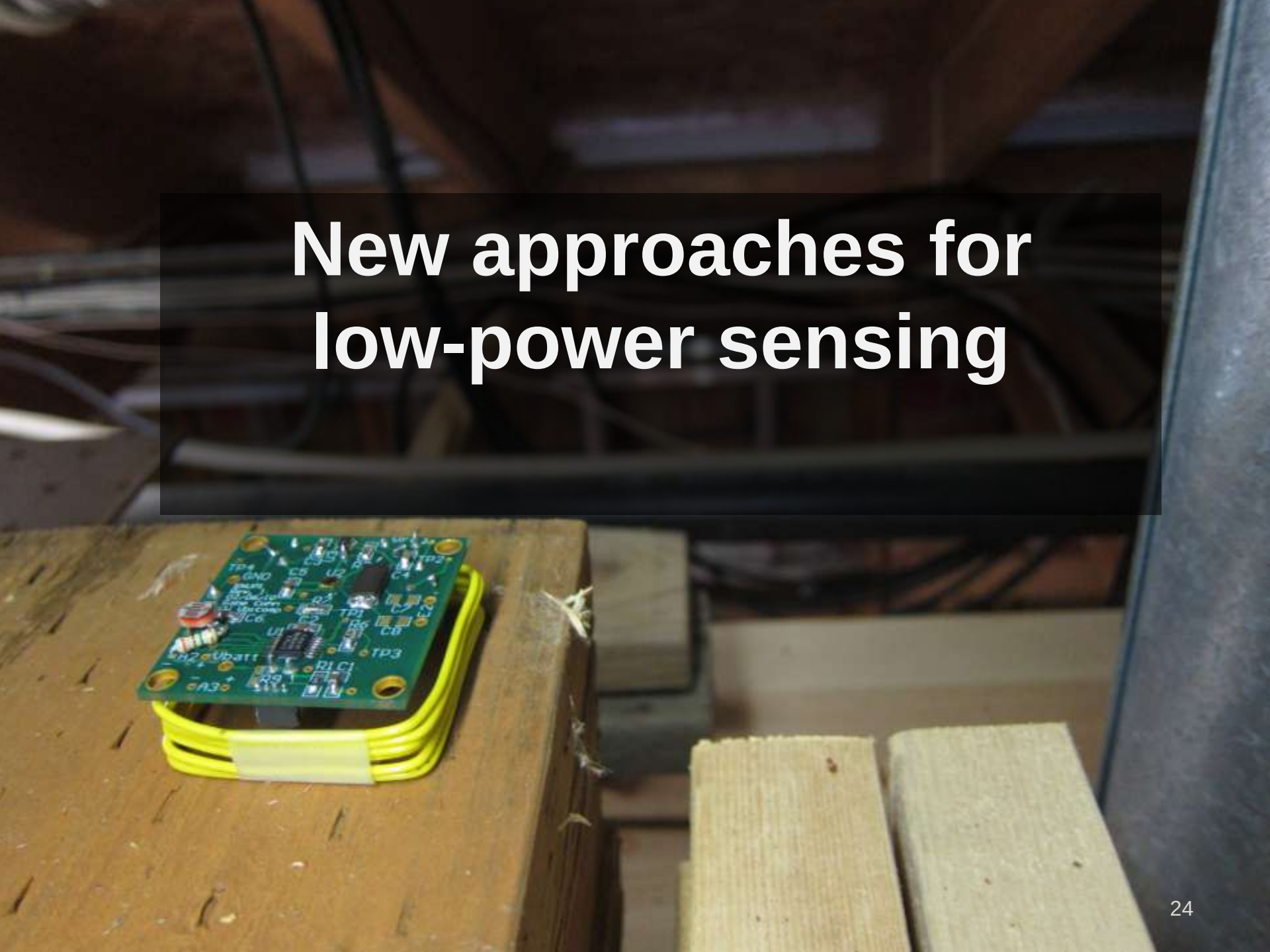

Gas Sensing
WOLF

GasSense

Regulator
Gas Meter

Regulator
Relief Vent
Battery Pack
Sensor Mount

New approaches for low-power sensing



hard to maintain

hard to maintain

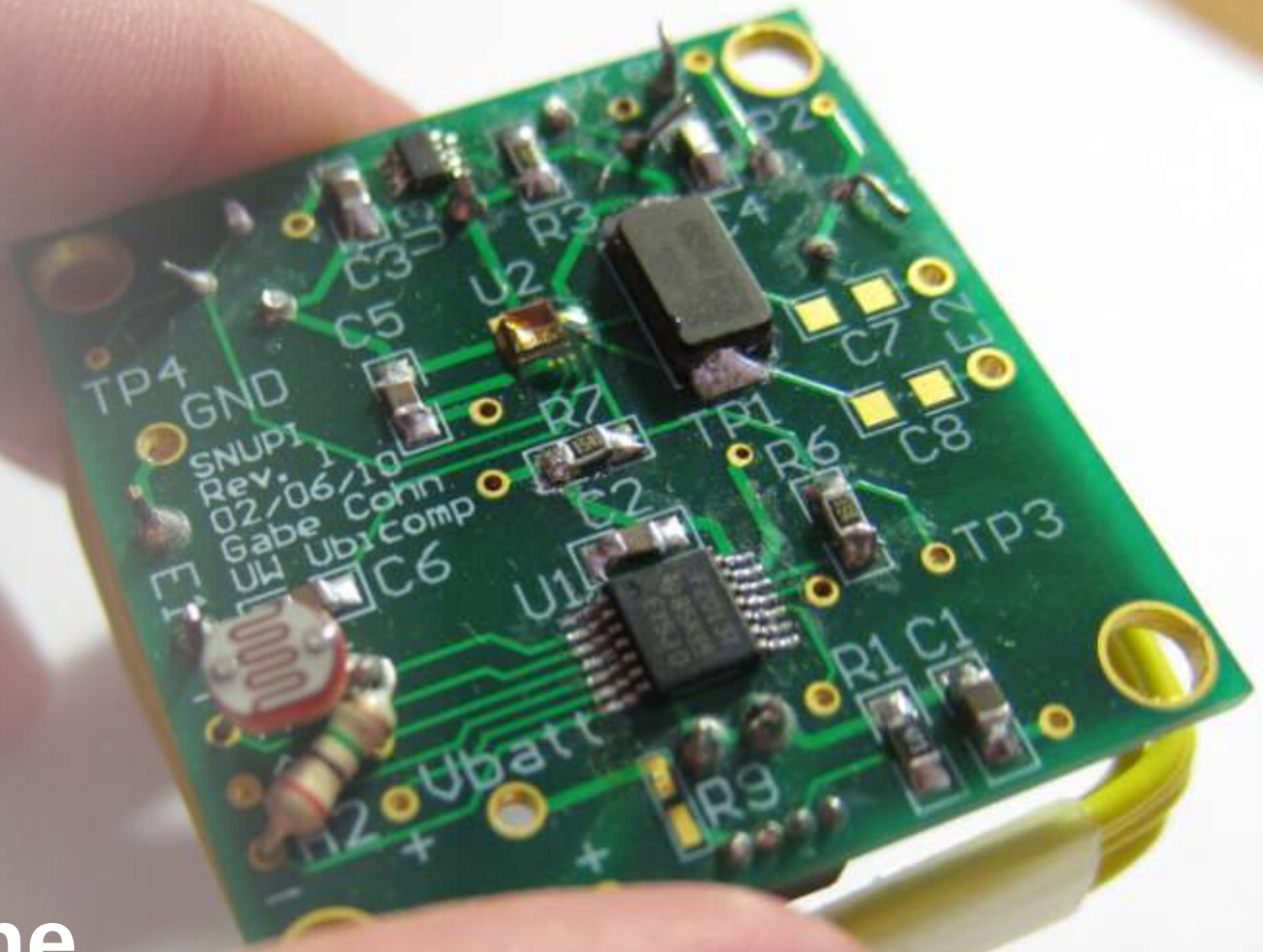
Sensor

Nodes

Utilizing

Powerline

Infrastructure



Ubicomp 2010

Powerline Coupling

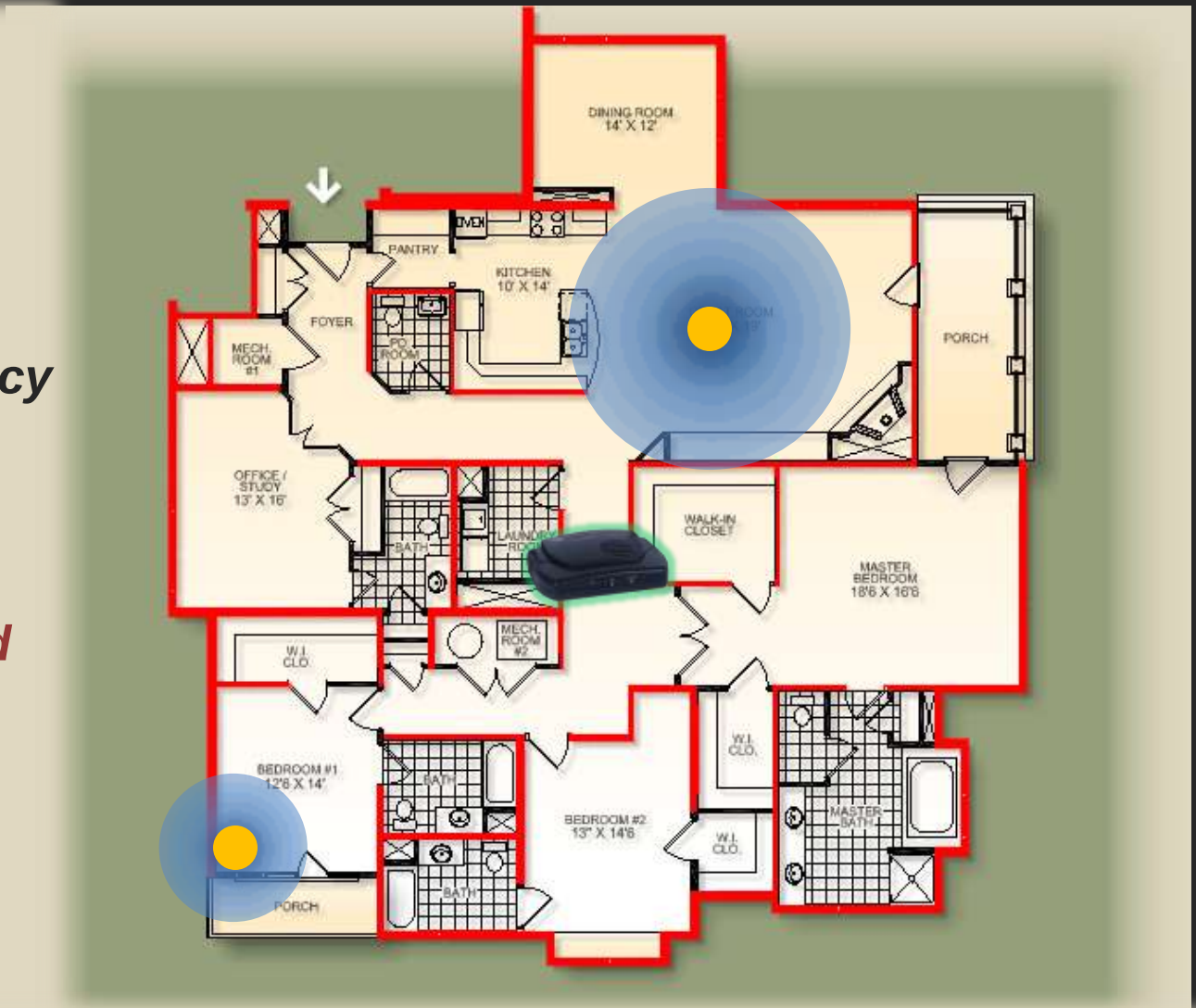
- Receiver plugged into powerline
- Powerline acts as *receiving antenna*
- Transmitter sends data to *nearest* powerline

Traditional Over-the-Air Wireless

Powerline Coupling

strongly dependent on frequency

ISM band 27 MHz



Hardware Overview

fully-programmable

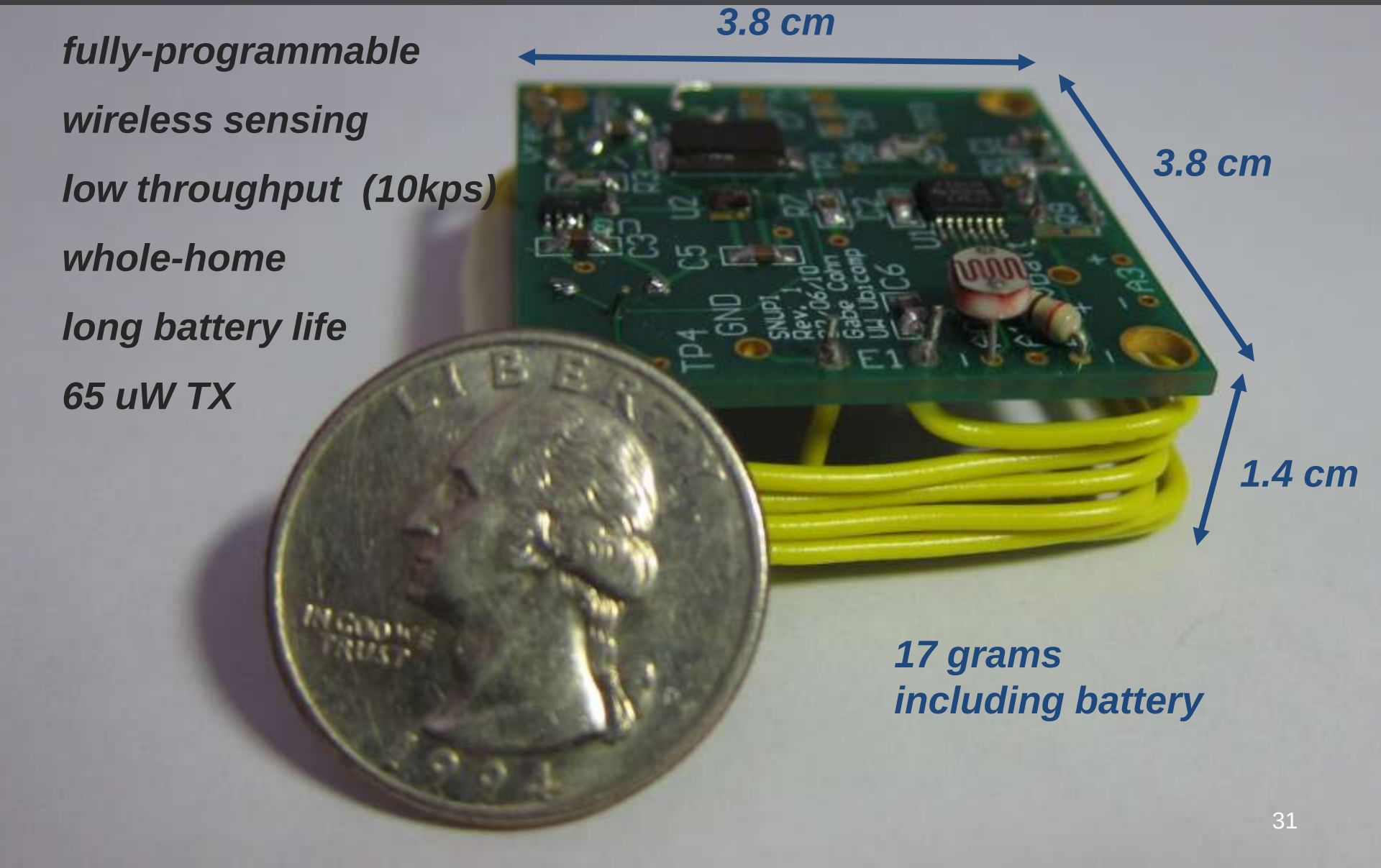
wireless sensing

low throughput (10kps)

whole-home

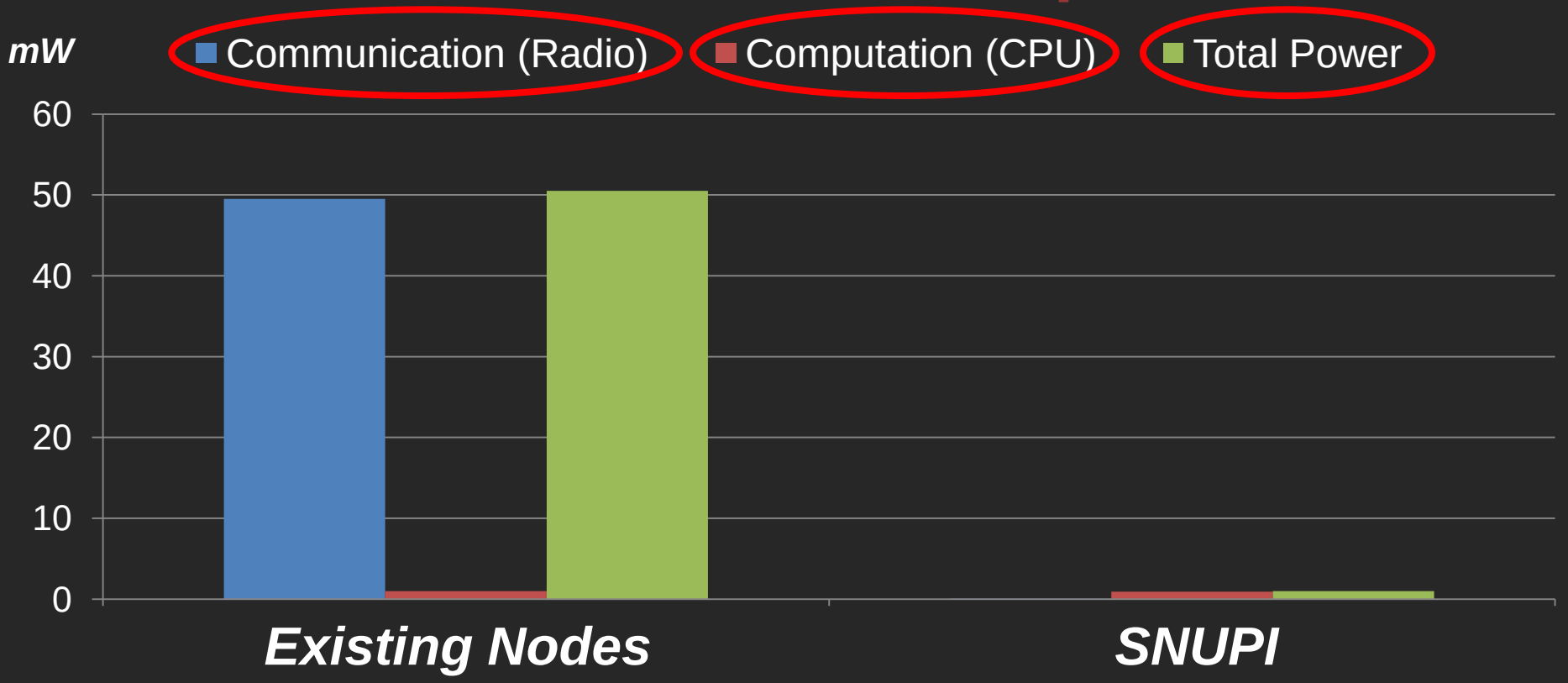
long battery life

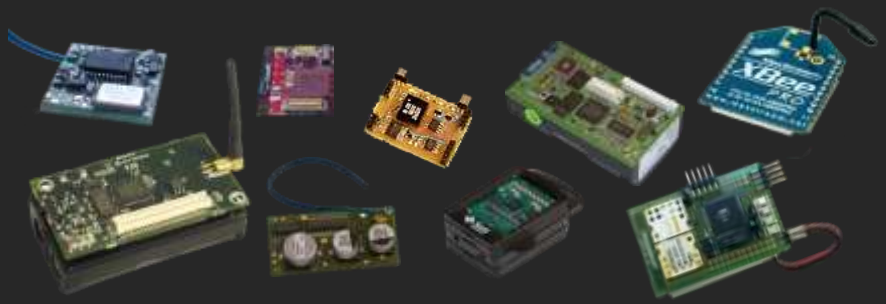
65 uW TX



SNUPI

Peak Power Consumption





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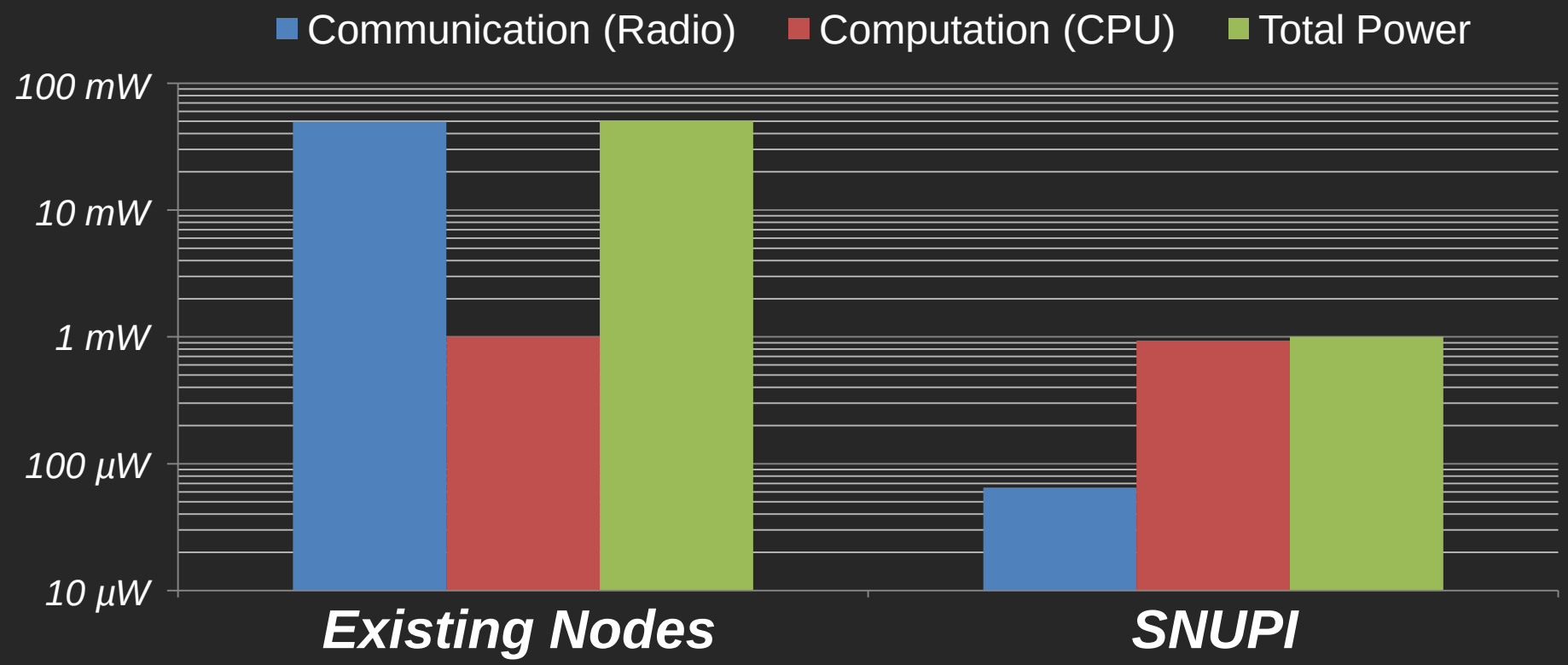
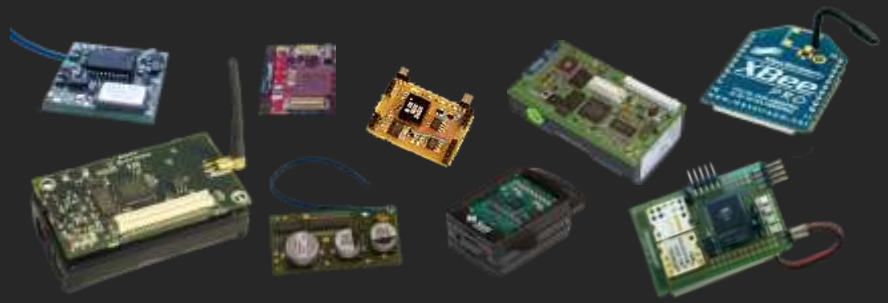
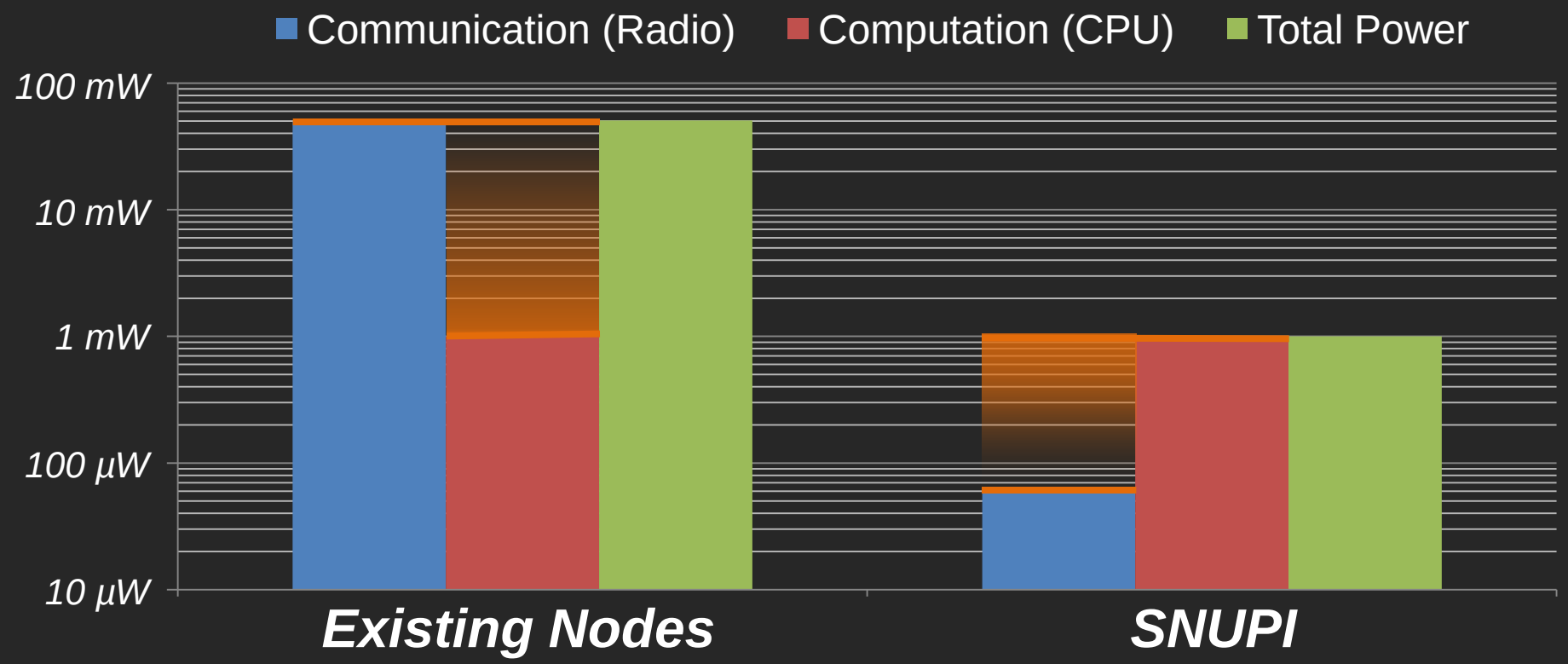




SNUPI

Peak Power Consumption

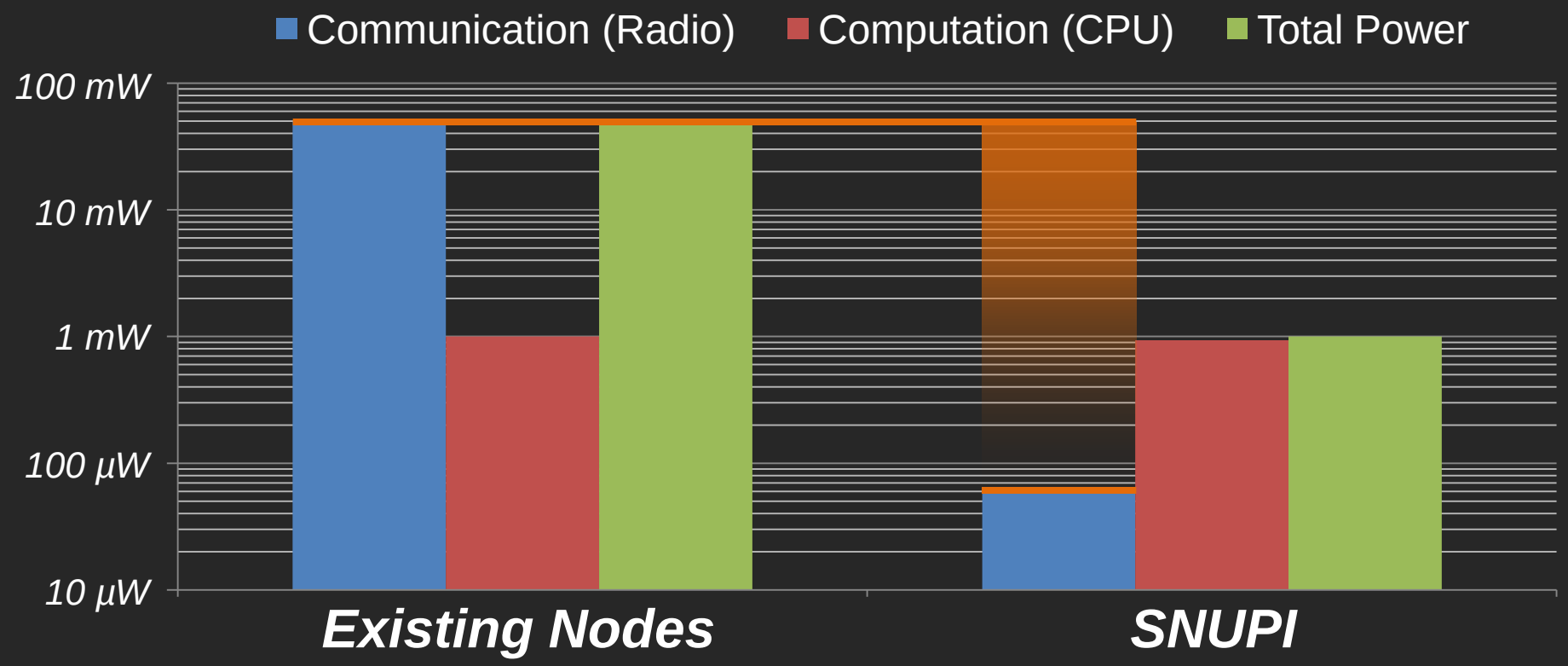


Communication/Computation Power Relationship

Reversed

SNUPI

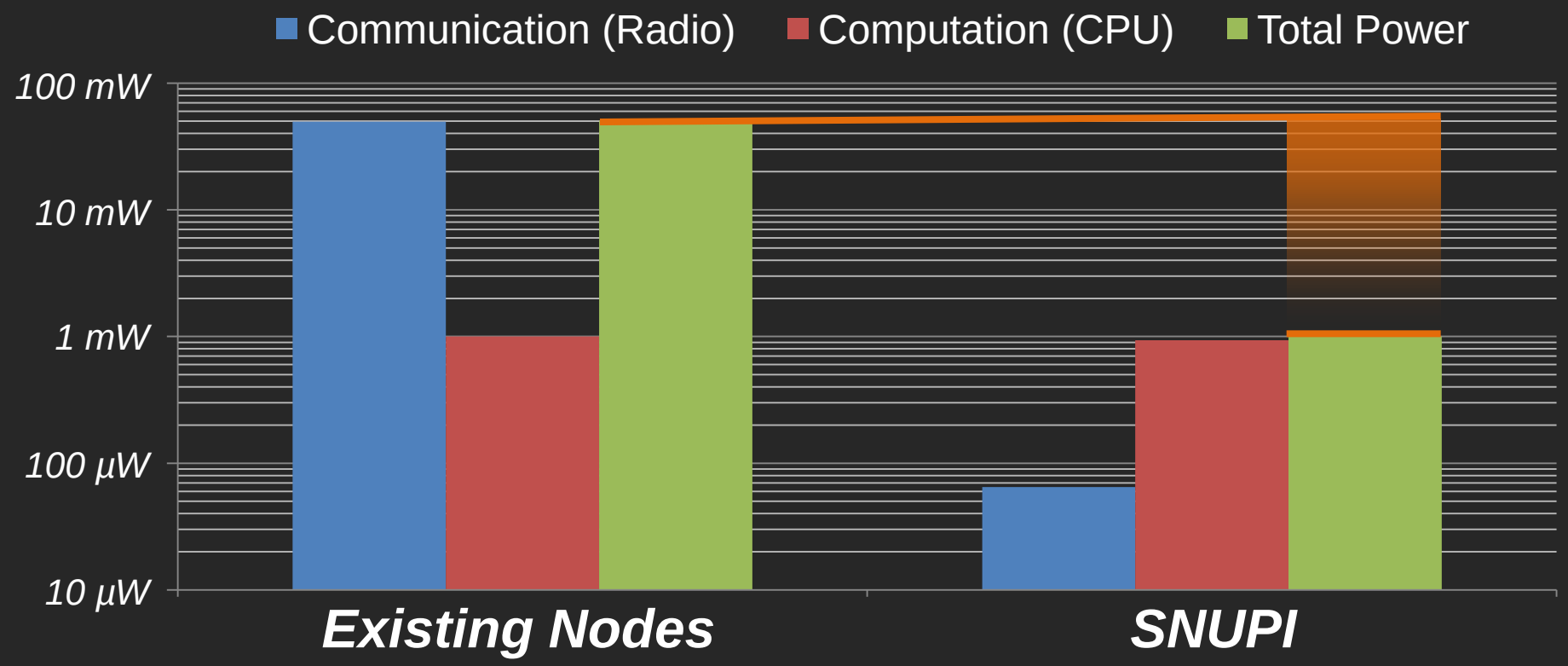
Peak Power Consumption



2 Orders of Magnitude Reduction in Communication Power

SNUPI

Peak Power Consumption



1 Order of Magnitude Reduction in Total Peak Power

Uses

- Long-lived sensor deployments
- Hard to reach areas

Making it Available - Scale

Zensi, Shwetak Patel's Energy Monitoring Startup, Purchased by Belkin

Zensi, an energy monitoring company based on technology developed by UW CSE professor Shwetak Patel and collaborators, has been purchased by Belkin.

Zensi's technology was licensed from the University of Washington and from the Georgia Institute of Technology, Patel's Ph.D. institution. The technology includes single-point-of-attachment sensors for electrical power, water, and natural gas — a single sensor in a home or business uses signal processing and machine learning to identify sources and rates of consumption. This dramatically reduces the cost of instrumenting the home or business and providing occupants with the information they need to behave in more economical and environmental ways.

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STARTUPS, CLEANTECH, DEALS

UW Prof Shwetak Patel's Energy Startup, Zensi, Bought by Belkin

Gregory T. Huang 4/21/10

Zensi, an energy monitoring startup co-founded by University of Washington assistant professor Shwetak Patel, has been acquired by Belkin, the computer hardware and wireless company based in the Lo Angeles area. Financial terms of the cash deal weren't given. The ne was reported earlier today by CNET.

Patel co-founded Zensi in 2008 while he was in graduate school at Georgia Tech in Atlanta, but he has continued to develop the technol at UW as a faculty member in computer science & engineering and electrical engineering. The company's technology includes sensors th you plug into a wall outlet to measure the amount of electricity used b each appliance or device in a home. Zensi's similar systems for water

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Green Tech

Edited by Martin LaMonica

April 21, 2010 5:35 AM PDT

Belkin buys crafty power-tracking start-up

by Martin LaMonica

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Electronics and wireless equipment maker Belkin is getting deeper into energy management as i company with technology that detects how electricity is used within a home.

The company, called Zensi, was founded by academics--i

Questions?

- Special Thanks and Acknowledgements:

  Students: Jon Froehlich, Sidhant Gupta, Eric Larson, Gabe Cohn, Tim Campbell

  Faculty: James Fogarty, James Landay, Les Atlas, Brian Otis, Matt Reynolds