Its Different: Hitchikers Tryst with Energy Consumption Patterns in India

Alice Security
Department of Computer Science
University of Southern California
alice@example.edu

Bob Privacy
Networked Embedded Systems Group
Swedish Institute of Computer Science
bob@example.se

Abstract

This paper provides a sample of a LaTeX document for ACM Sensys. It complements the document *Author's (Alternate) Guide to Preparing ACM SIG Proceedings Using LaTeX2ε and BibTeX*. This source file has been written with the intention of being compiled under LaTeX2ε and BibTeX.

To make best use of this sample document, run it through `pdflatex` and `bibtex` to directly produce a pdf document.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Miscellaneous; D.2.8 [**Software Engineering**]: Metrics—*complexity measures, performance measures*

General Terms

Delphi theory

Keywords

ACM proceedings, LaTeX, text tagging

1 Introduction+Related Work

- Why buildings must be targeted for energy [7]
- Importance of feedback [5]
- Why we need deployments
- Deployments- Residential, Office [1, 3]
- Previous such residential deployments, some of which were presented in Buildsys itself [10, 2, 6]
- Some applications-NILM[9, 4], Fixture Finder [11]
- Specific learnings from our deployment, some of them complement the ones given earlier [10]
  - Glowing LED in night
  - Deployments should be transparent
  - Noisy server owing to dust (specific to developing countries)
  - Electricity failure- as a consequence all systems should be capable to restart upon resumption of electricity
  - Unreliable internet -Forcing to use Sense-Store-Upload paradigm
  - Normalization -Voltage fluctuation, different measurement by different instruments

Also deployment was maintained as an open source project. Shows how we faced issues and tackled them. Also contains metadata log provided by the end user.

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2 Deployment Overview

Over the past year, we have deployed sensors across 22 homes. While 20 of these homes have been instrumented only with smart electricity meters, 2 homes have been extensively instrumented with upto 32 sensors measuring electricity, water and ambient parameter. Figure 1 shows the deployment in a 3 storey home where 32 sensors, 5 single board computers and 3 routers were used.

2.1 Sensing Infrastructure

For our sensing, we took a "leave no stone unturned" approach, where we chose to monitor as many physical parameters (such as ambient conditions, electricity usage, water usage) and non-physical parameters(such as network strength etc.). However, it must be noted, that we chose to deploy sensors in a way that home users can continue their regular routine without getting affected. We describe the various sensors to monitor electricity, water and ambient conditions below:

Electricity monitoring: A typical home electricity setup involves a meter which is installed by utility companies and measures overall electricity usage. Further electric cabling is divided into various Miniature Circuit Breakers (MCB's) which control separate circuits. Typical installations involve putting separate MCB's for heavier loads such as air conditioners and clubbing various lights, fans and other smaller loads into separate MCB. Further each individual appliance is controlled via a switch. There are two types of appliances- i) plug loads like refrigerator and electric iron, which need to be physically "plugged" into the sockets; ii) loads like lights and fans, which do not need to be "plugged" in by the user. We highlight the above described home electricity distribution in Figure 1. We have 3 different resolutions at which electricity can be monitored:

1. **Meter level:** We use Schneider Electric EM6400[1] smart meter to instrument the main power supply. While cheaper variants from the same company were available, we chose to use EM6400 since, in addition to real power, it also provides reactive power. This additional information has been known to be useful for NILM applications[9]. Figure 2a shows EM6400 smart meter deployed in the electricity panel.
2. **Circuit level:** We used our in-house developed Current transformer (CT) based monitoring circuits which can be clamped to individual MCB's. Manoj write 1-2 lines about this circuit. CT deployment is shown in Figure 2b.
3. **Appliance level:** We used jPlug[2] to measure individual appliance power consumption for 9 plug-load type appliances. We also used Current Cost based CT to measure the power consumption for electric motor (used to pump water), which is not a plug-load, yet has significant power consumption. jPlug and Current Cost CT deployment are shown in Figure 2c and Figure 2d respectively.

More details regarding sensors used for electricity monitoring are provided in Table 1.

Water monitoring: There are few differences in water distribution in India and US. In India, there are separate water lines for drinkable and non-drinkable water. Also, overhead water tanks (typically 1000 liters capacity) are used to store water. Electric motors are used to push water against gravity to be stored in the tank. Thus, the flow can be summarized as follows: 1) Water from utility comes to the home; 2) Electric motor is used to pump the water up to the tank; 3) Water flows downward from the tank when ever water is consumed. Thus, we put a water meter at the inlet (coming from the utility) and the outlet from the water tank (flowing downwards). Digital water meters are very expensive. Thus, we chose to use in-line water meters, which measure water volume flowing through them. These water meters have a 400 ma current loop Manoj: Add details and send a pulse every few liters. The precision is based on the quality of the sensor and the diameter of the water pipe. The water meter we used for overhead tank gives a pulse every 10 liters, whereas the one used for inlet supply from utility gives a pulse every 1 liter. These pulses can be measured using the circuit diagram for 400 ma loop shown in ... Figure 2e shows the water meter deployed inline at the overhead tank.

Ambient conditions monitoring:

2.2 Communication and Computation Infrastructure

Following computation resources (SBC/Servers were used)

- X RPi
- Plug Computers
- Main server

Following sensors were used.

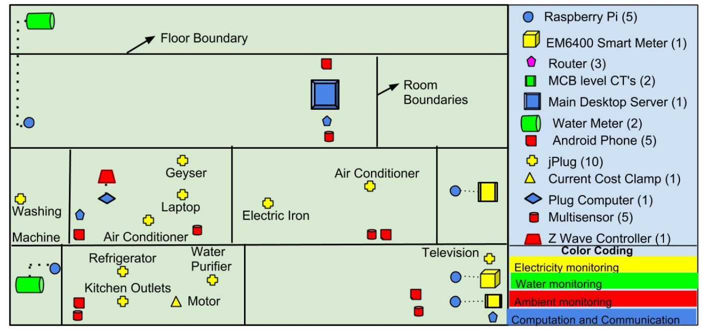


Figure 1: Schematic showing overall home deployment

- EM6400 smart meter: We used pyModbus to sample at 1 Hz. Gives 40 parameters including reactive power. Reactive power can greatly help in improving NILM accuracy [9].
- Appliance level meters: jPlug and Current Cost. jPlug gives data at 1 Hz and gives 10 parameters including reactive power. Current cost was needed for one appliance- electric motor.
- CT monitoring: Custom hardware based on XYZ.
- Multisensors: Measure motion (based on polling), light and temperature
- Water meter: 10 litre events.
- Android phones measuring x, y, z using FunF Journal[3]

Apart from this following soft-sensor streams were collected.

- Network statistics
- CPU, Memory usage for all computing resources. This was to serve as preventive measure.
- Weather streams

3 Learning

In this section we discuss the learning from previous work in similar domains and present unique aspects which came up in our deployment.

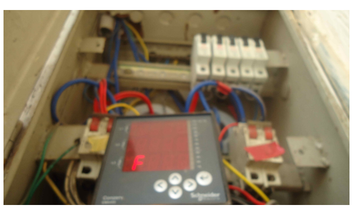
- Homes are not power panacea. We have a very special case of electricity failure. Add figure for electricity number of hours failure, failure by n'th hour, hist of failure hours
- Homes have poor connectivity. This forced us to develop a different paradigm which we call Sense-Store-Transfer. This is shown in Figure 4
- Homes are hazardous environments
  - Multi failed when put on inverter point
  - Node in one room will always fail
  - Wire snag and how it led to data loss of node 4
- Homes are remote environments: We had to raise 60

[1] Toput
[2] A variant of nPlug[8]

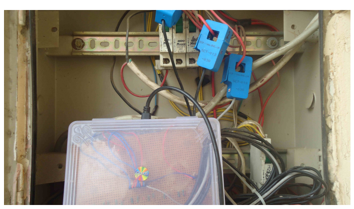
[3] http://www.funf.org/journal.html

Table 1: Deployment

Sensor name	Sensor type	Sampling frequency (Hz)	Resolution	Qua-ntity	Commu-nication	Observed parameters
EM6400	Electric Meter	1	Home	1	RS 485, WiFi	Voltage, Current, Frequency
Analog	Water Meter	5	Main supply and tank	2		
Homeseer HSM-100	Ambient multisensors	1 (for light, temperature) and polling for PIR	Room	6	ZWave	Light, temperature and motion
Android phones	Ambient multisensors	check from funf	Room	5	Manual	
Prototype CT	Current Transformers	20	MCB	8	WiFi	
jPlug	Appliance electric meter	1	Appliance	9	WiFi	
Current Cost	Appliance CT	0.1	Appliance	1	Proprietary	



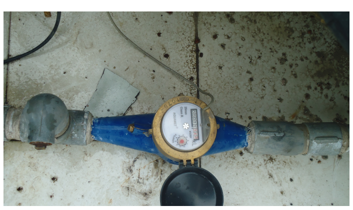
(a) EM6400 Smart Meter



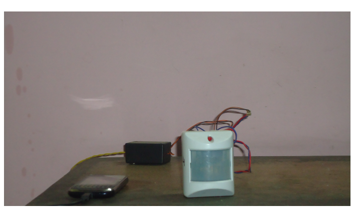
(b) In house CT monitoring system

(c) Appliance level monitoring using jPlug

(d) Appliance level monitoring using Current Cost CT



(e) Water Meter



(f) Android phone and Homeseer Zwave multi-sensor used to measure ambient parameters

Figure 2: Deployment Pictures

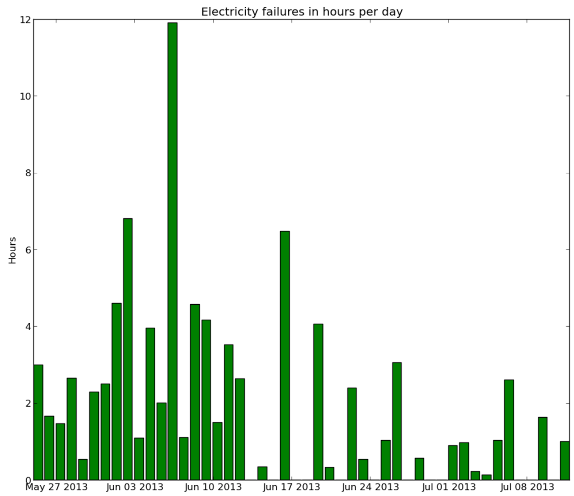


Figure 3: Electricity failure in hours

new issues on Github. We first did deployment in researchers home which had full access to all nodes. We also provided alerting mechanisms.

- User participation Even at researchers home, had asked the researcher to take notes. But even his engagement was not 100 %.
- Aesthetics matter
  - LED in night Figure 5
  - Noise- Noisy SMPS due to dust. Unique to our setting. Figure from FunF showing sound level before and after cleaning.
- Simplify the architecture We used Load-Store-Forward. Describe this in more detail and relate to earlier n/w connectivity. Also when number of systems is so large, simple CSV uploading is the best mechanism.

  Wherever possible use Ethernet with repeaters. Also, RPi are known to have problems with WiFi.
- Importance of meta data and calibration Figure showing power consumption of ref. after repair Figure showing different measurements for same appliance Figure showing voltage fluctuations
- Provision for more sensors than actual number required. x jplug, y multisensor failed due to ..
- Non availability of sensors in local markets

4 Case Studies

In this section we present some case studies from the data collected in this deployment.

4.1 Correlating Events and Activity Detection

In this section we show how multi-modal data can be used for activity recognition. Following plots show the same.

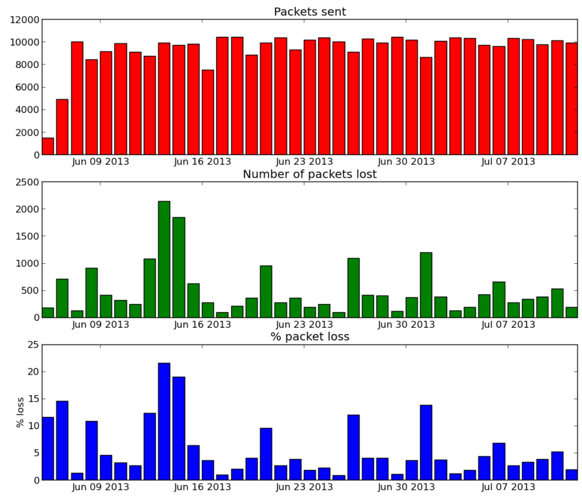


Figure 4: Overall packet drop while accessing internet

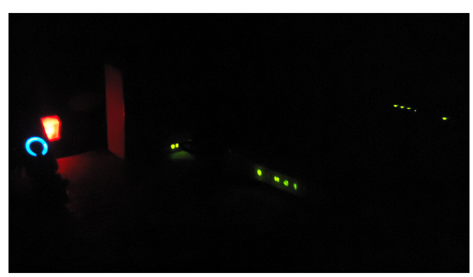


Figure 5: LED glowing in the night

4.2 Water-Energy Nexus

4.2.1 Water Filter

In this section we find out the effective cost of 1 litre of water. RO is known to waste a lot of water. From the water meter we observe the amount of water consumed to fill 1 litre of water. We also see the corresponding power draw of the RO. Thus, we can see that water has energy embedded in it.

4.2.2 Electric Motor

Another unique aspect of our setting is the use of electric motor to pump water. Figure showing 1 litre events before motor was turned on and figure showing 1 litre events after motor is turned on. Figure showing power consumption incurred by the use of motor.

4.3 Energy conscious habits

Figure showing how i turn the AC at 16 degrees and turn it off before going to sleep.

Running the ref. in least cool cooling mode and the impact it has.

4.4 NILM

Will be tough to do in timeframe.

To highlight any thing or add new stuff write like this in red

This is my comment. I would also do ... and put this image and put this table and so on and so forth

5 Conclusions and Future Work

6 References

[1] Y. Agarwal, B. Balaji, S. Dutta, R. K. Gupta, and T. Weng. Duty-cycling buildings aggressively: The next frontier in hvac control. In *Information Processing in Sensor Networks (IPSN), 2011 10th International Conference on*, pages 246–257. IEEE, 2011.

[2] G. Barrenetxea, F. Ingelrest, G. Schaefer, and M. Vetterli. The hitchhiker's guide to successful wireless sensor network deployments. In *Proceedings of the 6th ACM conference on Embedded network sensor systems*, pages 43–56. ACM, 2008.

[3] N. Batra, P. Arjunan, A. Singh, and P. Singh. Experiences with occupancy based building management systems. In *Intelligent Sensors, Sensor Networks and Information Processing, 2013 IEEE Eighth International Conference on*, pages 153–158, 2013.

[4] K. Carrie Armel, A. Gupta, G. Shrimali, and A. Albert. Is disaggregation the holy grail of energy efficiency? the case of electricity. *Energy Policy*, 2012.

[5] S. Darby. The effectiveness of feedback on energy consumption. *A Review for DEFRA of the Literature on Metering, Billing and direct Displays*, 486, 2006.

[6] S. Dawson-Haggerty, S. Lanzisera, J. Taneja, R. Brown, and D. Culler. @ scale: Insights from a large, long-lived appliance energy wsn. In *Proceedings of the 11th international conference on Information Processing in Sensor Networks*, pages 37–48. ACM, 2012.

[7] M. Evans, B. Shui, and S. Somasundaram. Country report on building energy codes in india. *PNNL*, 177925, 2009.

[8] T. Ganu, D. P. Seetharam, V. Arya, R. Kunnath, J. Hazra, S. A. Husain, L. C. De Silva, and S. Kalyanaraman. nplug: a smart plug for alleviating peak loads. In *Proceedings of the 3rd International Conference on Future Energy Systems: Where Energy, Computing and Communication Meet*, page 30. ACM, 2012.

[9] G. W. Hart. Nonintrusive appliance load monitoring. *Proceedings of the IEEE*, 80(12):1870–1891, 1992.

[10] T. W. Hnat, V. Srinivasan, J. Lu, T. I. Sookoor, R. Dawson, J. Stankovic, and K. Whitehouse. The hitchhiker's guide to successful residential sensing deployments. In *Proceedings of the 9th ACM Conference on Embedded Networked Sensor Systems*, pages 232–245. ACM, 2011.

[11] V. Srinivasan, J. Stankovic, and K. Whitehouse. Fixturefinder: discovering the existence of electrical and water fixtures. In *Proceedings of the 12th international conference on Information processing in sensor networks*, pages 115–128. ACM, 2013.