Protecting Consumer Privacy from Electric Load Monitoring (CCS ‘11)

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Overview

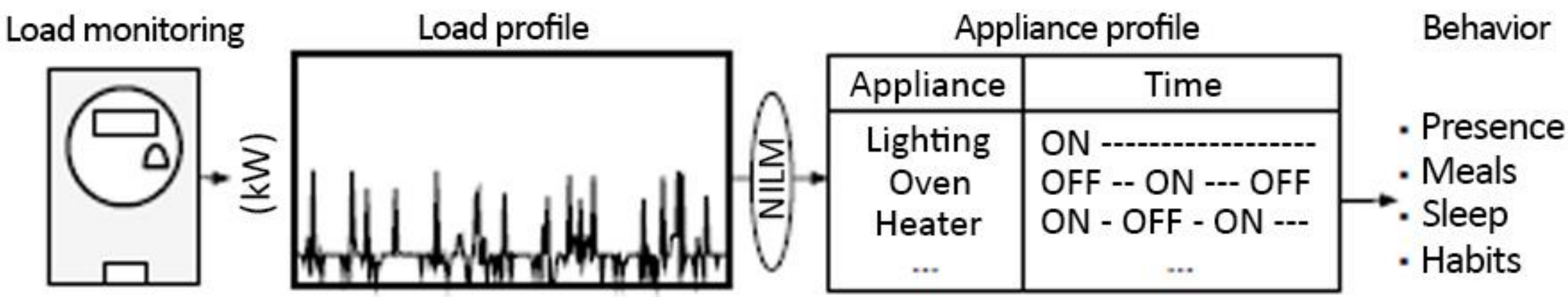
- Proposed a system which masks detailed energy profiles of homes by charging and discharging a battery to smooth the variance in energy usage recorded by Smart Meters.

Background

- Smart Meters use sensors to collect and report load profiles.
- Load profiles are histories of energy usage.
- Non-Intrusive Load Monitoring (NILM) algorithms expose occupant behavior from these profiles.

NILM Algorithms

- Decompose load profiles into *appliance profiles* based on known signatures.
- Pairs of symmetric ON/OFF “sister” features indicate appliance usage



- Goal
  - Protect consumer privacy.
- Constraints
  - Energy usage must be accurately reported.
  - Solution should not require changing the metering infrastructure.

Non-Intrusive Load Leveling (NILL)

- A *battery* and *control system* are placed between the smart meter and circuit breaker.
- Spikes and dips in usage are offset by (dis)charging the battery.
- As a result, the load observed by the meter is smoothed.

Ideal example of NILL

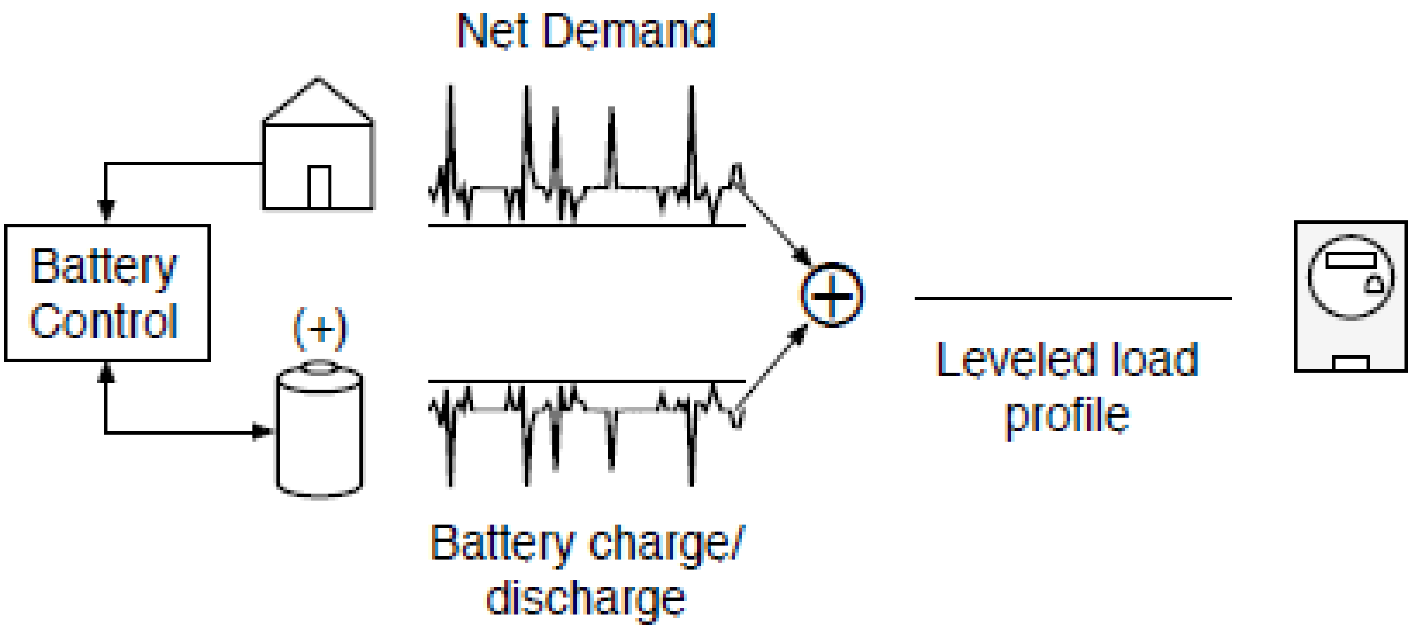


Figure 1: Idealized non-invasive load leveling (NILL).

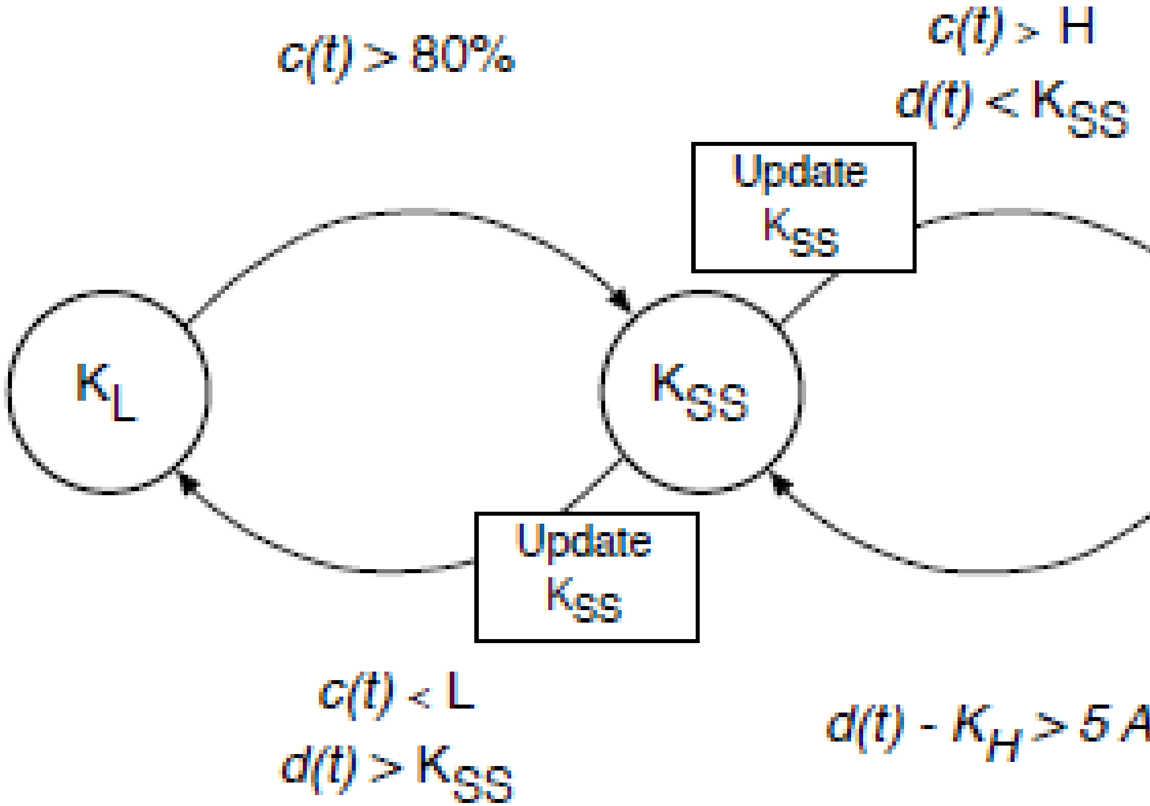
NILL Battery

- Special *deep-cycle* batteries are required.
- Should not be discharged below 20%.
- 10 batteries connected in series would be required for a real life setup of 120V.
- Approximate cost: $1000.

NILL Controller

- Attempts to maintain a steady state target load K_{SS}.
- Battery can go into special low (K_L) or high (K_H) states which requires adjustment by the controller.
- In the special states, alter K_{SS} to allow battery to recover while still masking events.

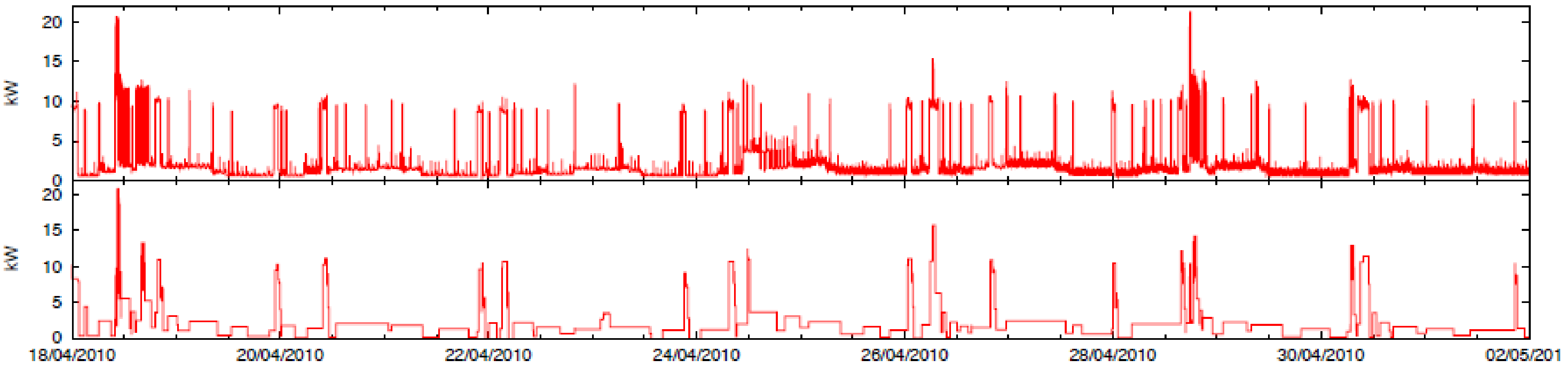
NILL Controller



Testing

- Real load profiles were collected from 4 homes over a period of 1-2 months.
- Granularity of the profiles was 1 second.
- A detailed NILL system simulation was carried out, based on this data.

Testing



Top: The net load (d) consumed by T1 between Apr. 18 and Apr 30. Bottom: The same load under the simulated NILL system with a 50Ah battery (u).

Results

Residence	Non-NILL	NILL	Change
Total Features			
H1	1047099	61793	-94.10%
H2	286960	20713	-92.78%
A1	430214	24893	-94.21%
T1	384847	33413	-91.32%
Features per hour			
H1	358	21	-94.10%
H2	199	14	-92.79%
A1	289	16	-94.21%
T1	277	24	-91.32%
Sister feature pairs			
H1	340986	10552	-96.91%
H2	110994	4735	-95.73%
A1	176540	6030	-96.58%
T1	147982	8120	-94.51%

Residual Features

- Any feature that appears in both the NILL trace and original profile.
- Can be due to NILL being in a low state.
- Or because the load was very heavy (e.g. using a microwave).

Residence	Features	Sisters	Residual Features (%)	Residual Sisters (%)
H1	1047099	340986	35969 (3.4%)	5526 (1.6%)
H2	286960	110994	13230 (4.6%)	3112 (2.8%)
A1	430214	176540	15556 (3.6%)	3648 (2.0%)
T1	384847	147982	30861 (8.0%)	7640 (5.1%)

Final Result

- Number of useful features revealed went down from hundreds or even thousands to around a handful.

Residence	Sister features	Per Day
H1	359 (0.11%)	5.9
H2	33 (0.03%)	1.1
A1	93 (0.05%)	3.1
T1	128 (0.09%)	4.4

Cost Reduction per Month

- Some amount of the peak load is shifted into off-peak hours due to the battery.
- Electricity is cheaper in off-peak hours.

Residence	O&R	Ont.	PG&E
H1	$8.94 (2.09%)	$11.11 (2.00%)	$18.67 (1.81%)
H2	$2.49 (5.16%)	$3.78 (4.27%)	$6.17 (4.28%)
A1	$3.41 (3.37%)	$4.96 (3.81%)	$10.22 (4.67%)
T1	$2.67 (2.53%)	$3.72 (2.97%)	$6.92 (2.62%)

Discussion Questions

- What are the key contributions of this paper?
- Is NILL likely to be implemented, given its massive initial cost (~$1000 just for the batteries)? Also, considering the batteries only last for 1-2 years?
- Can NILL be circumvented?
- Is the energy efficiency / consumer cost aspect of NILL really significant?