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Privacy for Smart Meters: Towards Undetectable Appliance Load Signatures

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Submitted in Partial Fulfillment of the Course Requirements for
ECEN 689: Cyber Security of the Smart Grid
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Overview

- Introduction
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- References

Introduction

Smart grid

Two-way communications within its components:

- Load management
- Distributed energy storage (in electric vehicles)
- Distributed energy generation (from renewable resources)

- AMI (Advanced Metering Infrastructure)

Introduction

Smart meter

- Measure the energy consumption in much more detail
- Communicate collected information to authorized parties

Provide a window into activities within homes, exposing one's private activities to anyone with access to electricity usage information.

Related work

1. Policy level

Personal data should "be collected for specified purposes and not be further processed for other purposes" (European Union Data Protection Directive)

Exceptions:

a) national or public security;

b) police investigations;

c) important economic or financial interests;

d) monitoring, inspection or regulatory functions connected with the exercise of official authority in previous cases.

Related work

2. Technology level

Metering data can be aggregated and encrypted so that an individual's information is anonymised.

NALM (Non-intrusive appliance load monitors)

NALM algorithms, providing means to identify appliance usage even when multiple household power signatures are aggregated

Related work

NALM

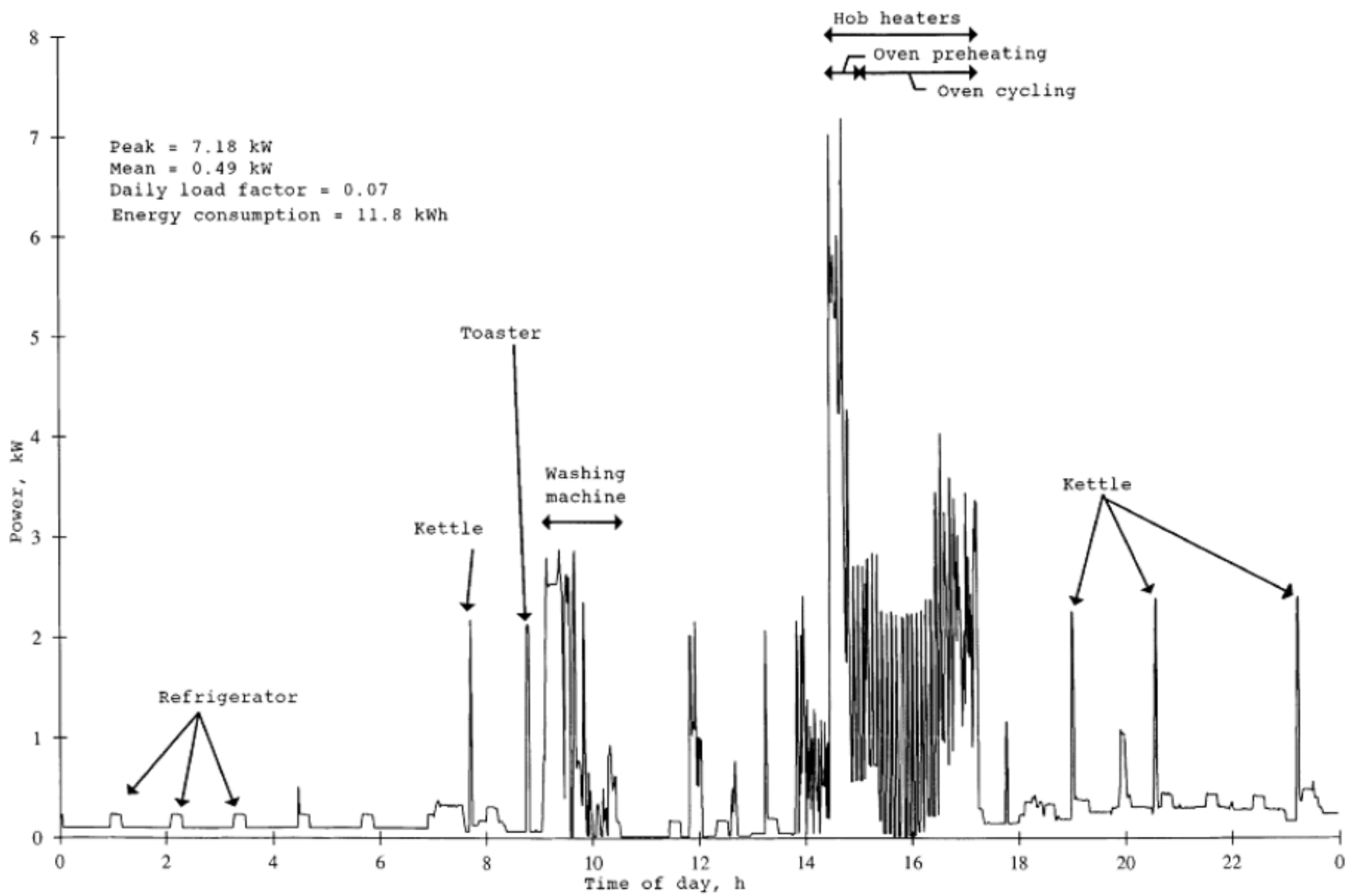


Fig. Household electricity demand profiled[2]

Motivation

Protect the privacy by managing energy usage within the home, before metering data is collected.

Privacy is protected: given load signature of a house, we cannot sufficiently distinguished whether an appliance load event exists or not.

System overview

a) a smart meter;
b) a utility provider;
c) consumers: electrical devices or appliances;
d) suppliers: alternative private sources of energy;
e) a power router;
f) a 'Load Signature Moderator' (LSM): responsible for shaping load signatures via power routing;
g) Home Area Network (HAN): home communications network, for energy management or other purposes.

System overview

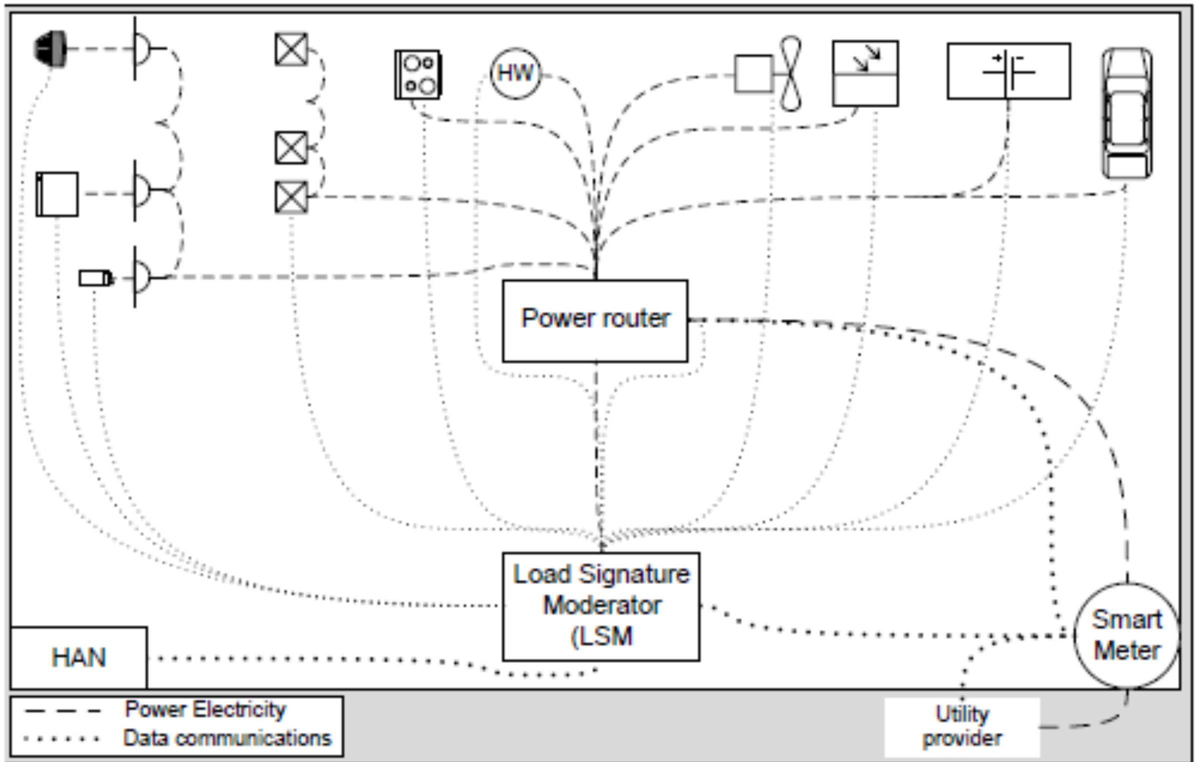


Fig. System overview[1]

System overview

Load signature moderation

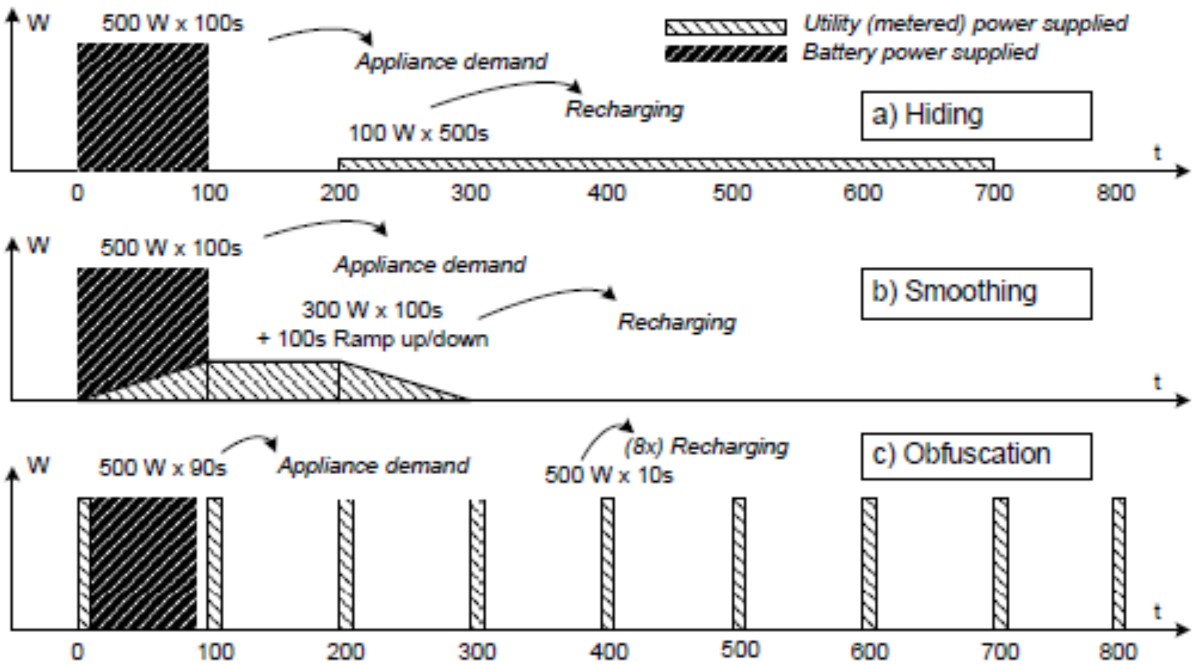
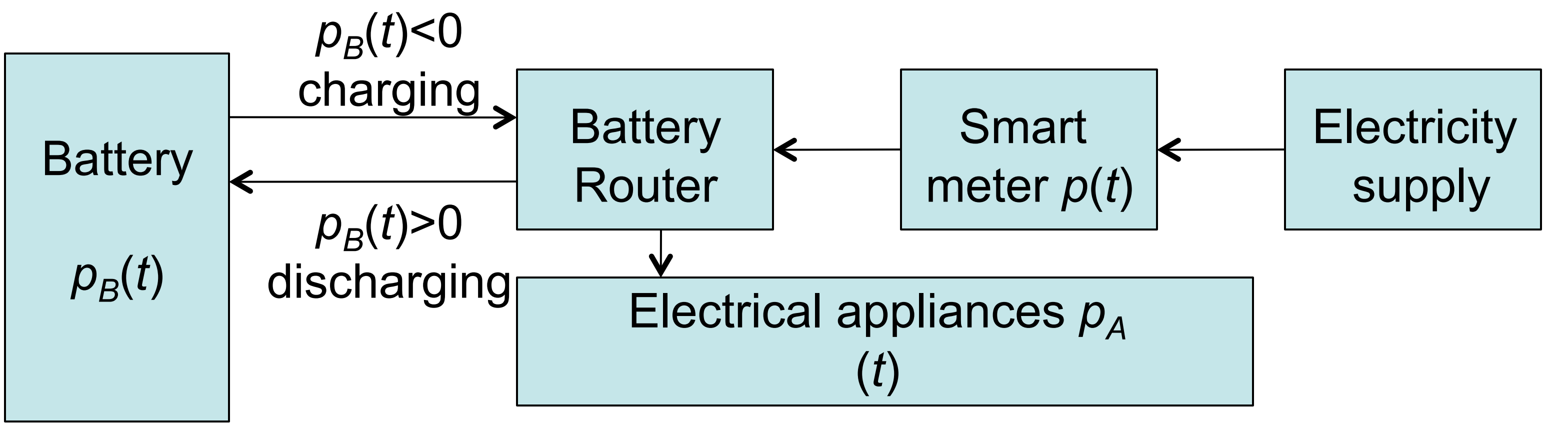


Fig. Example of load shaping strategy [1]

Moderation Strategy



$$p(t) = p_A(t) - p_B(t)$$

- $p(t)$ – the metered home load
- $p_A(t)$ – given consumption load
- $p_B(t)$ – the battery charge and discharge power

Moderation Strategy

Bounded moderation algorithm:

Resist against power load changes (to maintain a constant metered load $p(t)$).

The algorithm will force the battery to either discharge or recharge when the required load $p_A(t)$ is either larger or smaller (respectively) than the previously metered load $p(t - \Delta t)$.

Moderation Strategy

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Bounded moderation algorithm:

Current battery charge level: $B(t) = e(t) - e_A(t - \Delta t) + p_A(t)\Delta t$

if $D(t) = p_A(t) - p(t - \Delta t) > 0$ *(discharging case) then*

if There is enough battery energy/power to provide *$D(t)$ for Δt then*

Mix in battery power so that $p(t) = p(t - \Delta t)$

else

Use maximum battery power while $B(t) > 0$

end if

end if

if $C(t) = p(t - \Delta t) - p_A(t) > 0$ *(charging case) then*

if Enough battery 'emptiness' to absorb *$C(t)$ for Δt then*

Recharge battery so that $p(t) = p(t - \Delta t)$

else

Fully recharge battery

end if

end if

Measuring privacy protection

Privacy levels based on relative entropy:

$$D(P|Q) = \int_{x_{min}}^{x_{max}} f_P(x) \log \frac{f_{P(x)}}{f_Q(x)} dx$$

$dp_A(t)$ and $dp(t)$ are modeled as probability measures P and Q;

f_P (x) and f_Q(x) are the probability density functions of P and Q;

The higher the level of protection, the larger the relative entropy.

Measuring privacy protection

Evaluation

Datasets of $p_A(t)$:

obtained from real-time measurements at an old Georgian apartment on a 'busy' 24h period.

Reading takes every 1 min.

Four batteries: B1, 250W/500Wh; B2, 500W/1kWh; B3,1KW/2kWh; and B4, 2KW/4kWh

Measuring privacy protection

Simulation result

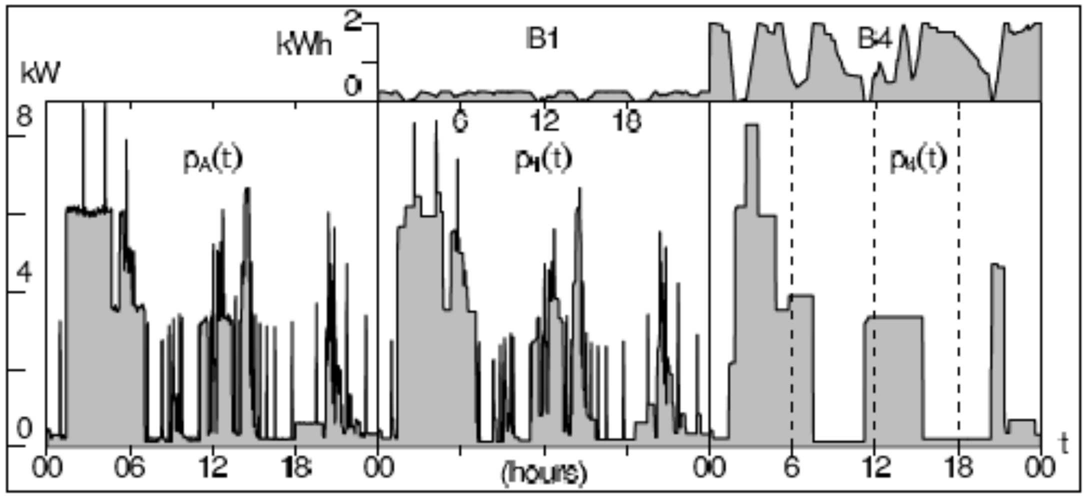

Fig. B1,B4 battery charge levels, $p_A(t)$,$p_1(t)$,$p_4(t)$ load signature[1]

Dataset	Battery	D(P||Q)	Cluster	R^2
Max=4.5kw 1386 events 4 clusters	B1	1.455	0.468	0.871
	B2	1.638	0.320	0.645
	B3	1.921	0.135	0.182
	B4	3.237	0.004	0.008

Assessment

- The balance between the privacy and the efficiency;
- "Smarter" algorithm can be designed. Expected/ predicted event may be masked or rescheduled;
- Fake appliance load signature can be inserted by charging the battery.

References

1. G. Kalogridis, C. Efthymiou, S.Z. Denic, T.A. Lewis, R. Cepeda, "Privacy for Smart Meters: Towards Undetectable Appliance Load Signatures," *Proc. IEEE International Conference on Smart Grid Communications*, Gaithersburg, Maryland, October 2010. Related work
2. E. L. Quinn, “Privacy and the New Energy Infrastructure,” Feb. 2009, http://papers.ssrn.com/sol3/papers.cfm?abstract id=1370731.
3. H. Y. Lam, G. S. K. Fung, and W. K. Lee, “A Novel Method to Construct Taxonomy Electrical Appliances Based on Load Signatures,” *IEEE Trans on Consumer Electronics, vol. 53, no. 2, pp. 653–660, 2007.*
4. A. Prudenzi, “A Neuron Nets Based Procedure for Identifying Domestic Appliances Pattern-of-Use from Energy Recordings at Meter Panel,” in *IEEE Power Engineering Society Winter Meeting, 2002, pp. 941–941.*