SpotLight: Focusing on Energy Consumption of Individuals

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What is SpotLight?

- A WSN application
  - Profile individual’s energy consumption
  - Provide real-time energy profile
  - Help users identify areas of inefficient power consumption

- A prototype implementation
  - May not be a thorough solution
  - Has known limitations
  - But can point out interesting areas for further research and points out key observations
Overview

- Motivation
- Problem description and discussion
- Related work
- Prototype system implementation and design
- Evaluations
- Conclusion
- Future work
Motivation

- **How much energy do I consume?**
  - What about in the lab and home?

- **I am unaware of my energy usage pattern**
  - Hard for me to optimize energy consumption

- **What about other resources?**
  - Water and Gas
Levels of Electricity Monitoring

- **Temporal Granularity**
  - Monthly Basis
  - Daily Basis
  - Real-time

- **Physical Granularity**
  - Individual Level
  - Appliance Level
  - Household Level

- **Monthly Bill**
Levels of Electricity Monitoring

Temporal
Granularity

Monthly Basis

Daily Basis

Real-time

Physical
Granularity

Individual Level

Appliance Level

Household Level

Monthly Bill

Control Box monitoring
Levels of Electricity Monitoring

- **Physical Granularity**
  - Individual Level
  - Appliance Level
  - Household Level

- **Temporal Granularity**
  - Real-time
  - Daily Basis
  - Monthly Basis

- **Monthly Basis**
  - Monthly Bill

- **Physical Granularity**
  - Control Box monitoring

- **Real-time**
  - Power Measurement Unit
Levels of Electricity Monitoring

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  - Individual Level
  - Appliance Level
  - Household Level

- **SpotLight System**
- **Power Measurement Unit**
- **Monthly Bill**
- **Control Box monitoring**
Fundamental Questions

- How to measure energy consumption of an appliance
  - Direct Measurement
    - Easy and precise but may not be scalable
  - Indirect Measurement
    - Hard and less precise but more scalable

- How to identify who is using it
  - Annotation: Users write down when and which
  - Inference
    - From absolute position
    - From relative position among users and appliances
    - And on/off status of appliances
Intuitive Ways to Answer to the Questions

- How do we know someone is using appliances
  - An appliance is on
  - UserA is in front of the appliance and interacts with it

- How do we say someone is wasting energy
  - UserA turned on a light
  - UserA left it on and went somewhere

- Some ambiguities from socio-economical reasons
  - UserA is using an appliance on behalf of UserB. Who is responsible for the energy consumption?
  - UserA cooks for others, who is responsible?
Objectives

- Provide useful information to users
  - Amount of wasted energy
  - Amount of useful energy per each appliance or each person

- Construct a fair and comprehensive accounting policy
  - Unambiguous and Agreeable policy

- Develop an easily deployable and usable system
  - Works out-of-the-box
  - Little or no human intervention
Related Work

- Intelligent Powermeter, Der intelligente Stromzähler, Germany
  - Real-time Powermeter monitoring device

From http://www.enbw.com
Related Work

- Demand response system, Berkeley
  - Control HVAC/Lighting
  - Based upon occupancy or demand

From Demand Response Enabling Technology Development
Tech report, Berkeley
Related Work

- MEMS nonintrusive electrical monitoring device, Leland et. al., Berkeley
  - Electrical monitoring
  - Energy scavenging for motes

From Energy scavenging power sources for household electrical monitoring, Eli S. Leland et al., Berkeley
Related Work

- **At the Flick of a Switch**, Shwetak N. Patel et al., Gatech
  - Detecting and Classifying Unique Electrical Events on the Residential Power Line
  - Less intrusive, real-time

From At the Flick of a Switch, Shwetak N. Patel et al, Gatech
Related Work

- **Ambient Devices**
  - Provide users with real-time current energy cost and usage

From http://www.ambientdevices.com
Classes of Appliances

- Underlying Assumptions
  - The person using the appliance is directly benefiting from it
  - Indirect use, where a person is using an appliance on behalf of another, is not considered

- Classification of appliances
  - Class I: Serviced inside a physical vicinity. E.g. Television, coffee machine and most of home appliances.
  - Class II: Serviced with remote access. E.g. servers, networked printers and some office appliances
  - Class III: Serviced independent of access. E.g. Refrigerator, alarm clocks
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Focus of our work
Definition: Service Range

- Service range of an appliance is a user defined vicinity boundary
- Token: Abstraction that indicates current status of usage

True Positive: token=1
False Negative: token=0

True Negative: token=0
False Positive: token=1
Token Issue/Expire : Case I
Token Issue/Expire : Case I

Service Range

Token : 0  
Token : 0
Token Issue/Expire : Case I
Token Issue/Expire : Case I

Service Range

Token : 1
Token Issue/Expire : Case I

Service Range
Token Issue/Expire : Case II
Token Issue/Expire : Case II

Service Range

Token : 0

Token : 0
Token Issue/Expire : Case II

Service Range

Token : 0
Token Issue/Expire : Case II
Token Issue/Expire : Case II

Service Range

Token : 0
Prototype System Implementation

- Users carry tag mote
- Appliances instrumented with a power meter and tag reader
- Server stores and processes data
Hardware Prototype

- MicaZ as ‘appliance motes’
  - MicaZ+COTS Power Measurement device
  - Measuring power consumption and RSSI value
- MicaZ as ‘tag motes’
  - MicaZ+Accelerometer
  - Broadcast an ID beacon when triggered by an on-board accelerometer
- MicaZ as ‘base mote’
  - MicaZ+Laptop
  - Relay messages
- Sensorbase
  - Centralized spatio-temporal database
Service Range and Radio Signal Strength

- MicaZ Mote as Tags and Readers
  - RSSI values represent coarse range information
    - RSSI based localization techniques makes use of this
  - Relative position could be inferred
  - Limitation: Service Range has to be symmetric around appliance / cannot be arbitrary

- Note: Home and office setting is assumed static
Technical Challenges

- RSSI values vary depending upon Antenna characteristics, users’ movement, obstruction of LOS, etc
- Simple threshold may not be good
- In some cases,
  - Calibration helps: Antenna Characteristics
  - Hysteresis helps: Noise along boundary
- But… these hamper usability issues
Evaluation Setting: User Defined Service Range

- 4 ‘appliance motes’
  - Three SOS S/W modules: PM, tag reader, UART
- 2 ‘tag motes’
  - One SOS S/W module: tag
- 1 BaseNode Mote
  - One SOS module: Snooping
Measured Service Range: Coffee Maker

- Bathroom
- Bedroom
- Kitchen
- Living Room
- Workspace
Measured Service Range: Bedroom Lamp
Measured Service Range: Livingroom Lamp
Measured Service Range: TV
Some Observations

- Service Range for RFID tag I
  - about -26 of the living-room lamp
  - about -20 of the TV
  - about -5 of the coffee machine

- Service Range for RFID tag II
  - about -22 of the living-room lamp
  - about -14 of the TV
  - about -8 of the coffee machine

=> Need to calibrate tag characteristics
=> Need to reject noise effect
Three Schemes

- **Unified Token Scheme**
  - Service range = Single RSSI value

- **Calibrated Token Scheme**
  - Service range = Tag specific RSSI value

- **Hysteresis Token Scheme**
  - Service range = Tag specific RSSI value
  - Expire tokens when RSSI overcomes Hysteresis
Ground Truth

- Using Campaignr with a local Sensorbase
  - Took Pictures and annotated users’ status
  - Sampling rate: 10s

- Ground Truth tells us
  - Who is/are using appliances
  - Who has/have left appliances on/off
Evaluation in terms of False Positive and Negative : TV

| Schemes   | User 200 | | | User 201 | | |
|-----------|---------|---|---|---------|---|
|           | Correct (%) | False Positive (%) | False Negative (%) | Correct (%) | False Positive (%) | False Negative (%) |
| Unified   | 39      | 60           | 1            | 73      | 0            | 27            |
| Calibrated| 59      | 35           | 6            | 64      | 4            | 32            |
| Hysteresis| 88      | 10           | 2            | 90      | 0            | 10            |
**Evaluation in terms of False Positive and Negative : Bedroom Lamp**

<table>
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<tr>
<th>Schemes</th>
<th>Correct (%)</th>
<th>False Positive (%)</th>
<th>False Negative (%)</th>
<th>Correct (%)</th>
<th>False Positive (%)</th>
<th>False Negative (%)</th>
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<td>99</td>
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<tr>
<td>Hysteresis</td>
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<td>1</td>
<td>1</td>
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Evaluation in terms of False Positive and Negative: Livingroom Lamp

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<th>User 201</th>
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<tbody>
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<td></td>
<td>Correct (%)</td>
<td>False Positive (%)</td>
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<td>Hysteresis</td>
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</table>
Performance of Various RSSI, Vicinity, Token Mechanisms
Appliance Power and Energy Consumption per User

(a) TV Power Consumption

(b) Coffee Maker Power Consumption

(c) Living Room Lamp Power Consumption

(d) Bedroom Lamp Power Consumption

(e) Total Power Consumption

(f) Total Energy Consumption
Useful/Wasted Power and Energy for TV

(a) Vicinity of User200 from TV (from RSSI)

(b) Vicinity of User201 from TV (from RSSI)

(c) Token Issued to User200 by TV

(d) Token Issued to User200 by TV

(e) Power Consumed by User200 for TV

(f) Power Consumed by User201 for TV
Useful and Wasted Consumption for all Appliances

(a) Power Consumed by User200

(b) Power Consumed by User201

(c) Energy Consumed by User200

(c) Energy Consumed by User201
Conclusion

- Proof-of-concept implementation
  - Presented a system that profiles energy consumption pattern in individual level
  - Detection scheme was reasonably successful under simple evaluation setting
  - Presented various information that encourages people optimize their energy consumption pattern

- But the system needs to
  - Be easy to deploy and use
  - Have comprehensive and fair policy
Future work

- More comprehensive view needed
- Deployment under more complex setting needed
- Monitor other resources: Water
- Cope with various RSSI uncertainties or try other localization technique?
- Improve usability and scalability
- Cope with various limitations