Non-intrusive Appliance Load Monitoring (NIALM): Promise and Practice

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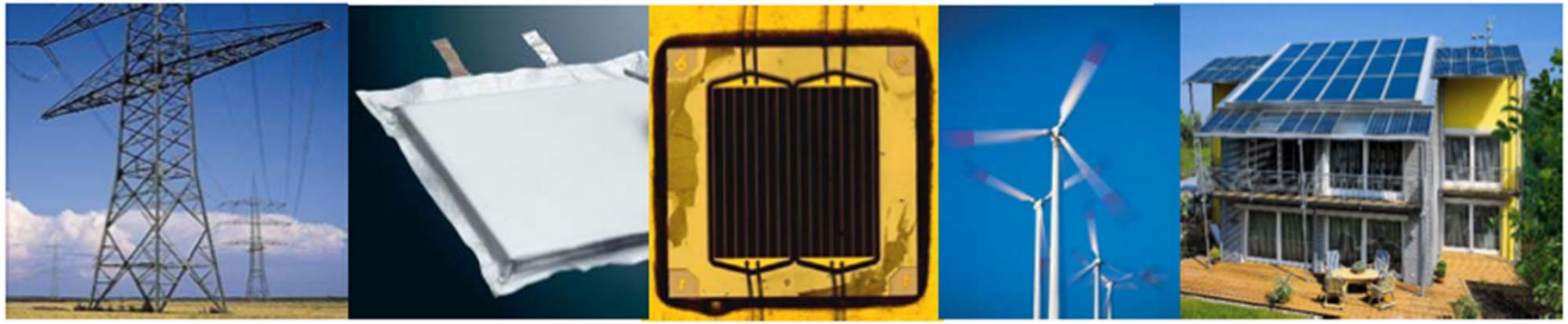

Building America Stakeholder Meeting

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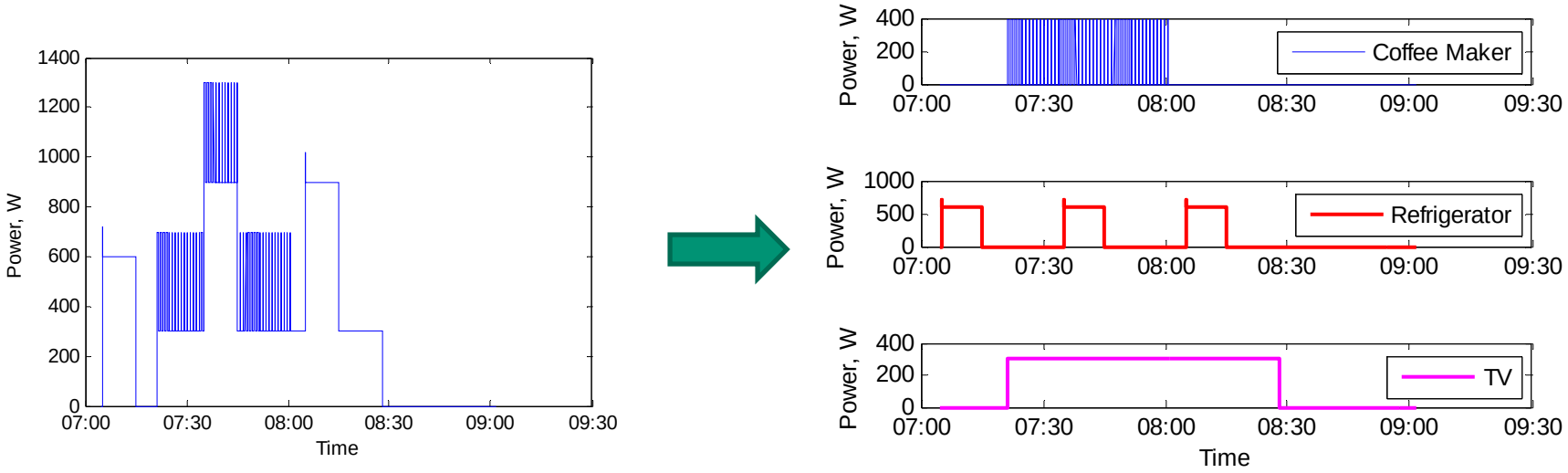
What Is NIALM?

- Non-Intrusive Appliance Load Monitoring
  - A.k.a. Non-Intrusive Load Monitoring



- Main breaker/circuit level
- Data acquisition (hardware) and disaggregation algorithms (software)

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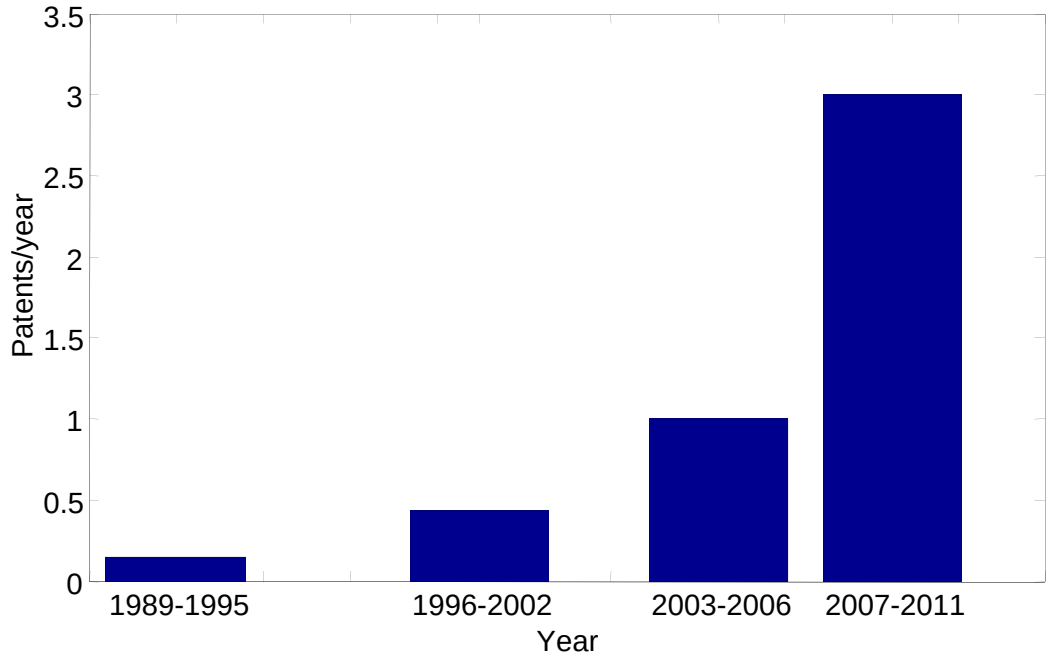
NIALM: Interest

- Significant growth in U.S. granted patents



- Both large (Belkin, GE, IBM, Intel,) and small (4home, PlotWatt, Enetics, Navetas) companies

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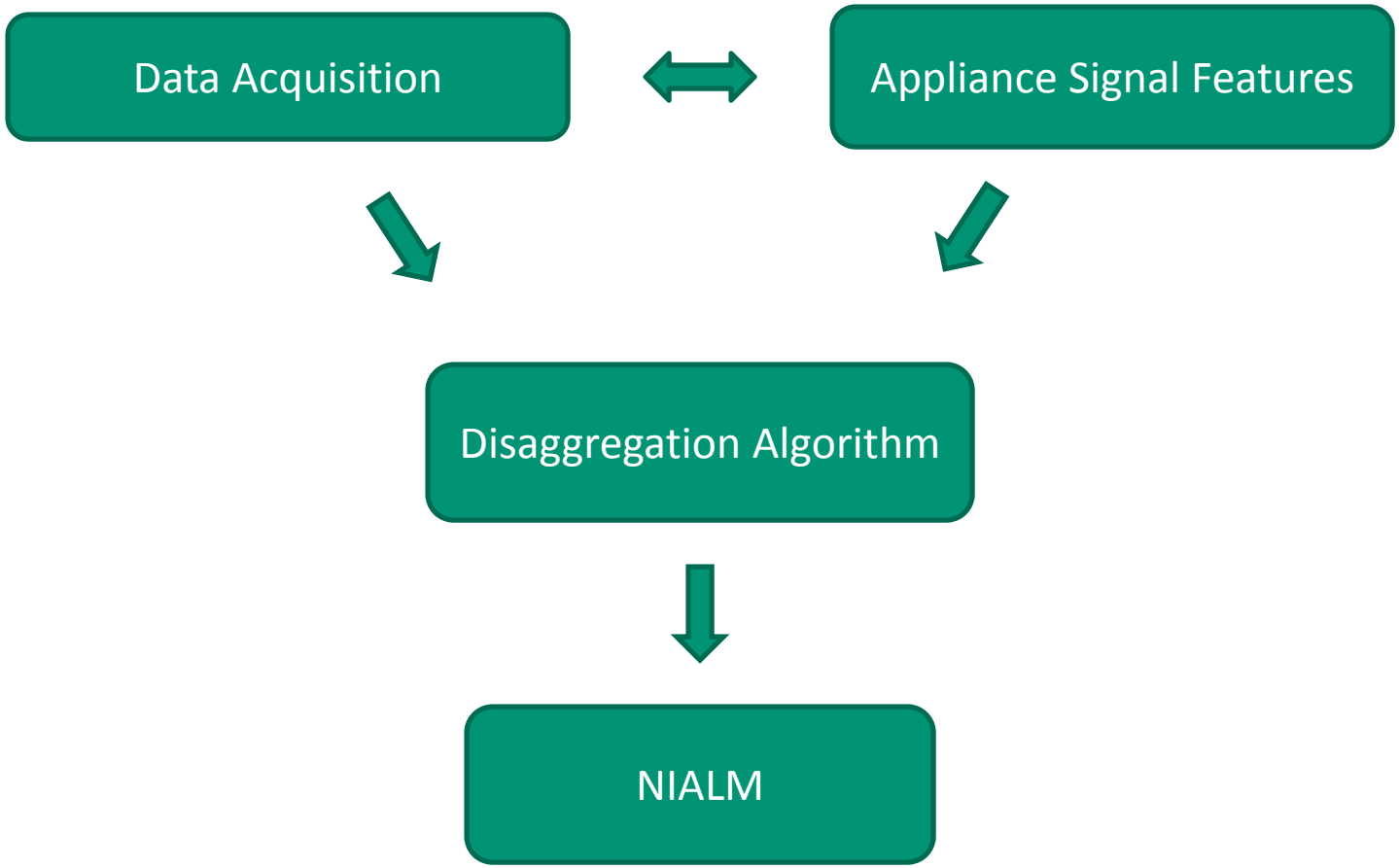
NIALM: Motivation

- Energy saving potential
  - Electricity constitutes >70% of residential primary energy consumption
  - *Whole-house* electricity consumption reduction of 5-15%
    - More specific, actionable feedback has greater savings!
  - Potential for further savings for fault detection and diagnostics
- Smart Grid – unique business opportunity
  - Large smart meter deployment underway
  - Data acquisition specs for NIALM can be incorporated into smart meters
  - Non-intrusive “manual” alternative to home automation
- Time-of-use electricity pricing – valuing Demand Response
  - Potential transition to time-dependent pricing in Europe and North America

The HEM Barrier: Complexity of HEM use and deployment

- Complexity of HEM systems impedes their acceptance and use by consumers due to:
  - Deployment complexity
  - Complexity of use
  - Complexity of information presented
- NIALM *if fully developed* can potentially close this gap
  - *Deployment*: May not require professional installation
  - *Complexity of use*: Detect appliances and track their presence in time
  - *Complexity of information presented*:
    - Provide specific information for detected appliances (e.g., state, current power draw, historical data and comparisons)
    - Tailor energy-saving tips to each household
    - Increase credibility (accuracy) of information and tips

How Does NIALM Work?



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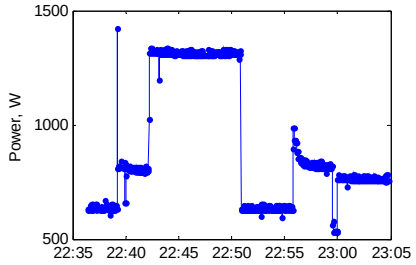
Data for NIALM: Sampling Rate

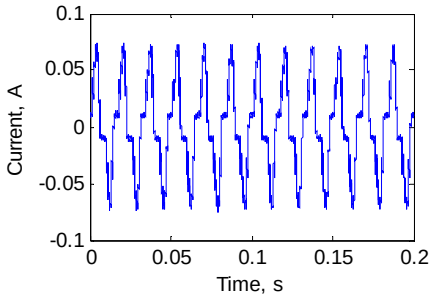
Typical daily number of switching events in a household: up to ~ 10^3-10^4 (Baranski 2004)

0.1 Hz – minimum sampling rate

Inexpensive hardware: 1 Hz



More expensive hardware: > 5 kHz



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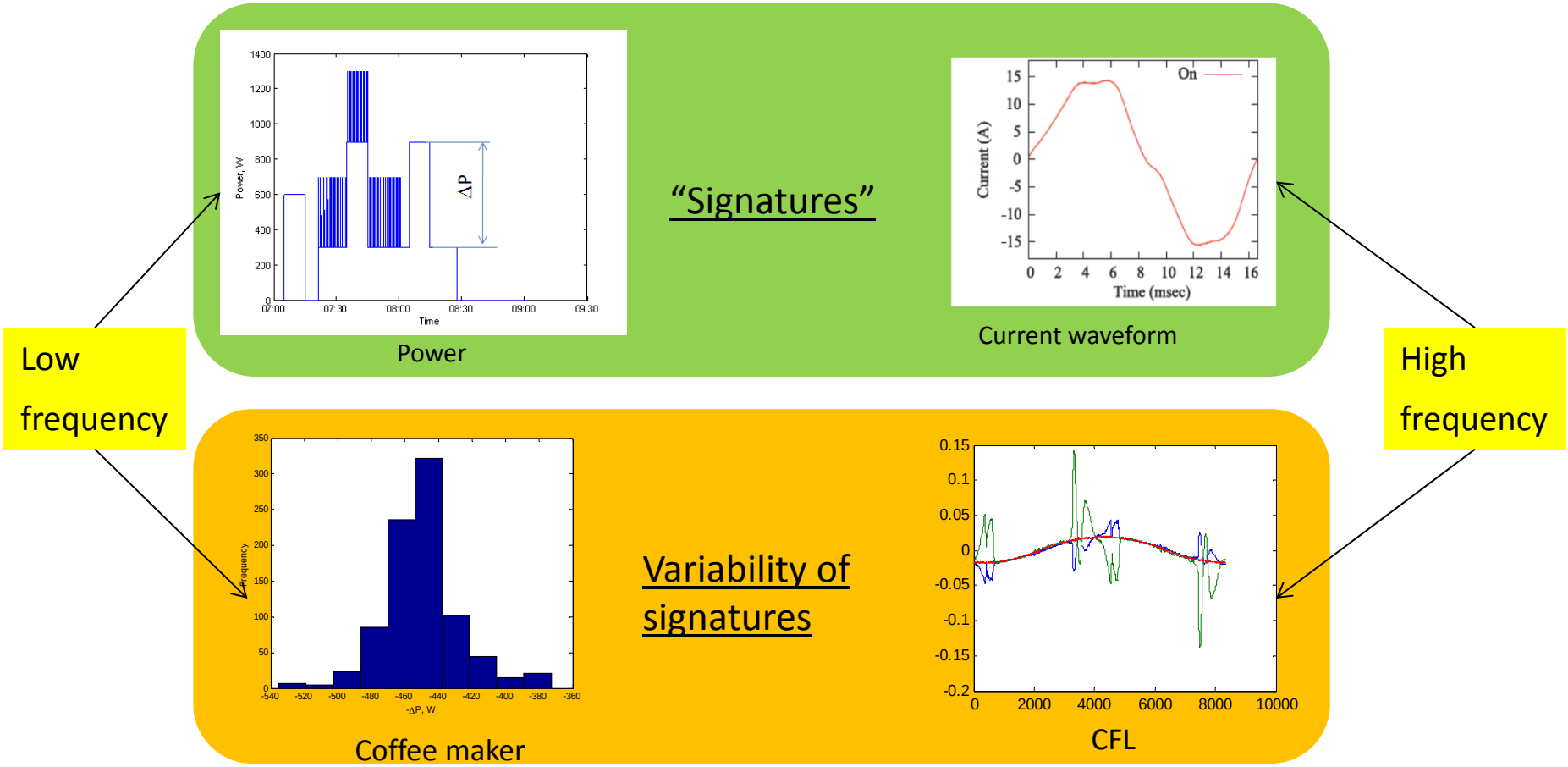
Conventional NIALM: Challenges



- No distinct signatures (overlap, missing/ corrupted data, multi-state-, permanent-, and variable power devices)
- Matching signatures with appliances

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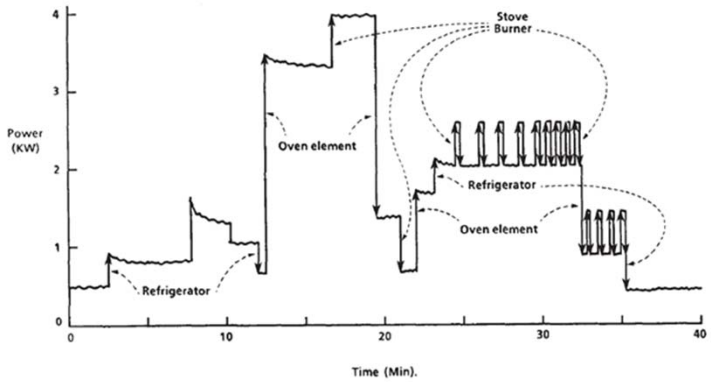
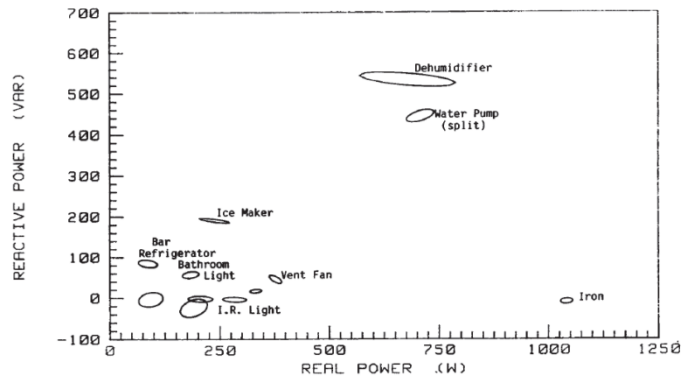
Basic Method (MIT)





- Commercial Product:
  - SPEED (Single Point End-use Energy Disaggregation) by Enetics
    - Requires professional hardware installation
    - Capable of NIALM of large appliances
    - Requires training
    - $1,300

Hart (1992)

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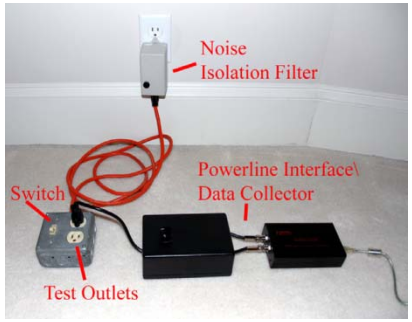
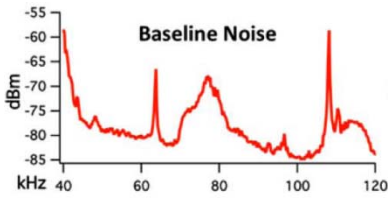
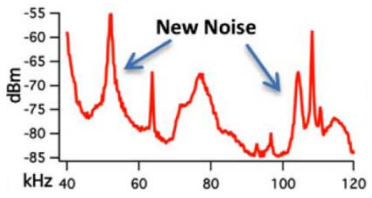
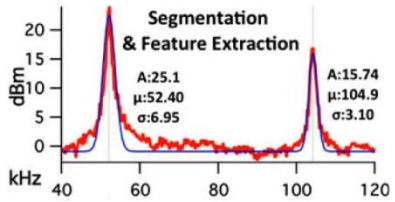
Advanced method (Patel)

- Basic idea 1: appliance connected to a socket induces noise (electromagnetic interference) in another socket
- Basic idea 2: switch mode power supplies (SMPS) generate distinctive noises









- Commercial Products:
  - In development by Belkin (since 2010)
  - In development by Intel (since 2009)
  - Major challenges to overcome:
    - Distinctive signatures
    - No-SMPS appliances
    - Power-line communication
    - Power draw estimation
    - Cost

Patel et al. (2007)

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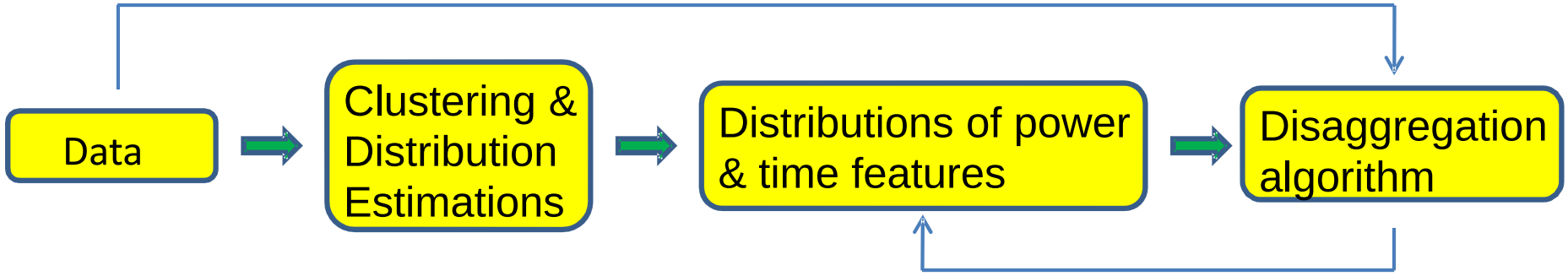
Fraunhofer Approach to Low-Frequency Data

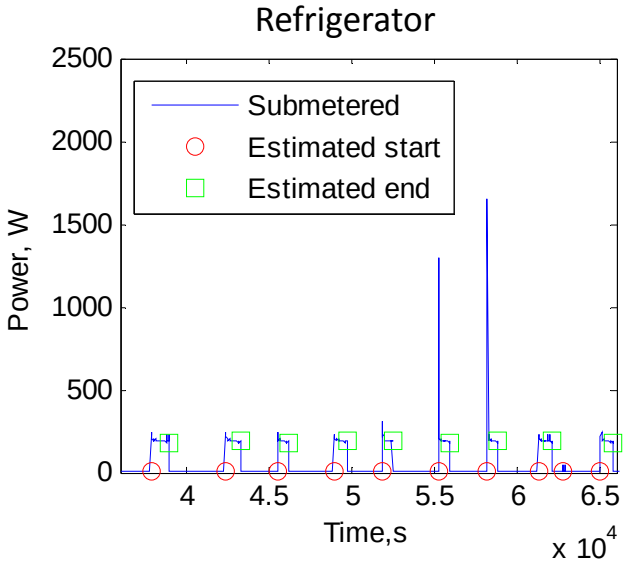
- **Principles:**
  - Appropriate to major appliances
  - Detection and use of transient events to obtain signatures
  - Power signature statistics (not unique)
  - Time on/off statistics (self-learned) in addition to power signatures
  - Probabilistic algorithm that optimally decodes appliance states
  - Currently applied to on-off appliances, but can be extended
- **Advantages:**
  - Can work with a 3rd-party data, potentially including smart meter data
  - High accuracy for overlapping appliances
  - Robust to missing and/or corrupted data
  - Easier appliance matching – can be based on both power and time of use

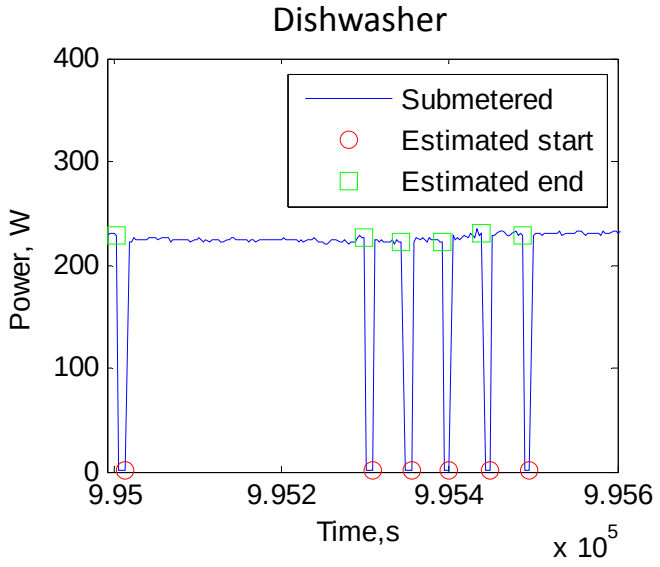
Our Approach to Low-Frequency Data: Scheme



- Data are collected for ~ two weeks
- Negative changes of power are clustered and matched to positive changes
- Each cluster can correspond to appliance
- Cluster signature (power, time) are statistically characterized
- Obtained statistical distributions can be used to disaggregate new data
- Clusters need to be matched to real appliances

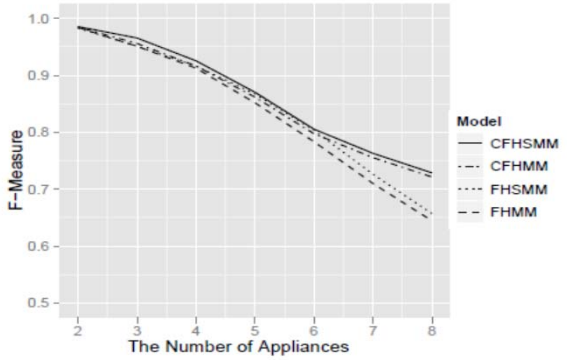
Our Approach to Low-Frequency Data: Some Results





- Real household publicly-available data (Kolter and Johnson, 2011)
  - 9 appliances, 3 weeks of monitoring
  - Overall accuracy
    - Our method: 0.89
    - Other methods : 0.71

Accuracy in Kim et al. (2011)



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Our Approach to High-Frequency Data*

- Principles:
  - Appropriate to both MELs and major appliances
  - Detection and use of transient events
  - Two or more “orthogonal” methods for waveform characterization
  - Probabilistic fusion of orthogonal methods to enhance accuracy
  - Requires ~ 50-100 kHz sampling rate
- Advantages:
  - Enhanced classification accuracy (high true positive rate, at low false positive rate)
  - Can incorporate additional waveform characterization methods to further enhance accuracy

*Supported in part by DOE through a subcontract from Lawrence Berkeley National Laboratory (LBNL).

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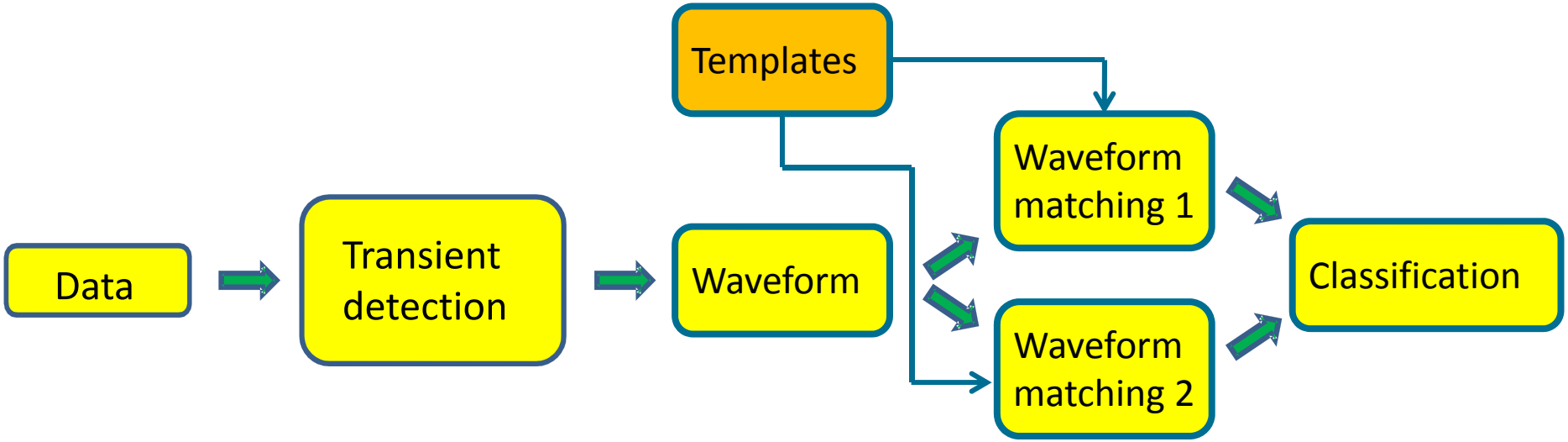
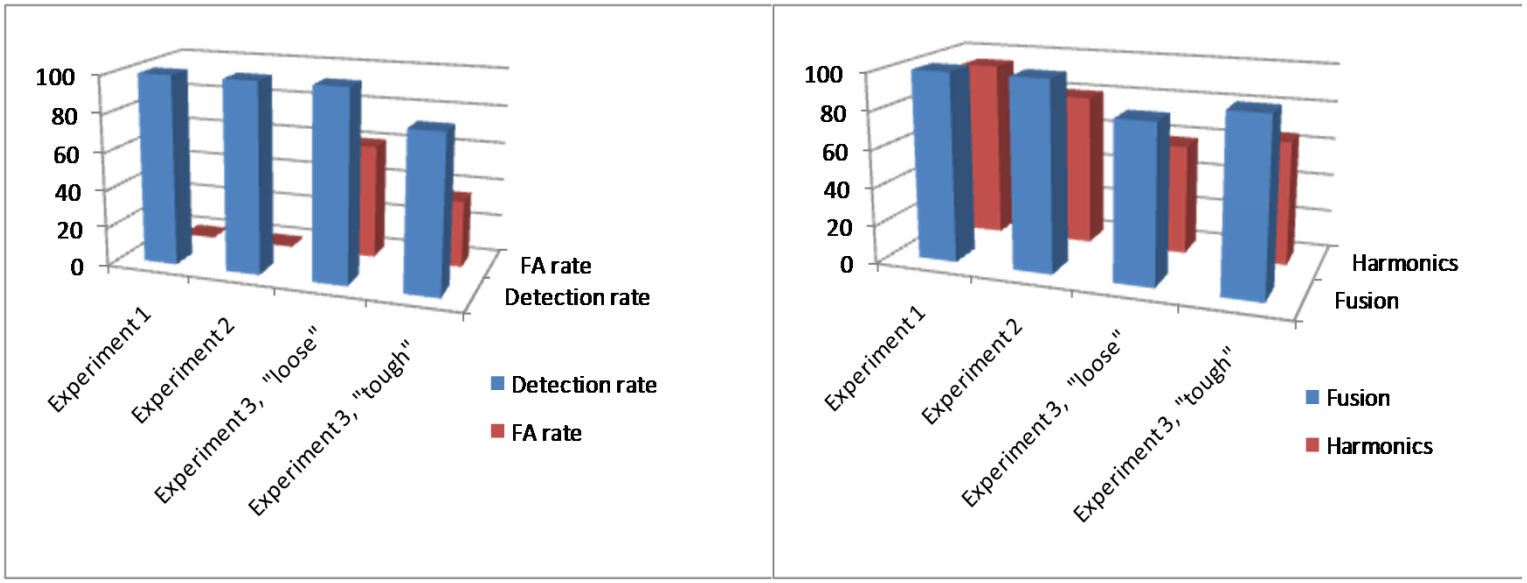
Our Approach to High-Frequency Data: Scheme



- Method currently requires training (waveform templates for each MEL)
- After transient is detected, waveform of the change is obtained
- Two or more “orthogonal” methods implemented to match waveform to template
  - We use image processing method (Fourier descriptors ≈ harmonics) and multivariate statistical technique (Partial least squares, used in spectroscopy)
- Results are fused together to classify the waveform

Our Approach to High-Frequency Data: Some Results



- *Experiment 1*: CFL lamp, CRT TV, halogen lamp, fan (no overlap in waveforms, power draw ~ 20 – 200 W)
- *Experiment 2*: printer, CRT monitor, CFL lamp, incandescent lamp, fan (noticeable overlap in waveforms, power draw ~ 20 – 200 W)
- *Experiment 3*: LCD TV, Pioneer receiver, netbook, vacuum cleaner, CFL light, pencil sharpener, hair dryer, night lamp, DVD, incandescent lamp (noticeable overlap in waveforms, power draw ~ 2 – 2,000 W)

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Conclusions

- NIALM can enable significant energy savings
- NIALM deployment low-cost IF embedded in smart meter
- NIALM is challenging!
  - Appreciable research, one product
  - Technical Challenges
    - Variability and overlap of “signatures”
    - Automatic appliance matching
- Fraunhofer NIALM
  - Developed two new methods that outperform most other methods
  - Current status: proof of concept
  - Further applied research is required