RepEL: A Utility-preserving Privacy System for IoT-based Energy Meters

Phuthipong Bovornkeeratiroj, Srinivasan Iyengar, Stephen Lee, David Irwin, and Prashant Shenoy

University of Massachusetts Amherst, Microsoft Research India, University of Pittsburgh

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iotdi

University of Massachusetts Amherst

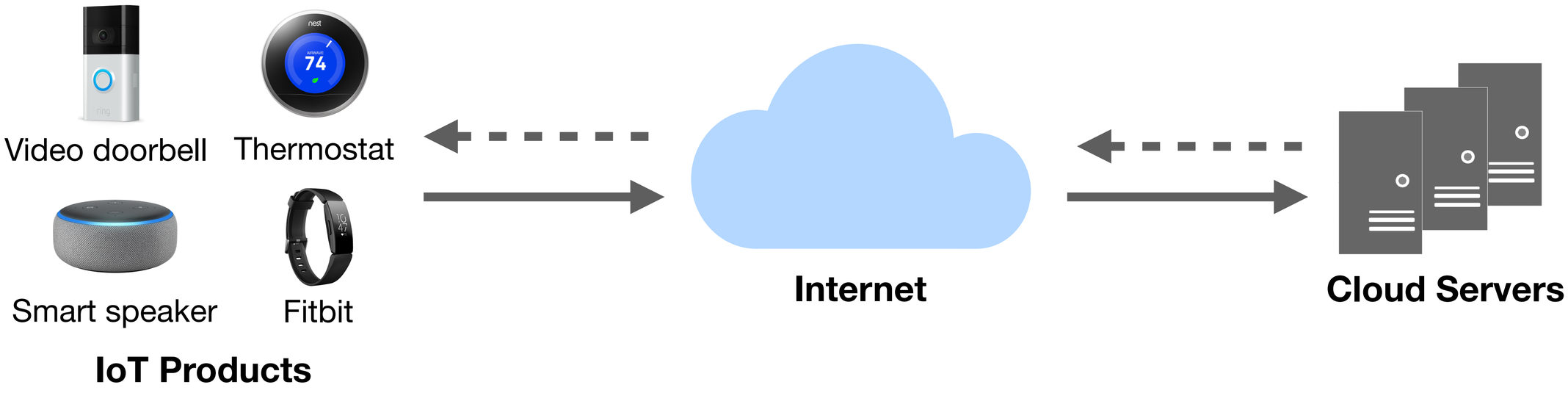
IoT in Smart Homes

Many IoT products for smart homes

- Smart light bulbs, voice assistants, thermostats, fridges, etc.

Cloud-based IoT architecture

- Send data to cloud servers for analytics



Privacy of IoT Data

- **Cloud analytics of IoT data**
  - Useful services to user
  - e.g. safety monitoring
- **Privacy Leakage**
  - Data reveals privacy information
  - e.g. continuously stream all activity in the house

*Graphics from: canary.is

Utility Preserving Privacy

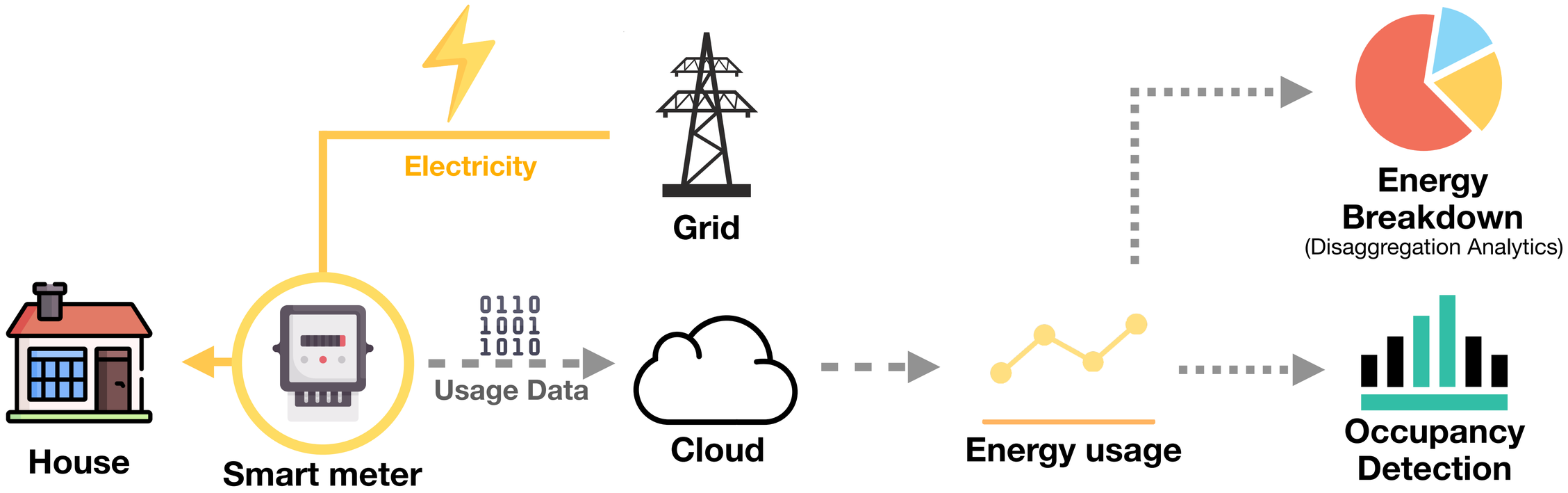
- **Traditional methods for IoT Privacy**
  I. **Data obfuscation** - obfuscate data before uploading
     - Suppress private information, cloud analytic impossible
  II. **Local processing** - no cloud transmission
     - Limited ability for sophisticated analytics

- **Trade-off:** **Utility of data analytics** vs. **Privacy of user**

- **Utility-preserving Privacy:** how to intelligently transform IoT data such that
  - Private information suppressed ✔ **Privacy**
  - Non-private information retained ✔ **Analytics**

Utility Preserving Privacy for Energy

- **Smart meter** - Monitor electricity usage at fine time granularity



Utility Preserving Privacy for Energy

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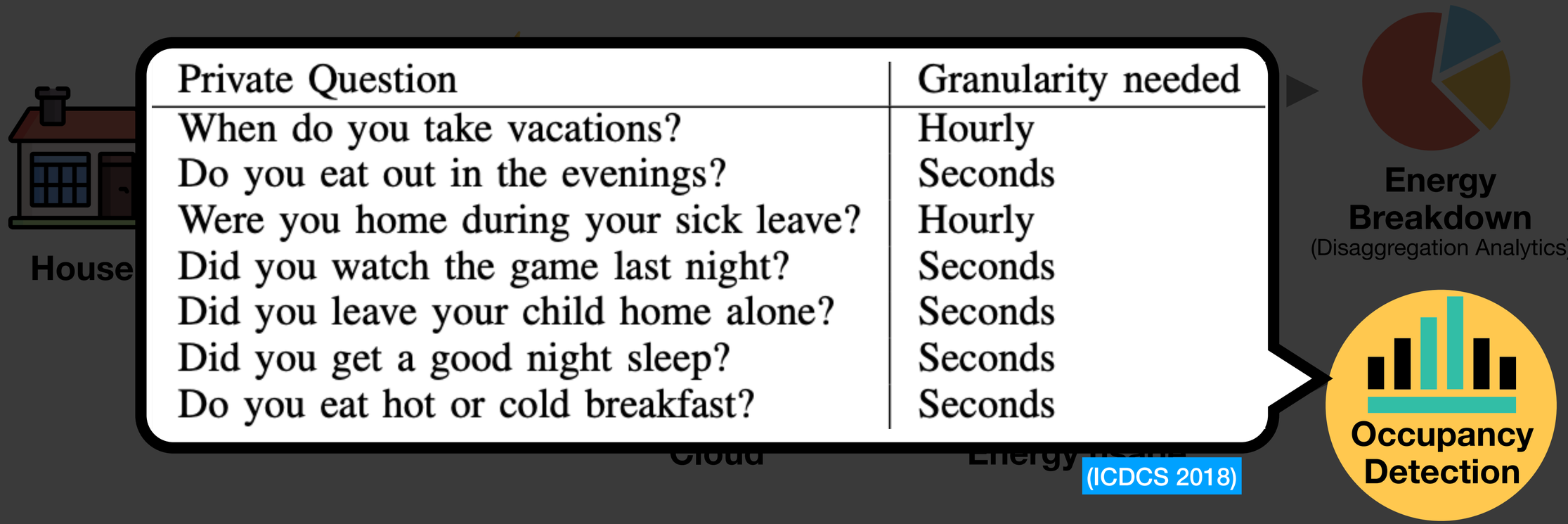


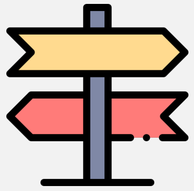
Utility Preserving Privacy for Energy

- **Smart meter** - Monitor electricity usage at fine time granularity

Key question:

> “How can we allow disaggregation analytics and prevent occupancy attacks?”

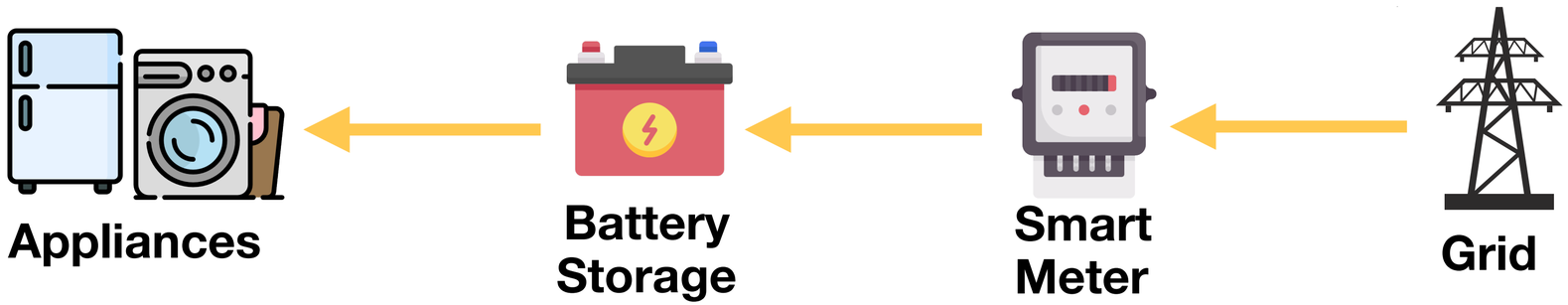
Talk Outline



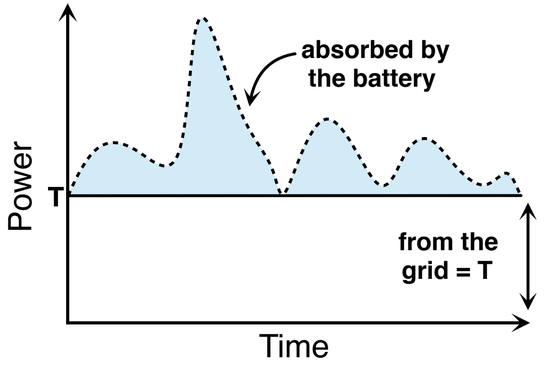
- Motivation
- **RepEL Utility Preserving Privacy**
- Experimental Results
- Conclusion

Smart Meter Privacy using a Battery

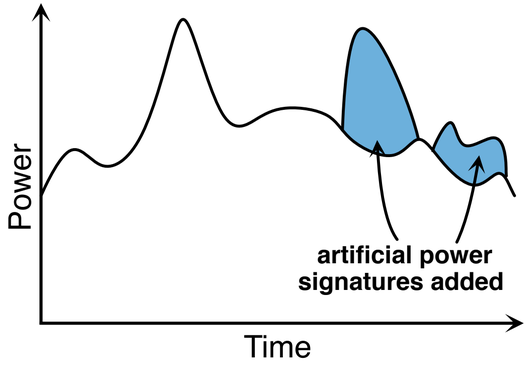
- **Key idea:** use a **battery storage** as energy buffer
  - Use charge/discharge to transform usage seen by smart meter



- **Current state of art:** data obfuscation using battery



Flattening (Yang, et al.)



Noise injection (Chen., et al)

Our Approach: RepEL

(**Rep**lay **E**nergy **L**oad)

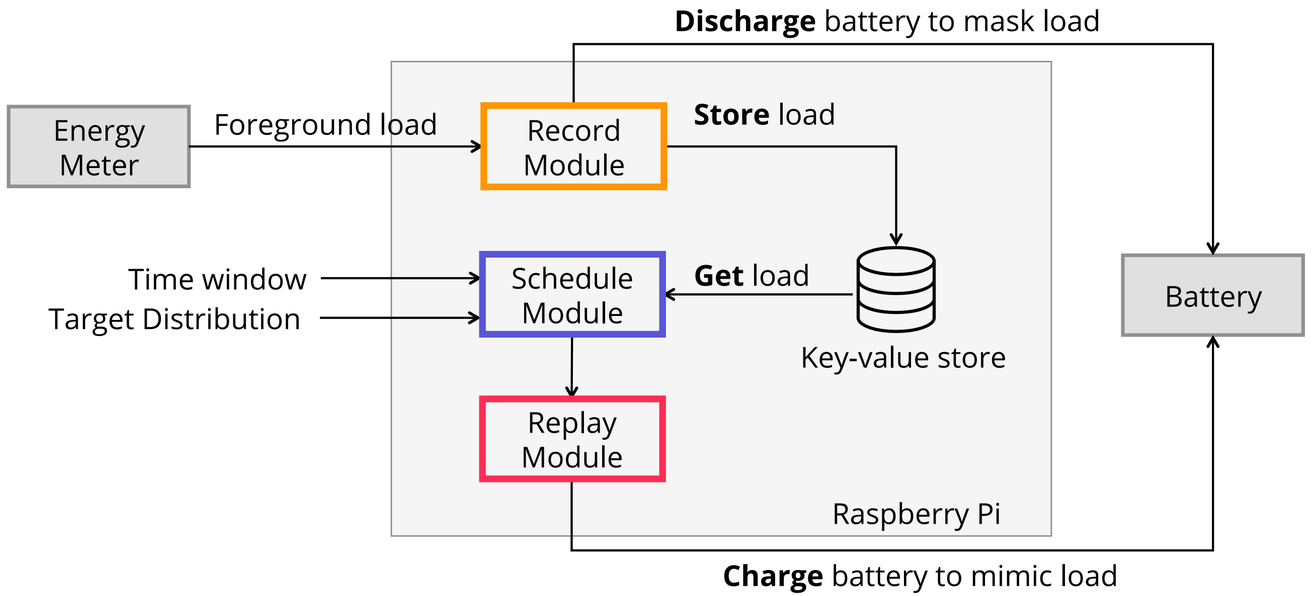
- **Key idea:** permute & randomize while retaining usage of each appliance
  - Use battery to suppress actual usage when it occurs
  - Record this usage
  - Use battery to replay usage at later time
- **Record and Replay**
  - Retains individual appliance usage
  - Permutes time order of usage as seen by meter

❌ **Time-based occupancy attack**

✅ **Usage-based cloud analytics**

RepEL Architecture

- **Re**play **E**nergy **L**oads in **3** steps



Step1: Record - record energy consumption of foreground appliance

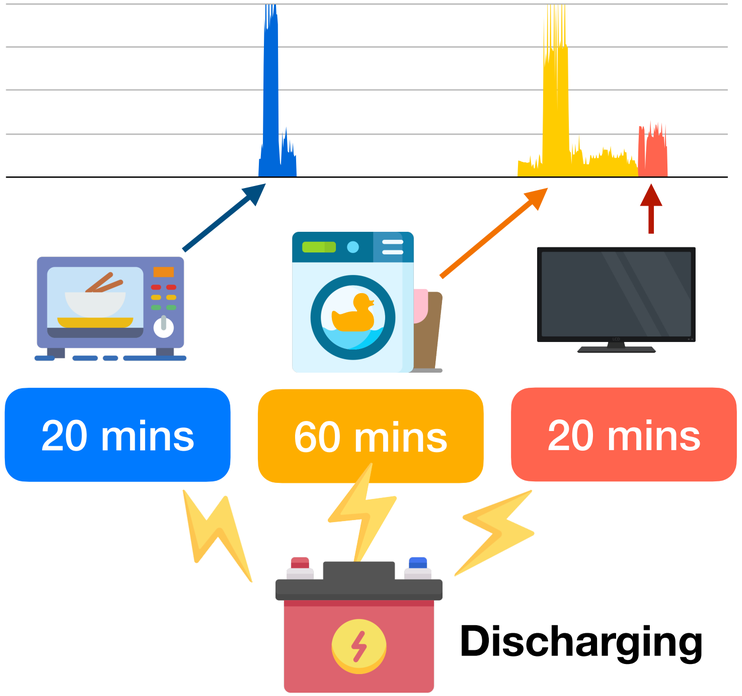
Step2: Schedule - schedule the time to replay using a target distribution

Step3: Replay - replay recorded trace based on schedule and policies

RepEL Algorithm Pipeline

Record

Time window #1

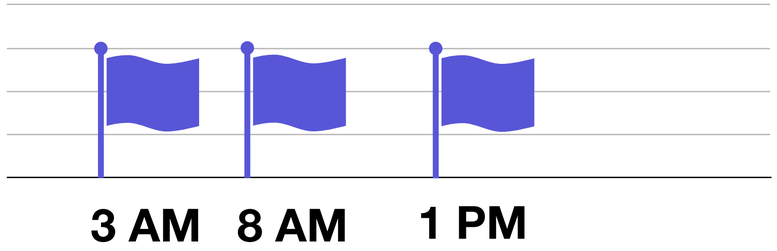


no original load seen

Schedule

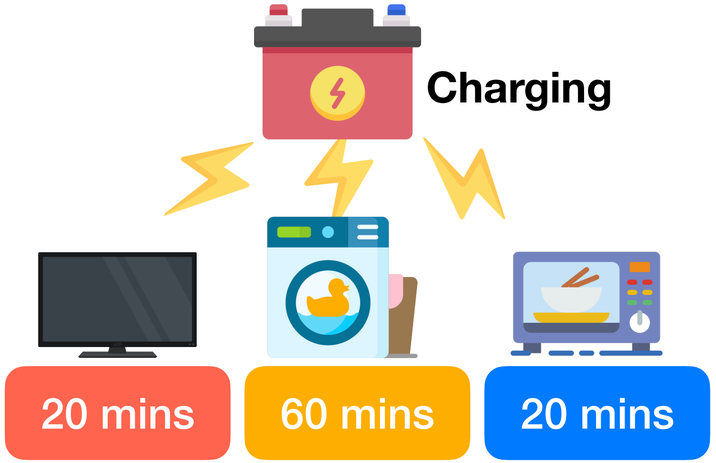
Time window #2

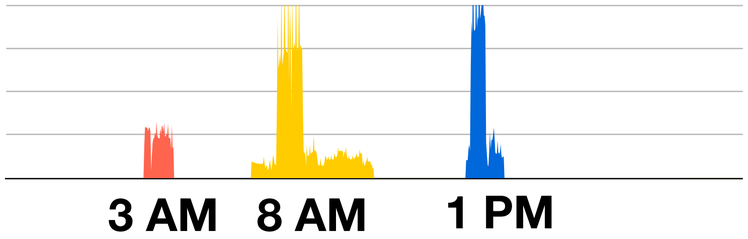
Schedule 3 start times



Replay

Time window #2

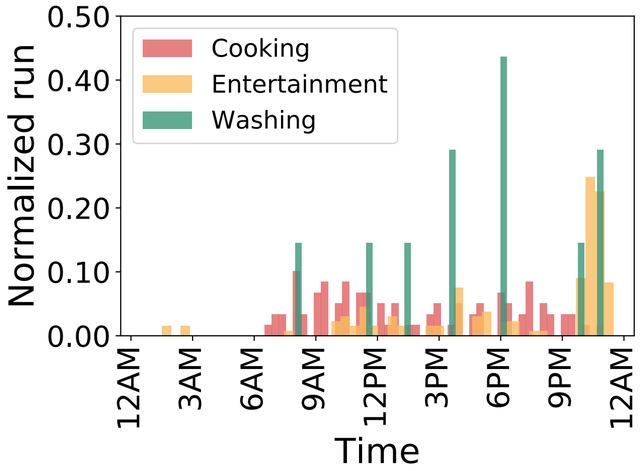




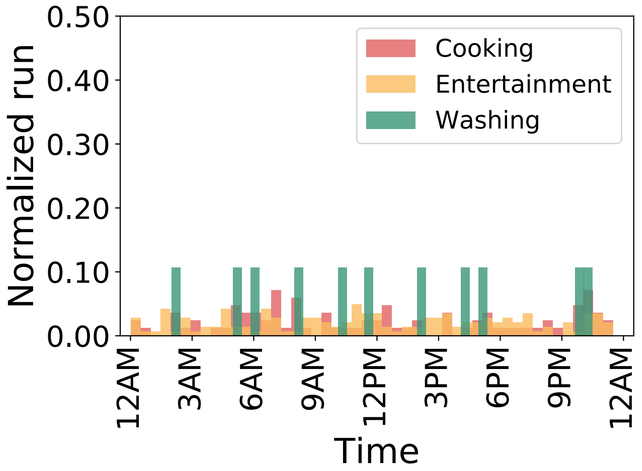
Result in randomization & permutation

RepEL Replay

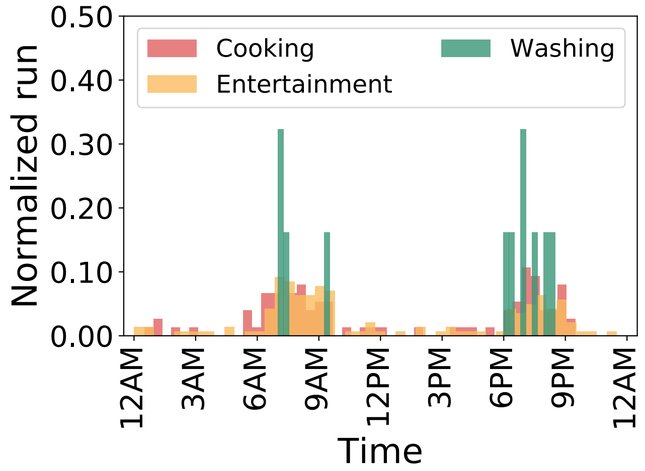
- **RepEL** use **MCMC sampling** method called **Metropolis-Hasting Algorithm** to **mimic any distribution** during schedule step



Original distribution



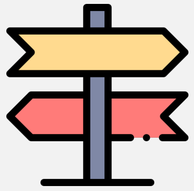
Uniform distribution



Bimodal distribution

- **Vacation mode** 
  - Long absence periods means **nothing to record**
  - **Replay random loads** from previous week

Talk Outline



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Experimental Setup

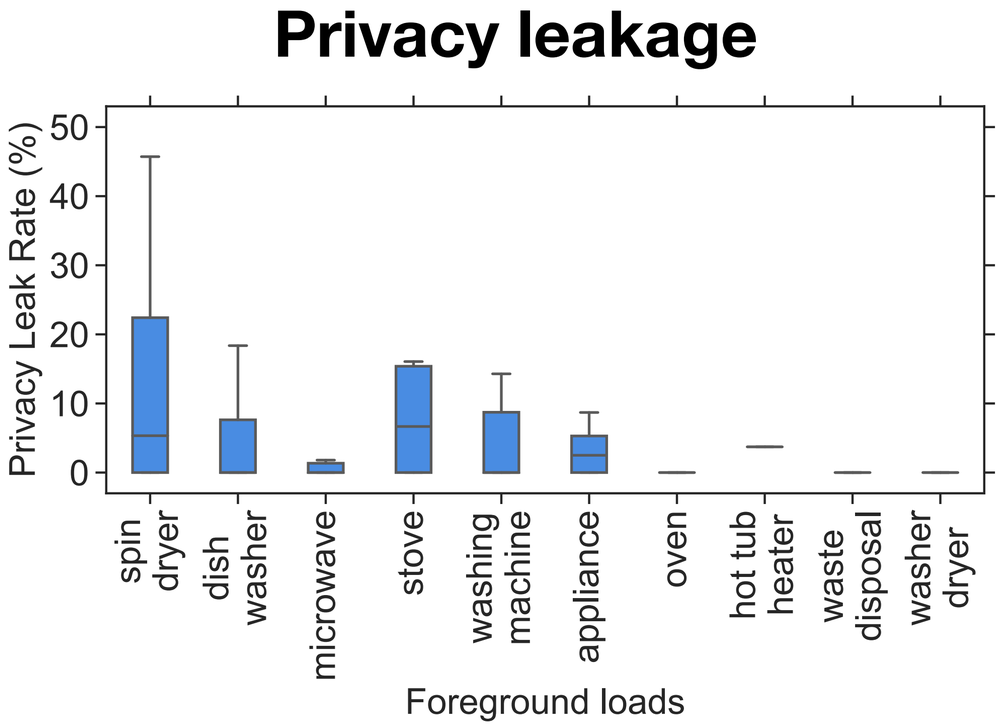
Metrics

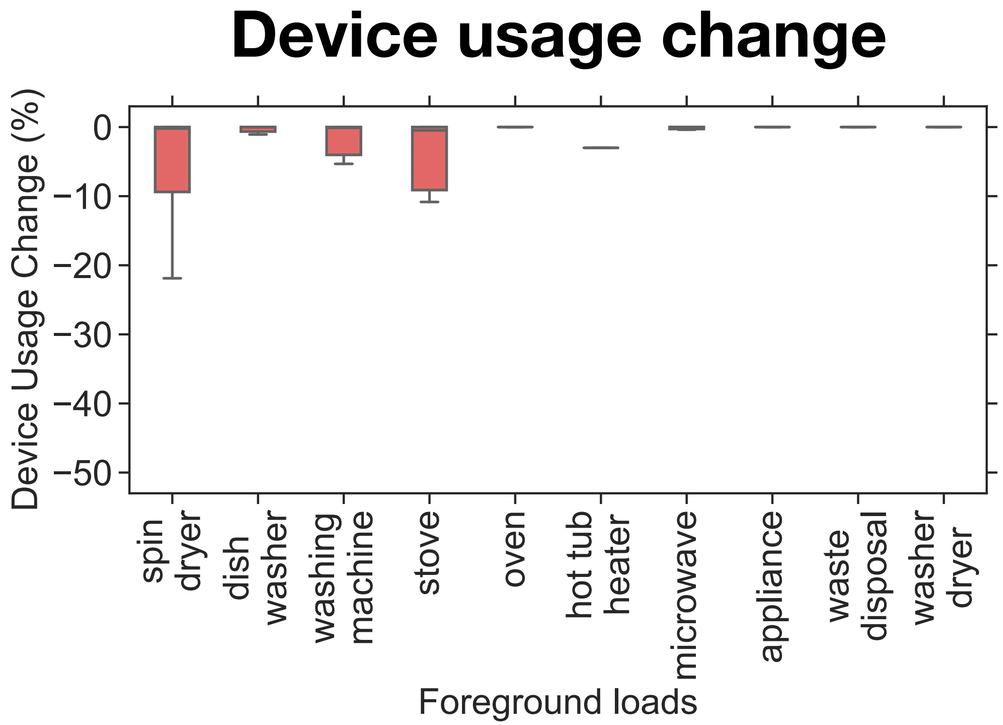
- **Privacy leakage rate** $= 100 \times \sum_{i=1}^{N} \frac{is\_leak(i)}{N}$
- **Device usage change** $= 100 \times \frac{\sum_{i=1}^{N} (replay\_profile_i - energy\_profile_i)}{\sum_{i=1}^{N} energy\_profile_i}$

Dataset

- **Dataport from Pecan Street Inc.** - 19 houses, 1 month, minute-level data
- **ECO from ETH Zurich** - 4 houses, 22-36 days, second-level data

RepEL Privacy vs Utility



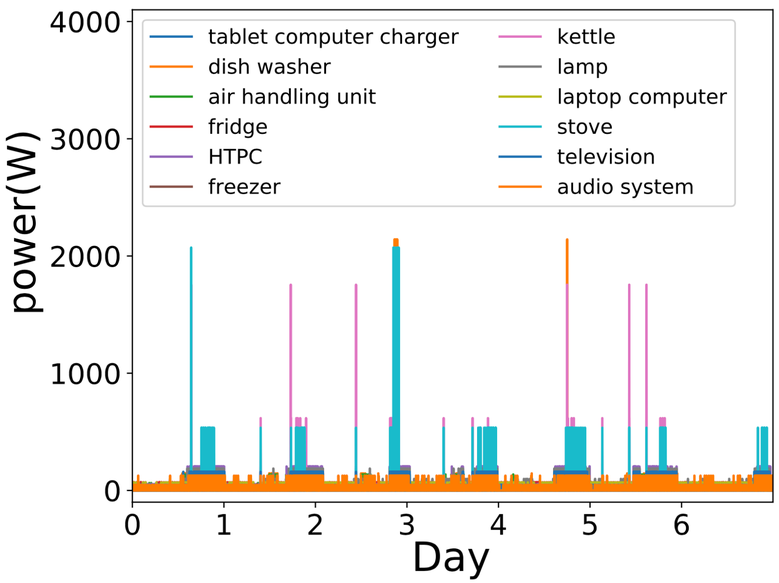


Result: RepEL provides **<10% privacy leakage** with **<3% error in usage**

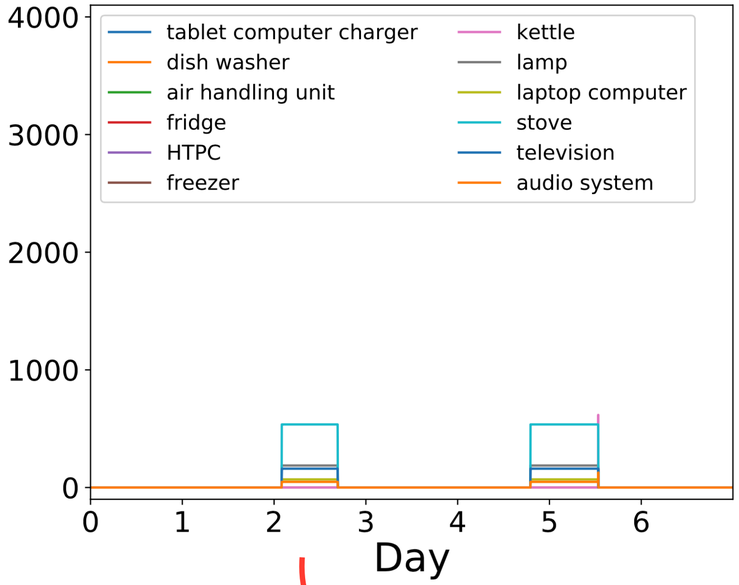
Disaggregation analytics accuracy

Comparison with LS2

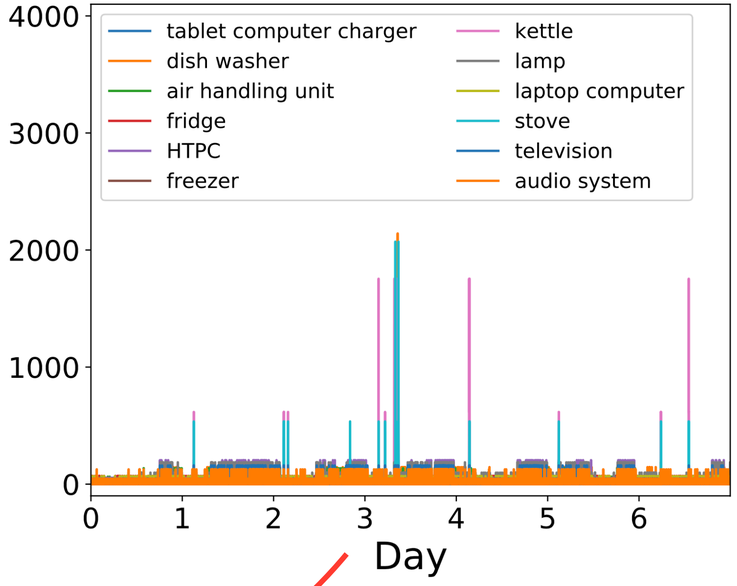
Original disaggregation



LS2 disaggregation

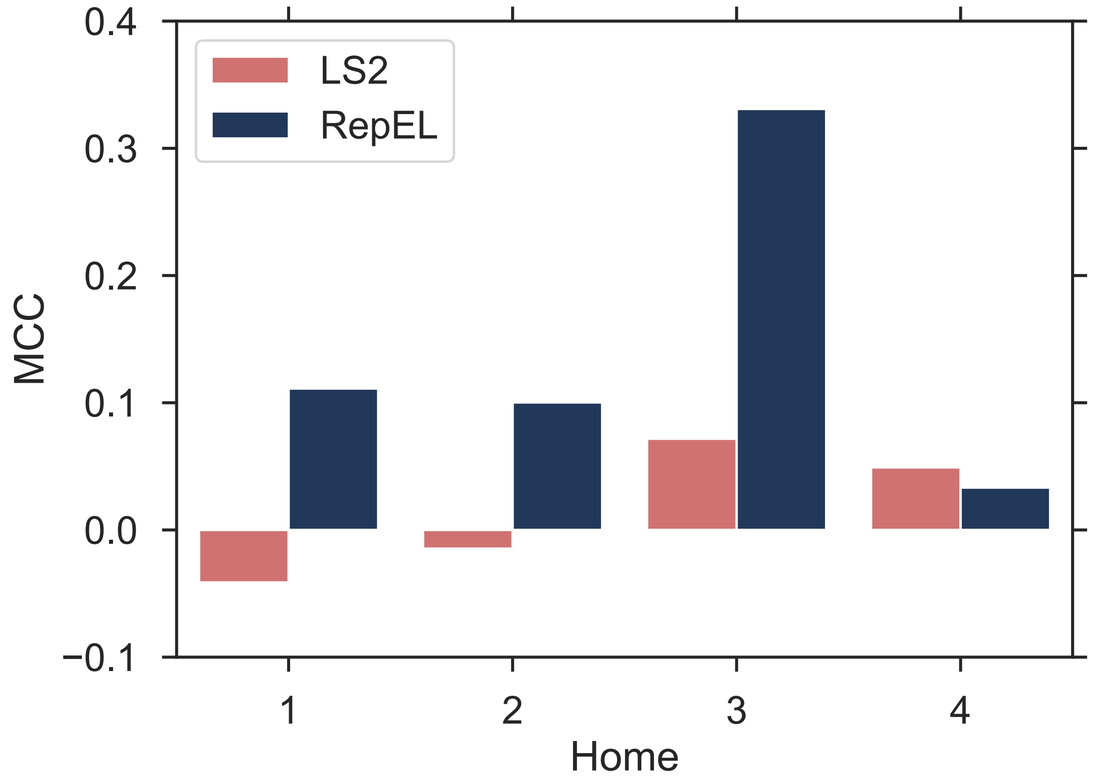


RepEL disaggregation



Metric	LS2	RepEL
MAPE	64.25	6.53
MSE	4.07e+11	1.36e+10

Occupancy Detection Accuracy



Result: RepEL has **reasonable good privacy property** but **slightly worse than LS2**

But **LS2 cannot preserve utility information**

Conclusion

- Proposed a **utility-preserving privacy** system (**RepEL**) for smart meter
- Implemented and evaluated on two plug-level home energy trace dataset
- Our results show:
  - **RepEL** can **prevent** adversaries from **inferring behavioural patterns**
  - Also **RepEL** can **preserve** **utility information** in the trace

Thank you

Contact us:
phuthipong@cs.umass.edu