

# From Energy Audits to Monitoring Megawatt Loads: A Flexible and Deployable Power Metering System`

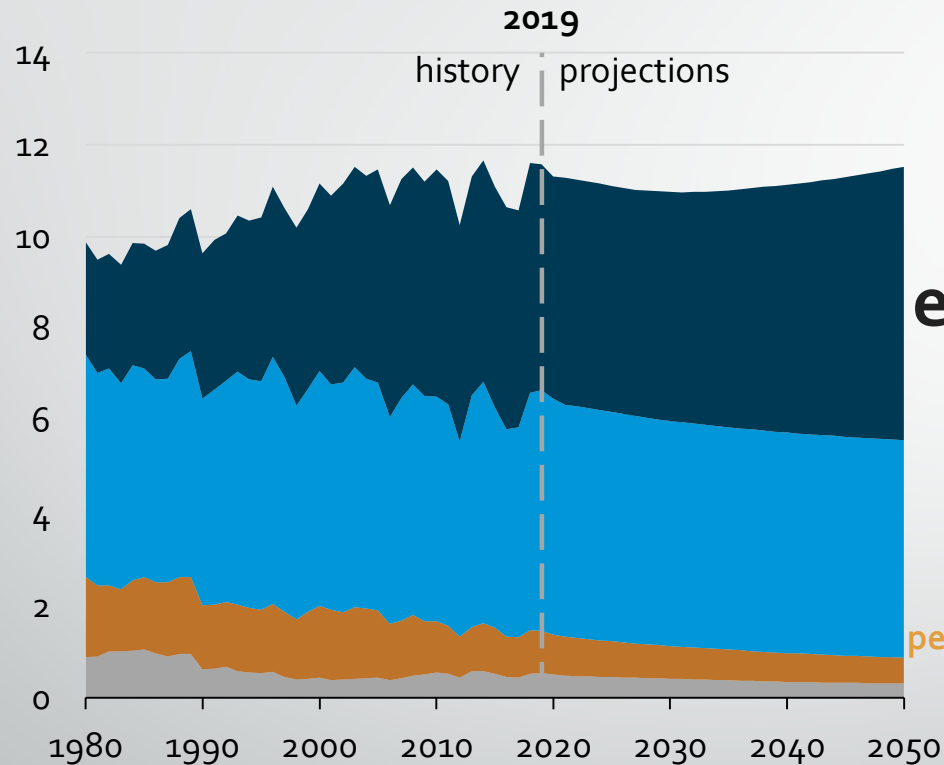
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Presented by: Akinori Kahata

# Back Ground: Energy Consumption

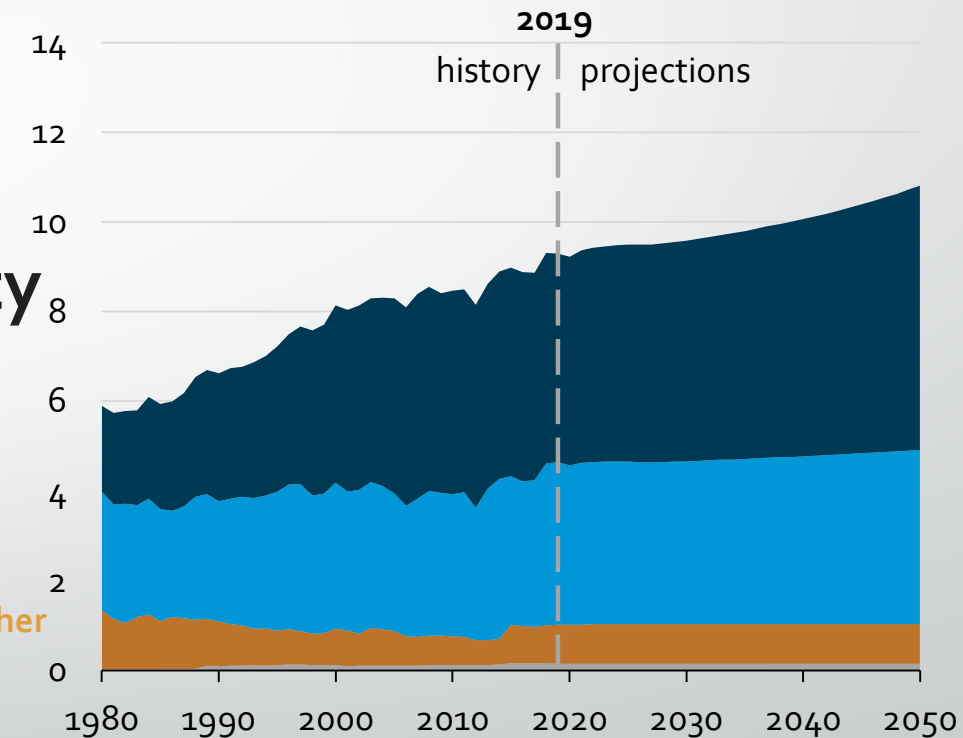
## Residential sector

(AEO2020 Reference case)  
quadrillion British thermal units



## Commercial sector

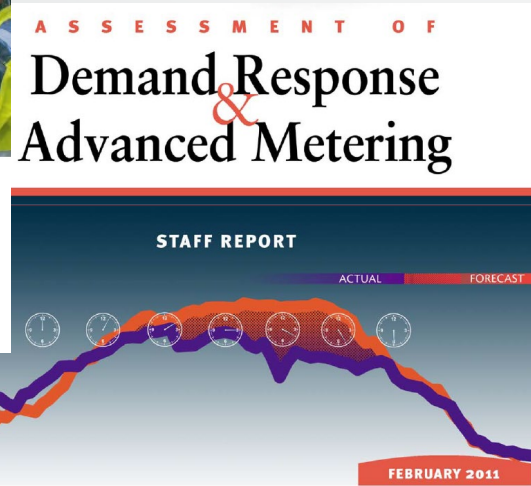
(AEO2020 Reference case)  
quadrillion British thermal units



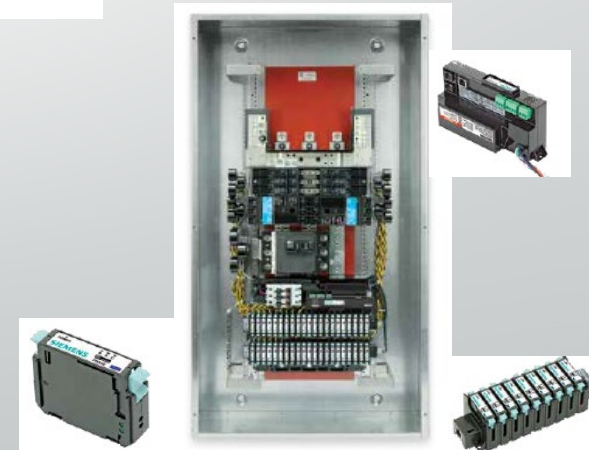
Electricity usage is - **Major cost for users**  
- **Source of carbon emissions**

# Measurement of Electricity is Important for smart consumption

The U.S. Government launch many Project



Various type of Meters



References : Department of Energy <http://www.ferc.gov/legal/staff-reports/2010-dr-report.pdf>  
[https://betterbuildingssolutioncenter.energy.gov/sites/default/files/program/DOE\\_BBI\\_2019\\_Progress\\_Report.pdf](https://betterbuildingssolutioncenter.energy.gov/sites/default/files/program/DOE_BBI_2019_Progress_Report.pdf)

References : Belkin WeMo Insight. <http://www.belkin.com/us/p/P-F7C029/>, 2017.

Obvious Power Panel+. <http://www.obvious.com/Products/PPP-O-XX,2017>.

Neurio Energy Monitor. <https://www.neurio.energy-monitor/>, 2017.

Siemens Embedded Micro Metering Module, 2017.



# Problem:

## Drawbacks of Existing Meter

### Problems

- Expensive
- Wired
- Hard to install
- Inaccurate
- Inflexible
- Difficult to calibrate

### Trade Offs

**Accuracy**

**submetering  
granularity**

**Installation cost**

**complexity**

**Common Problem for IoT sensors**



# Suggestion: New type of meter “Triumvi”

## Core Concept

- (1)Stand alone
- (2)Self-powered
- (3)Non-contact
- (4)Circuit-level True-power metering system

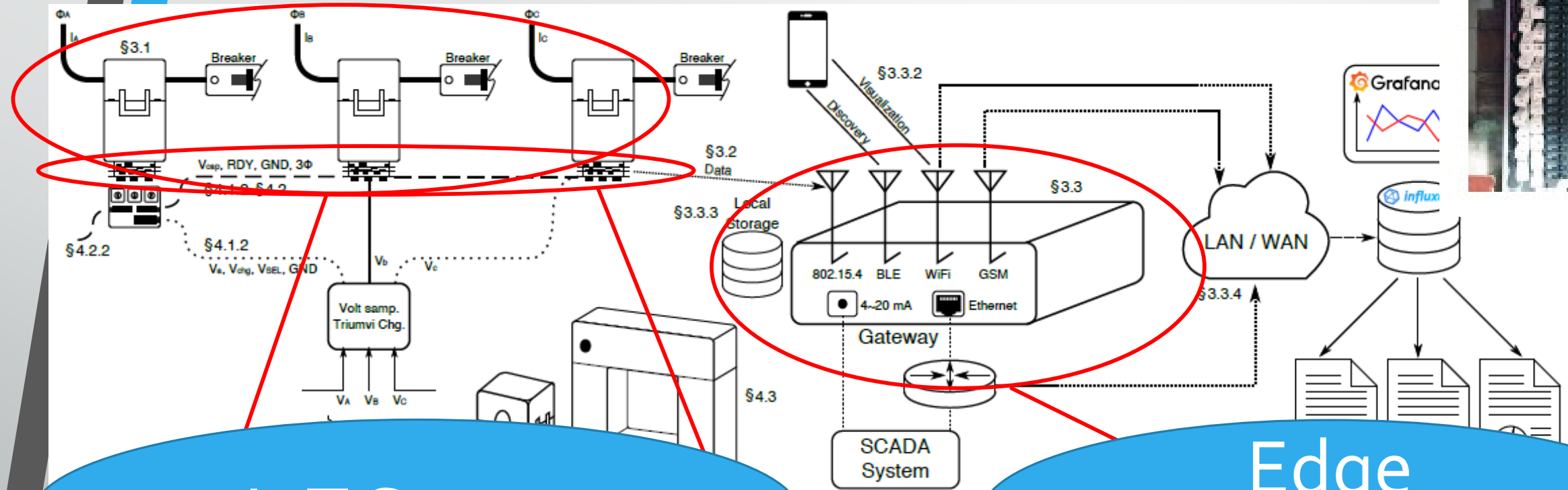
## Property

- Easy to deploy
- Non contact power meter
- Configuration module
- Wireless radio
- Wireless gateway
- visualization

**The point of challenge:**

**How to keep the accuracy of measuring under these condition**

# System Overview of **Triumvi**



IoT Sensor

Edge  
Computer

Share  
Task

**Module**

Under the limitation

- Sensing the natural phenomena
- Transmit row data to Edge computer

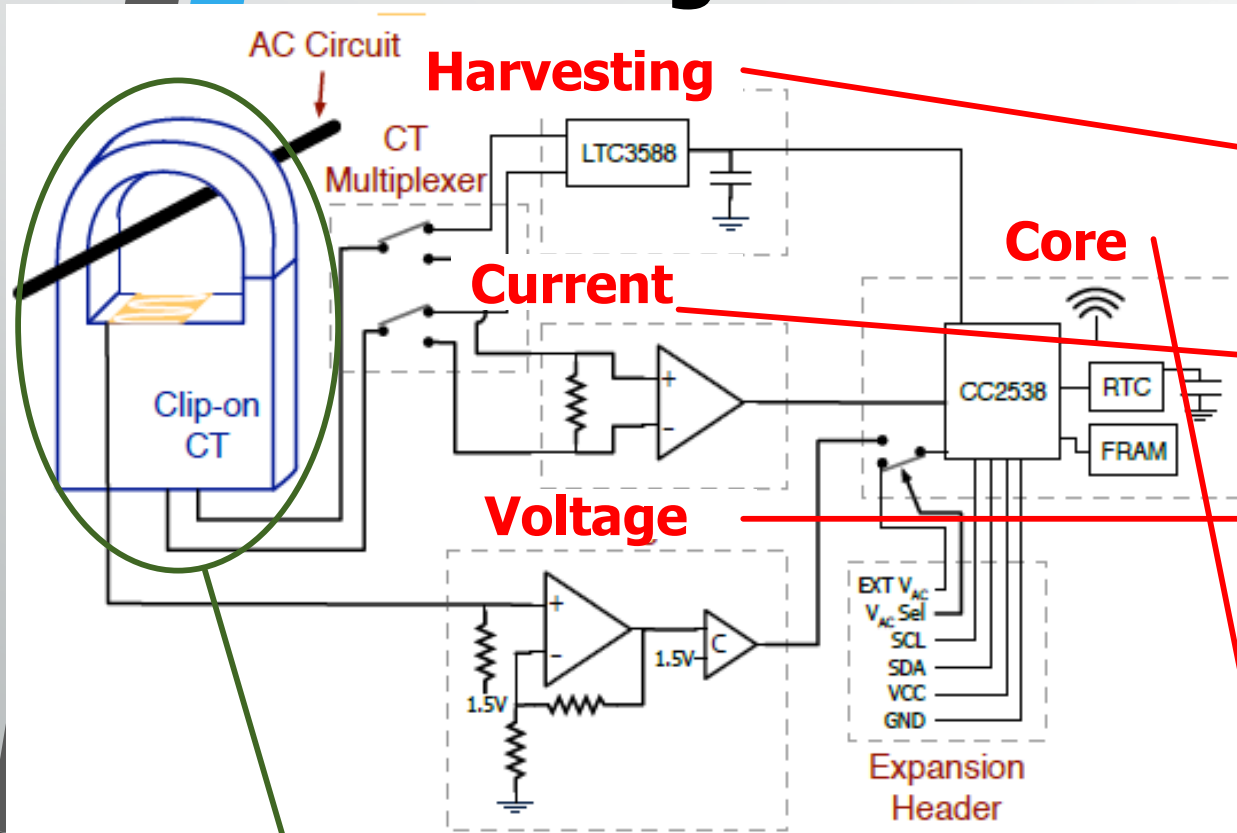
- Processing the Data
- Sending the data to cloud
- Storage the data
- Monitor the sensor



# Triumvi Core Meter(1)

## Design

## 4 Roles



1. Energy to Power Themselves
2. Measurements of the current
3. Measurements of the voltage channels
4. Resulting power measurement

### Current Transformer(CT)

- Induces a current when the circuit is drawing current
- It provide current for both harvesting and current measurement

# Triumvi Core Meter(2) : Four Advantage

## 1) Energy-Harvesting Power Supply

- It enables to reduce wire

## 2) Voltage Measurement

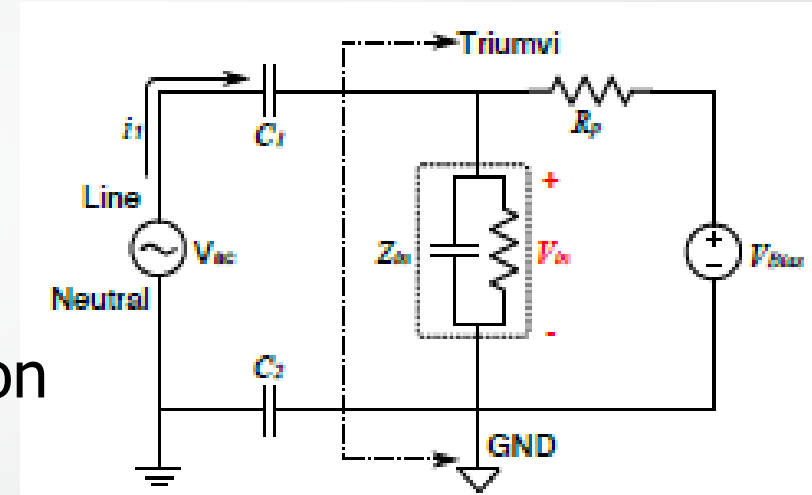
- Only Extract voltage phase to avoid calibration

## 3) Multiplexing the Current Transformer

- Cut cost and make device small

## 4) Additional Meter Functions

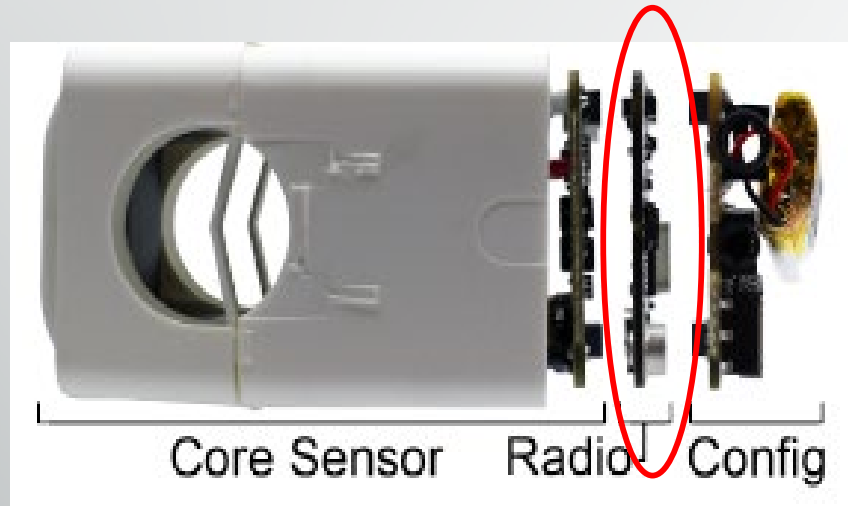
- ① Real Time Clock
- ② Reset Button (easy to re-deploy for other circuit)
- ③ The meters can calculate power factor





# Radio module

## Radio of Metering System Stack



## Property and Merit

- Wirelessly transmit the data for collection
- Can be chosen to match deployment requirements.
- The requirements for radio are minimal; be able to transmit a packet to a nearby gateway.

## Constrain due to power harvesting

- must be able to transmit a packet while consuming, only the minute amounts of energy available through harvesting.

# Gateway Services

## 4 Roles

### 1. Send current time to the meter

- Respond to request from the Triumvi node(meter), which needs current time for Timestamping.

### 2. Decoupling Data from wireless Radios

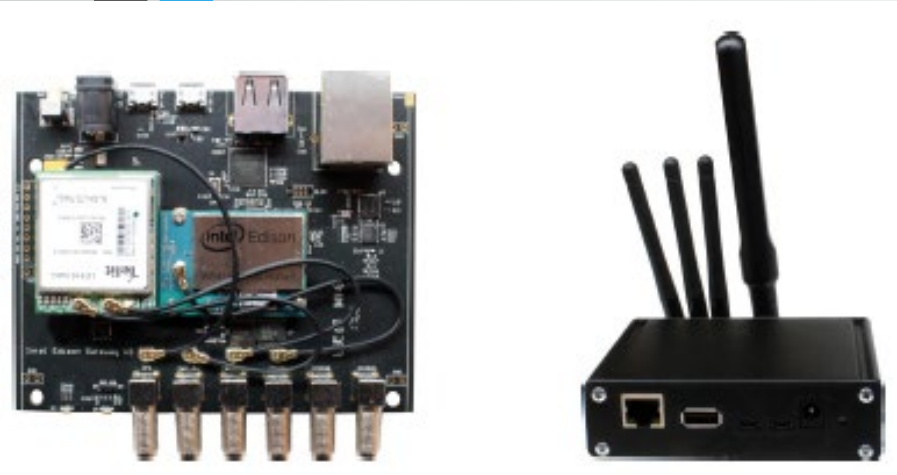
- Resource of the meter is limited for data process, then the gateway become intermediary, and facilitates data transmit from meter to smart device.

### 3. Local Data Storage

- Can log data to an internal database

### 4. Cloud Data Offload

- Offload the collected data to a cloud backend



# Deployment And Usage Concerns:

Environment are diverse,  
then meter should adjust the different environment

## A. Residential and Commercial Buildings

- we can use for flexible objective below
  - 1) Energy Audits and Exploratory Research
  - 2) Upgrades for Proven Deployment

## B. Three Phase Loads

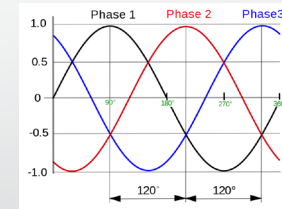
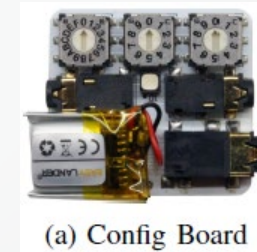
- Many loads are not single phase loads
- HVAC, industrial monitor

## C. Large Loads(Like Industrieds)

- Triumvi can support up to 1000 Amps

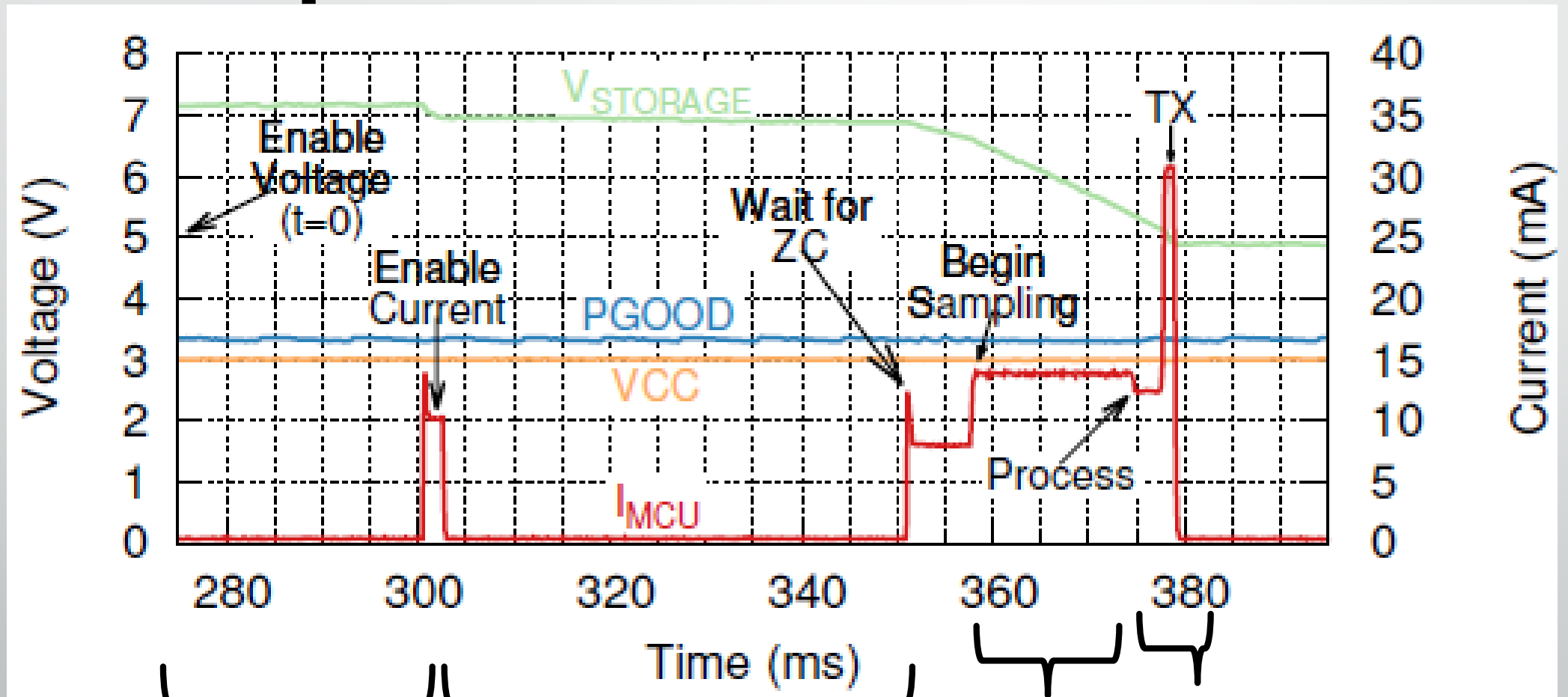
## D. Detailed Load Analysis

- Triumvi can send a raw current waveform if request



# Implementation:

## Set up of the Triumivi meter

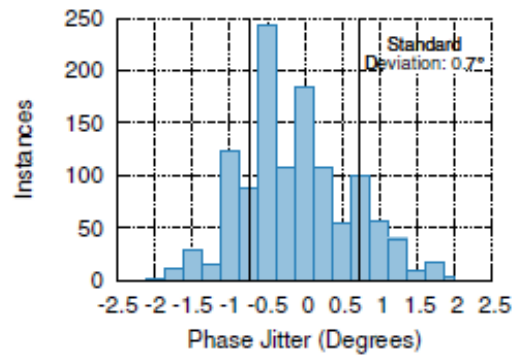


Set up **Voltage**  
measurement circuit

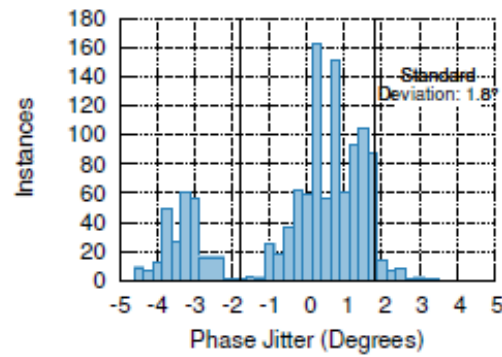
Set up **Current**  
measurement circuit

**Sampling** **Computes power,  
encrypts, and  
transmits(4.34ms)**

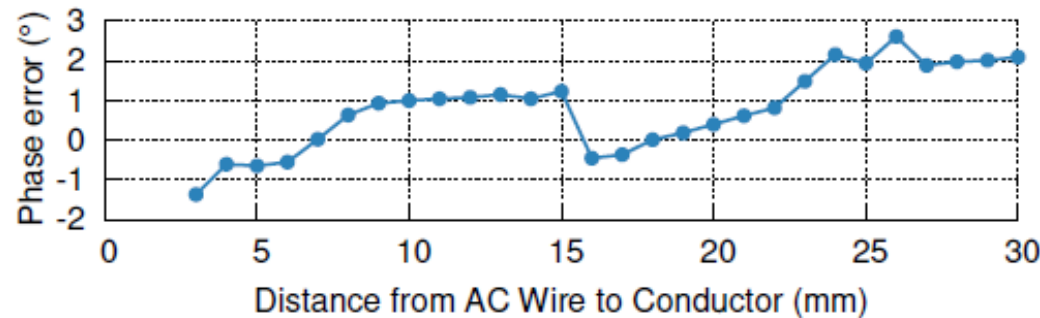
# Evaluation (1) : Voltage sensing



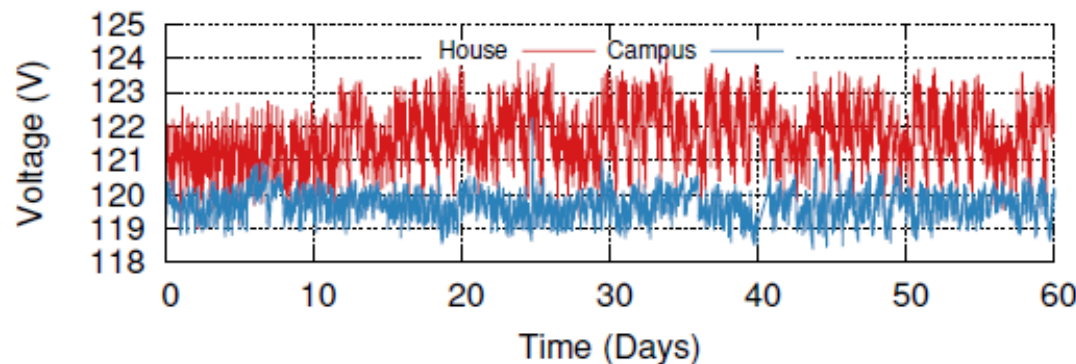
(a) Comparator Only



(b) Varied Wire Position



(c) Error from Distance



**Phase Error**  
**(1) Wire Fixed**  $< 0.7^\circ$   
**(2) Wire Free**  $< 1.8^\circ$

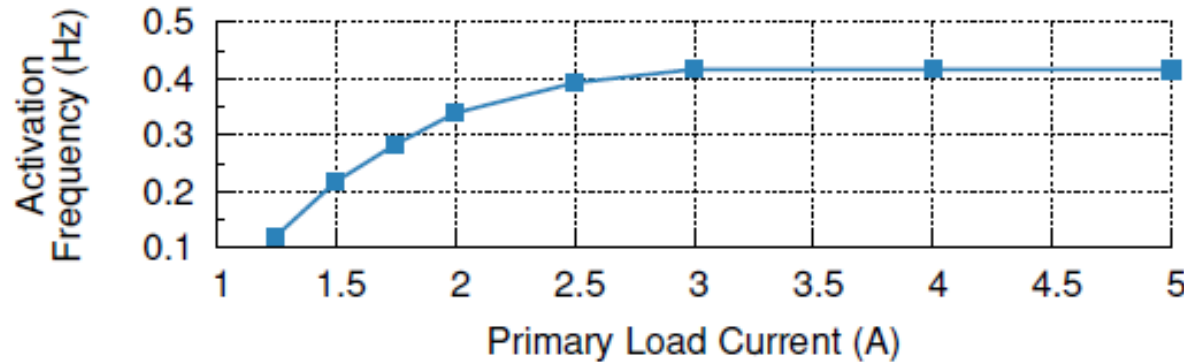
**The distance between wire and conductor is less than 18mm**

**Phase error**  $< 1.5^\circ$

**RMS voltage fluctuation**

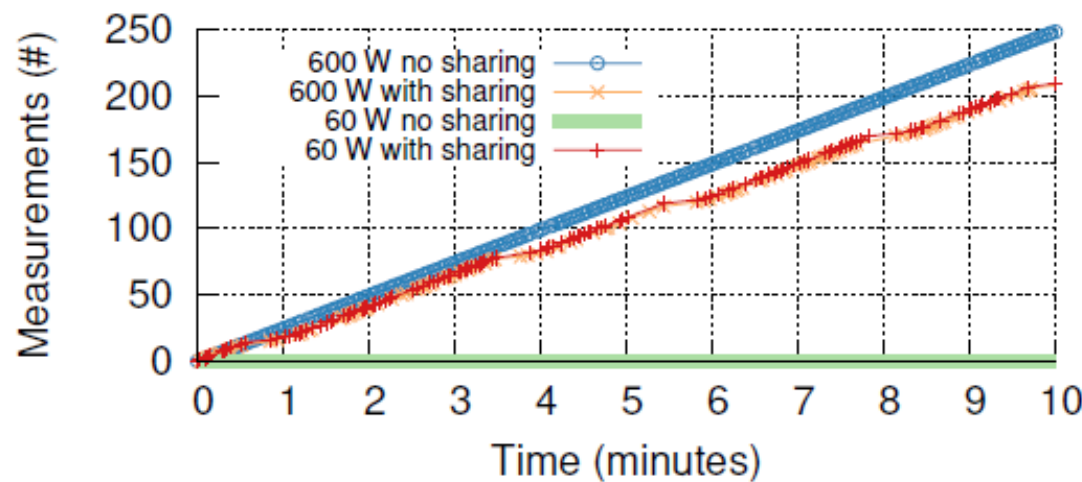
$< 2.8\%$

# Evaluation (2): Sample Rate and Measurement Range



**Requirement Load  
For enough Harvesting**

**>3A**

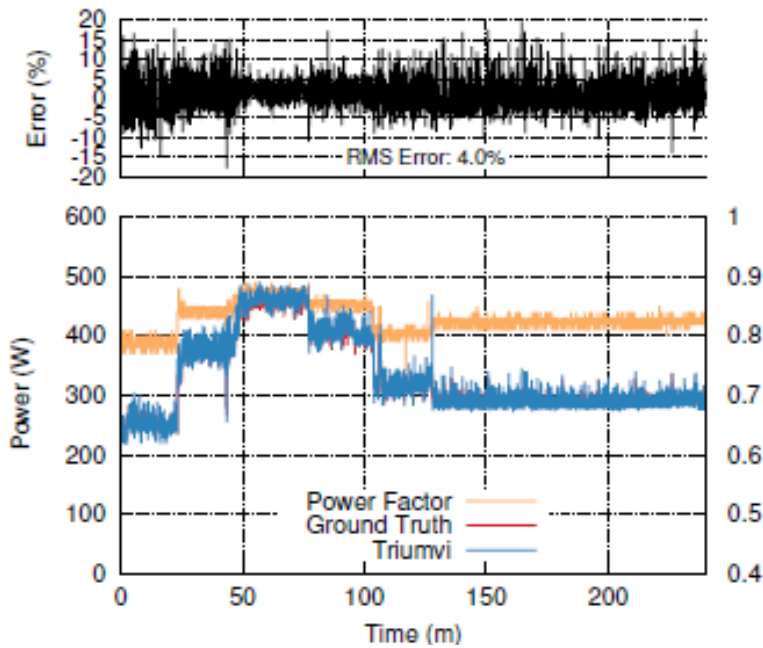


**Charge sharing is an effective  
way of the minimum load  
requirement**

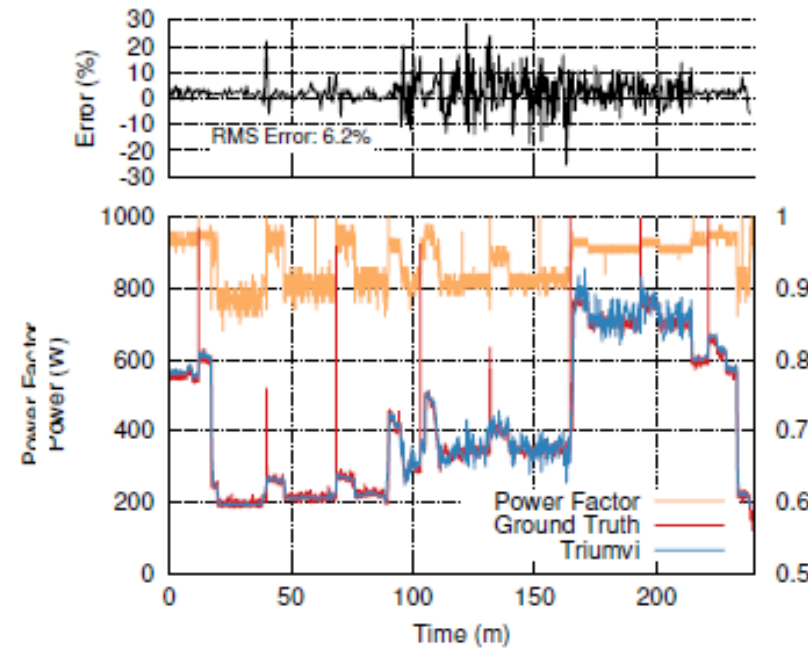
**Activation rate(Current level) is very low**



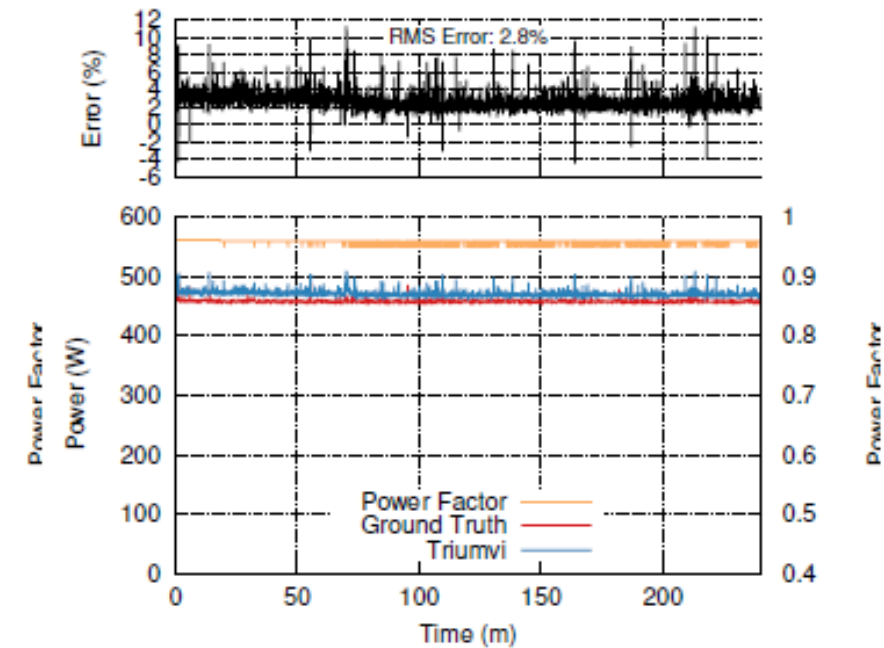
# Evaluation (3)-1 : Power Meter Accuracy Real World Loads



**Computers +  
Lab Equipment**



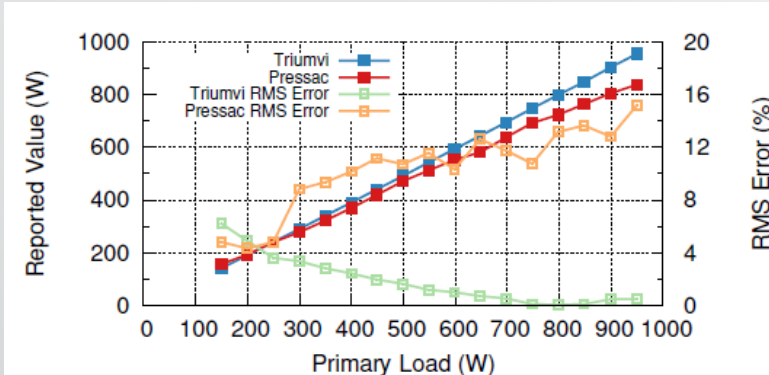
**Desktop + Audio +  
Lightning**



**Server Rack**

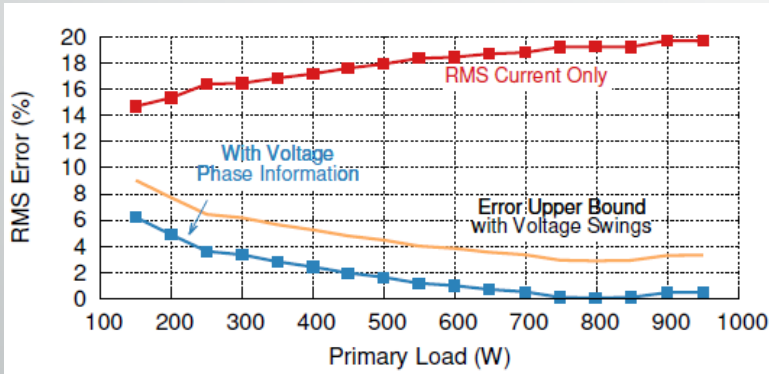
**The Average of RMS error is 4.3%**

# Evaluation (3)-2 : Power Meter Accuracy Comparison with Current-Only meter



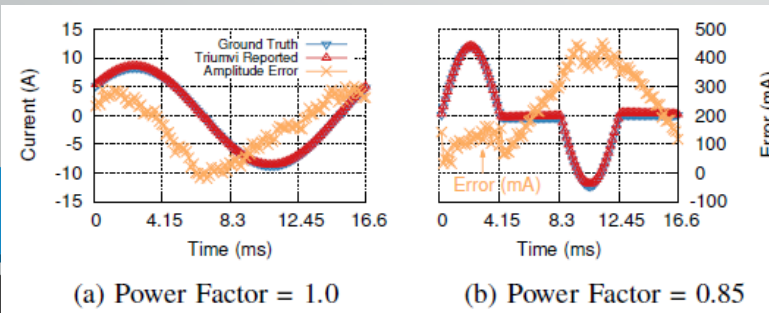
Compare with Pressac CT device, which measure Watt by only current

-Triumvi is much better



Compare between using voltage information or not for

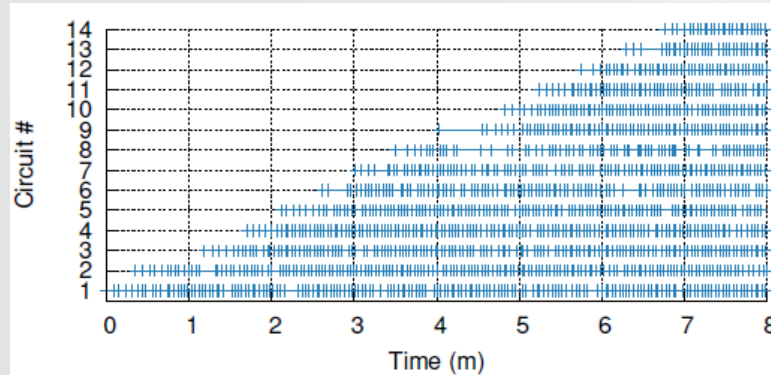
-Using voltage information is much better



Current Waveform Accuracy

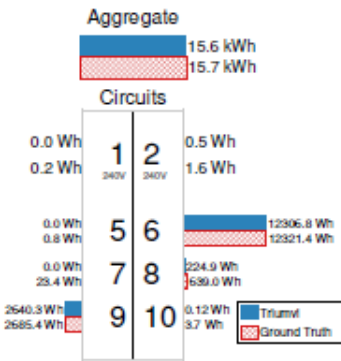
-less than 4% error

# Evaluation (4) : Deployment

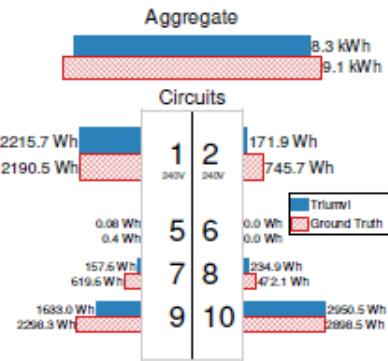


- 1) Install overhead
  - 1 circuit need approximately 30 second to install
  - **Enough short to deploy**

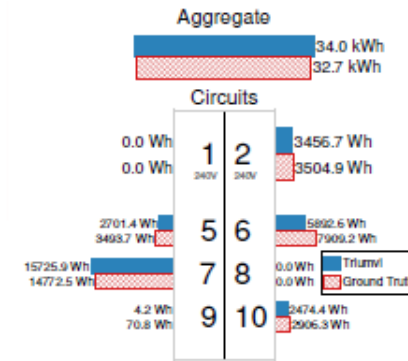
- 2) Error under the real environment
  - Error is only 3.7%
  - **It's enough for energy audit**



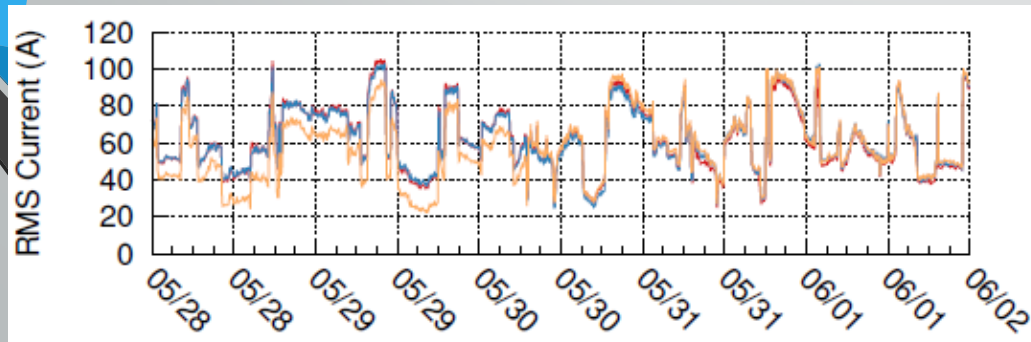
(a) Home 1



(b) Home 2



(c) Home 3

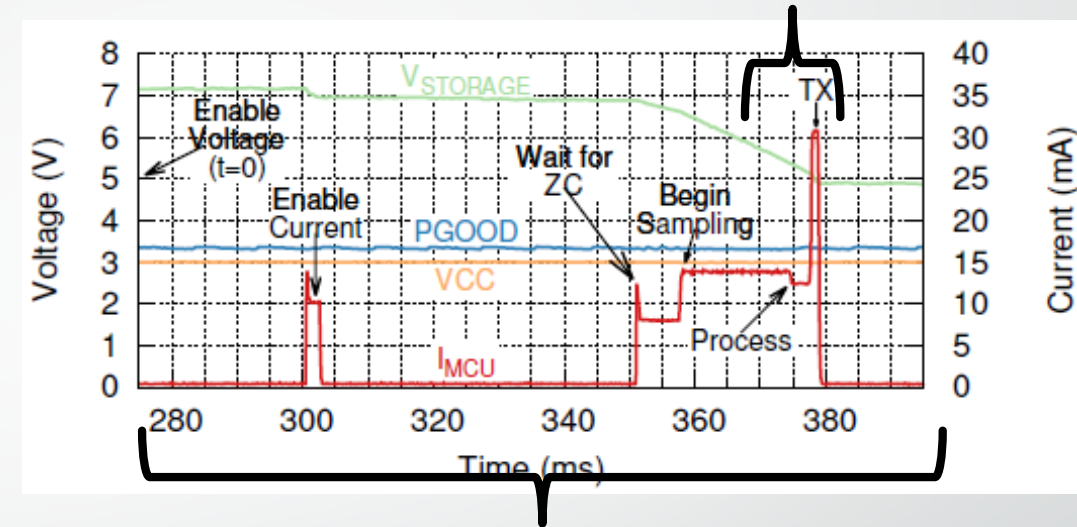


- 3) Industrial Use Case  
(Under large industrial environment)

# Evaluation (5) : System Properties

Time of process, encrypt, transmit is **4.34ms**

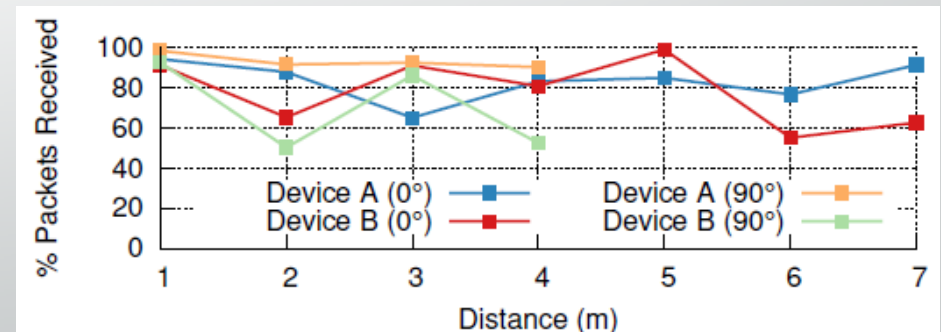
- 1) Encryption Energy consumption
  - AES operation needs 84  $\mu$ s, 10.2  $\mu$ j (0.6% energy consumed)



- 2) Radio Transmission
  - packets can be successfully received outside of the metal panel box

The total energy consumption is **8.4mj**

- 3) Meter Cost
  - Hardware cost of Triumvi is \$7.00





# Further Discussion

## - Limitation of the system and possible solutions

### 1) Voltage Measurement limitation

- Without runtime calibration, systems cannot get amplitude information
- Possible to identify the nominal voltage as typical AC voltages
- Another approach may be to provide hints from the nearby gateway.

### 2) Insufficient Harvesting Detection

- When harvesting energy is not enough, meter can not transmit a message.
- It could be solved the meter's priority.

### 3) How to do Energy Analytics

- Smart meter need to provide useful information to consumers.
- Have to connect the data to analytics systems and building management systems





# Conclusion of the paper

- Triumvi can measure circuit level current accurately enough under the concept below.
  - (1) Standalone
  - (2) Self-powered
  - (3) Non-contact
  - (4) Circuit-level True-power metering system





# Questions and Critiques

## Relationships between IoT devices and Edge computing

1. Why should gateway decouple the data from meters? Why meters can not send an ideal data for smartphone?
2. How scalable? How much meters can be connected with a gateway?
3. RTC might not necessary because the Triumvi node can send a time request packet to the gateway which immediately responds with the current time.
4. What happens if the network gateway is unavailable. How much onboard storage is there? Does data get lost or overwritten? The absence of the gateway, even temporarily, might really harm this device's usefulness.

## Real deployment issues

1. How much cost need to deploy the triumvir?
2. How are better or worse the evaluation result compared with other meters?