Plug Load Monitoring

Embedded Systems

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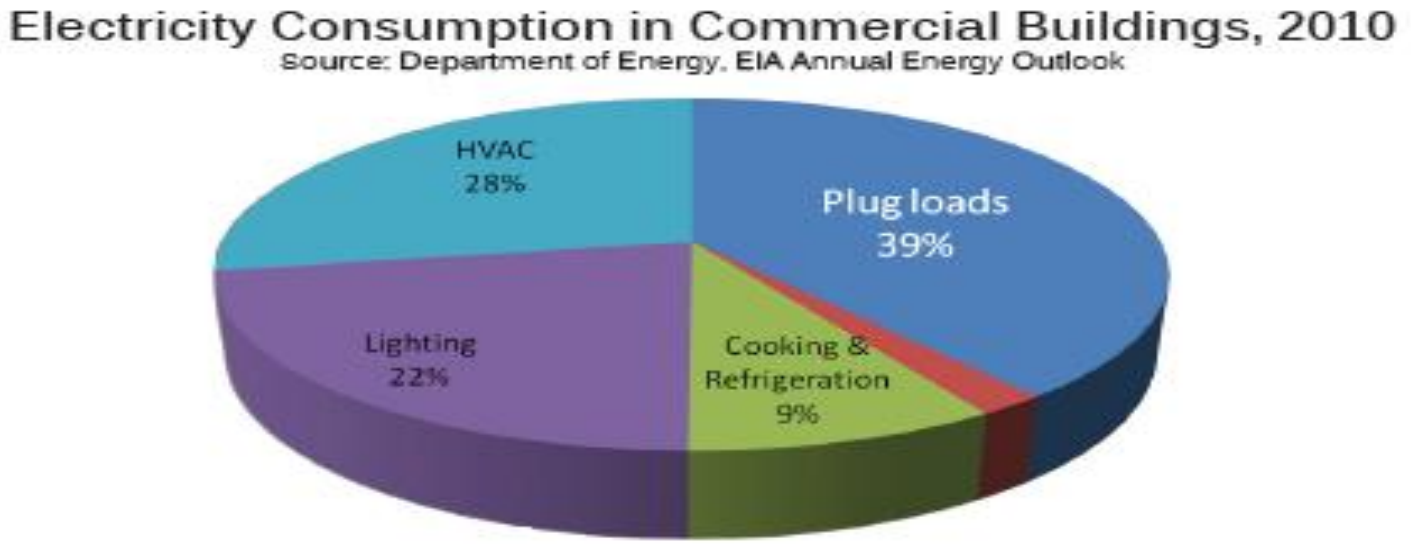
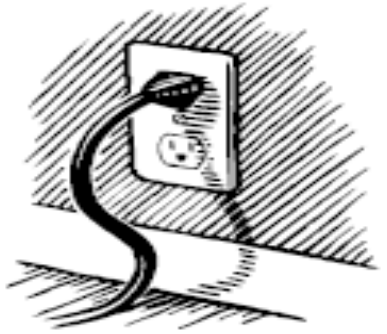
Motivation

- Detailed and accurate energy accounting is becoming an area of critical importance
- Plug loads account for a major share of total power consumption in both domestic and work environments
- Managing plug-loads can be a very effective tool for building managers (BM) to reduce energy usage during Demand Response events.

What is Plug Load

- A Plug load is the energy consumed by any electronic device that's plugged into a socket
- Plug loads account for nearly 40% of electricity used in offices and much of this energy is wasted.



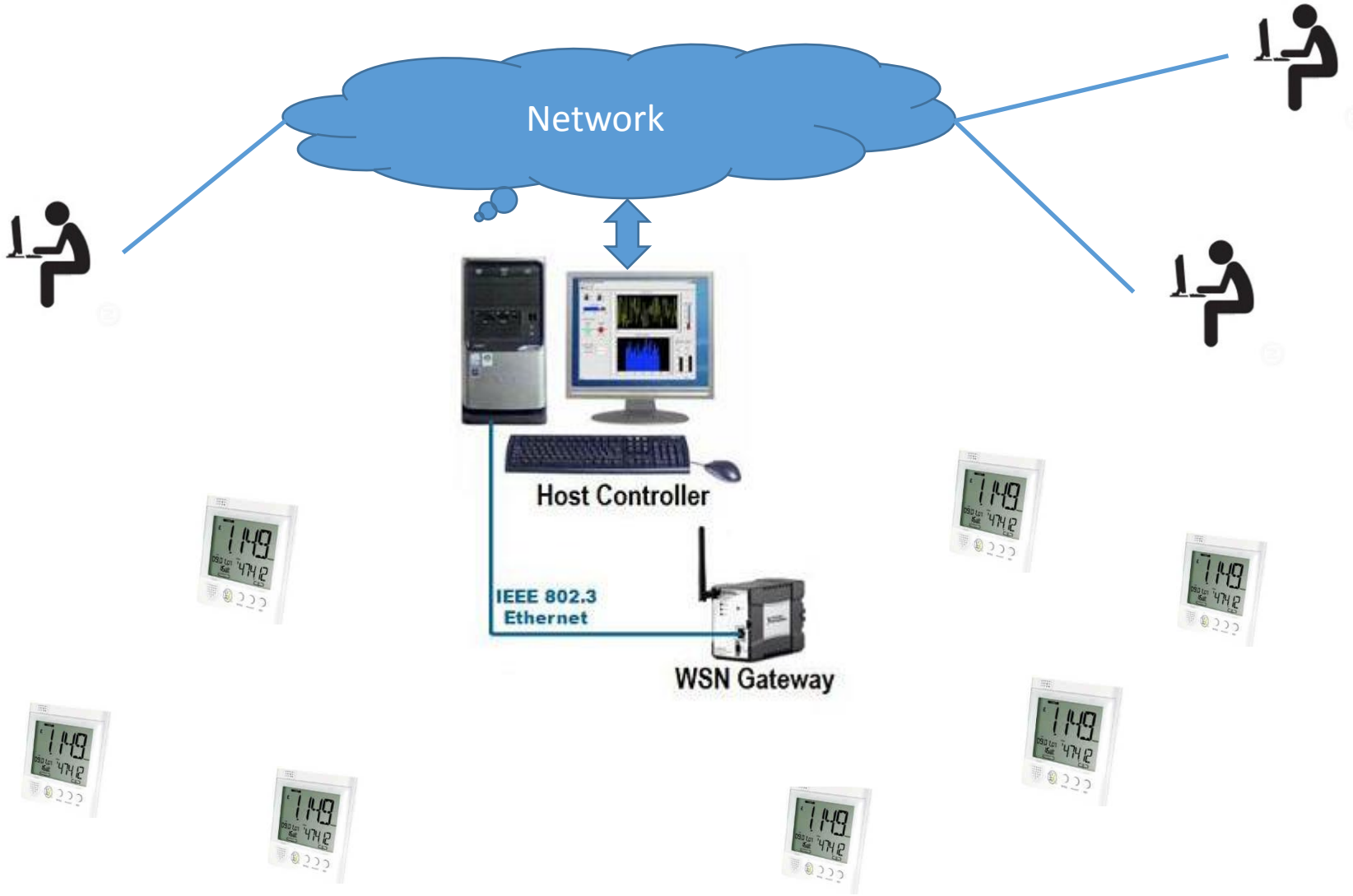


Challenges

- Plug loads cannot be easily categorized among it’s many types

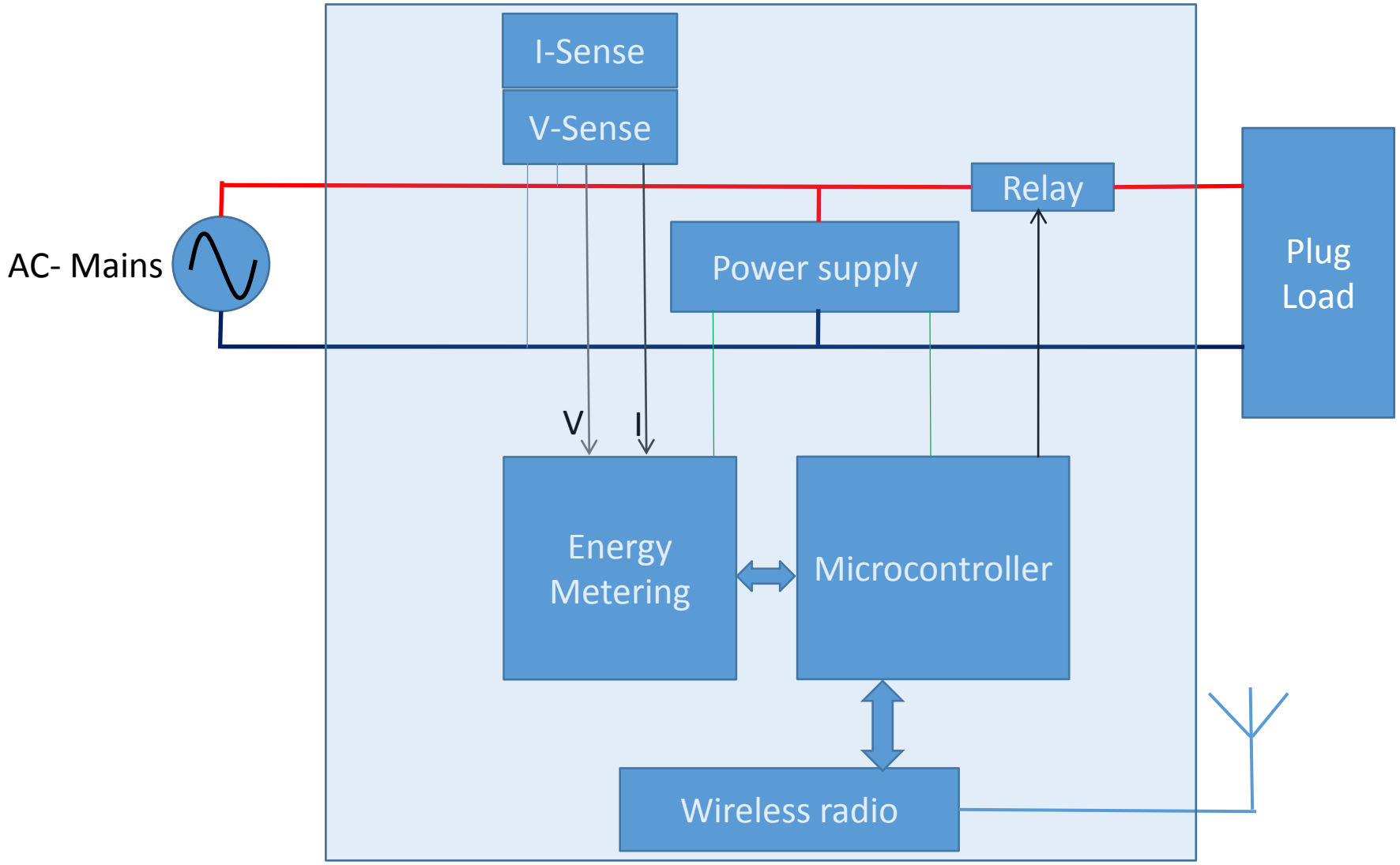
- Plug loads are often difficult to monitor because they are decentralized

Key components in a plug load monitoring system



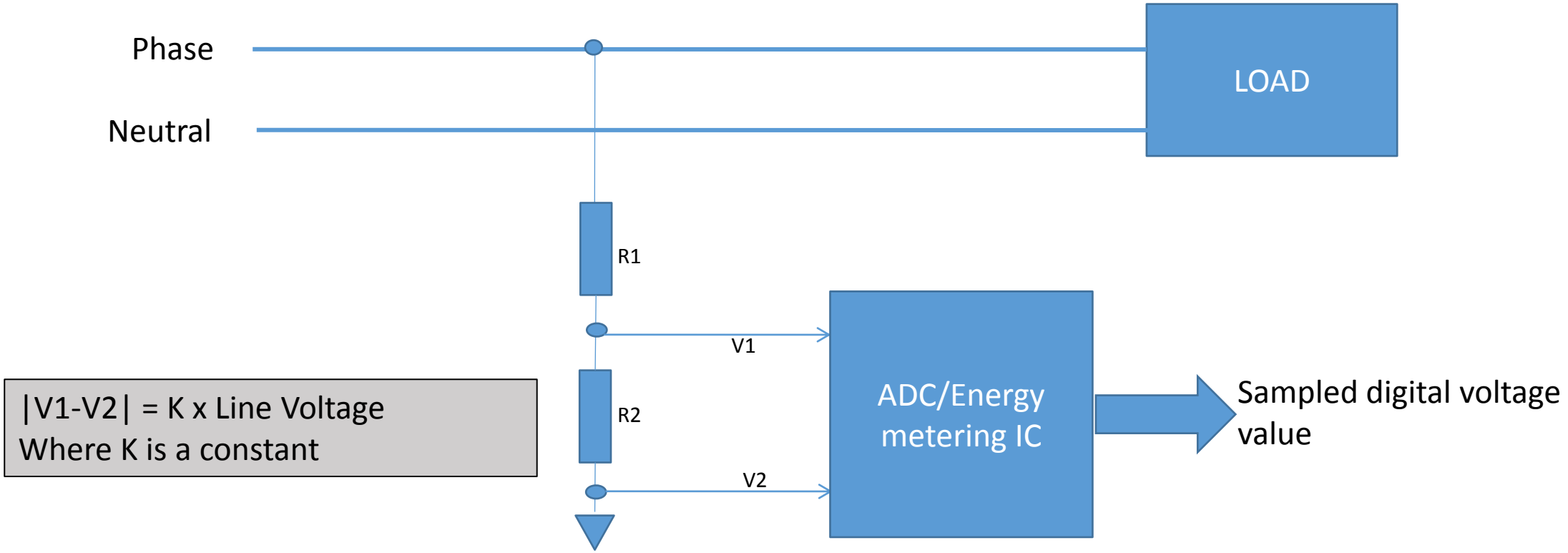
- **Smart Energy meters**
- **AdHoc WSN**
- **WSN gateway**
- **Host Controller**
- **End users/BMs**

Smart Energy Meter Design…



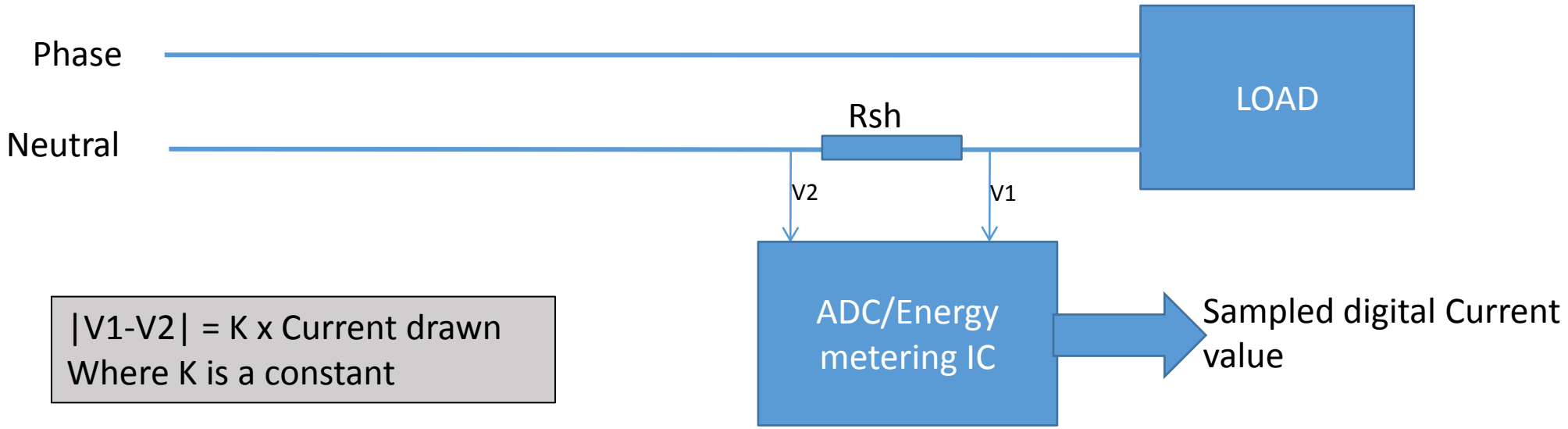
Voltage sense circuitry

- Voltage can be easily sensed by directly tapping into the phase wire with the help of a simple voltage divider circuit.



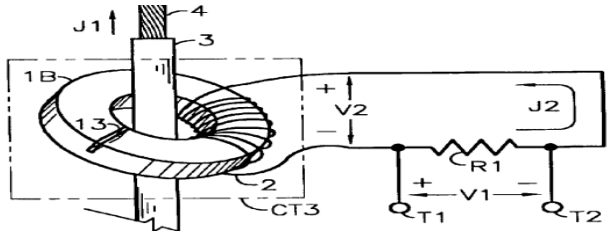
Current Sense Circuitry

- Using Shunt Resistance

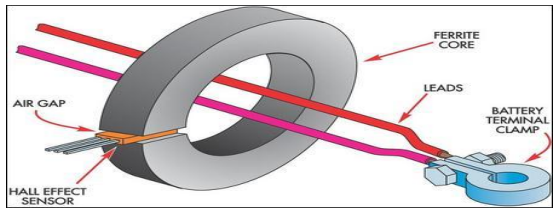


|V1-V2| = K x Current drawn
Where K is a constant

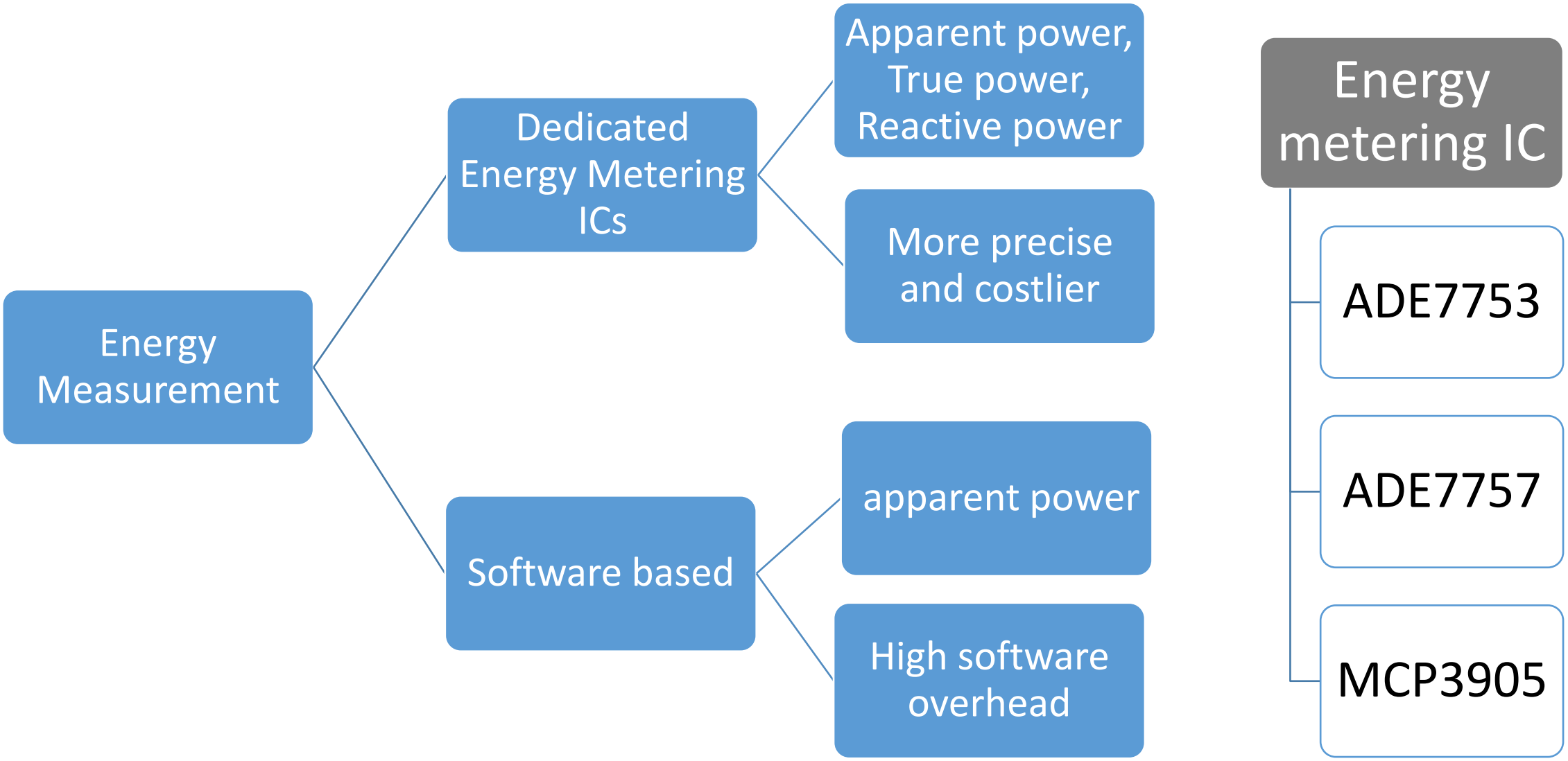
- Using Current transformer



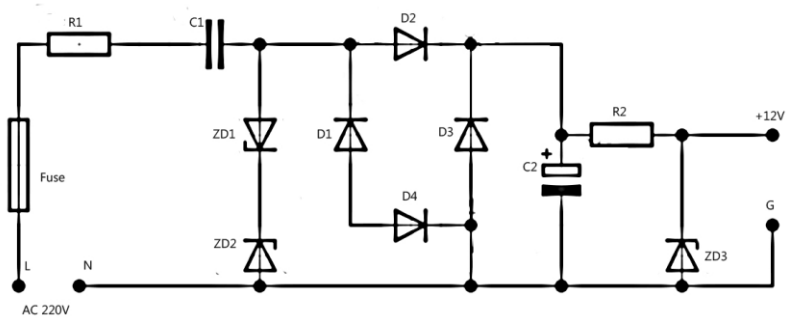
- Using Hall effect sensor



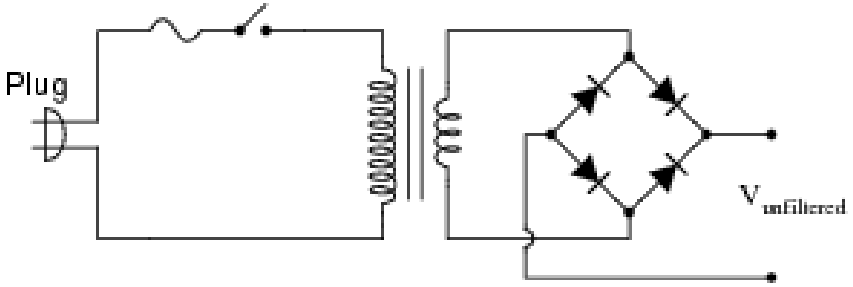
Energy measurement



Power supply, Actuation and Wireless Interface

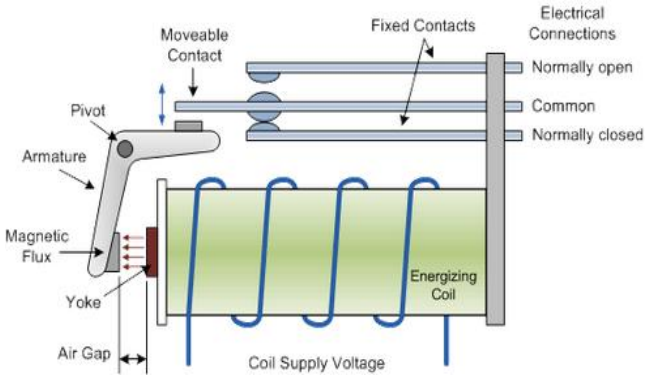


(a) Direct Rectification

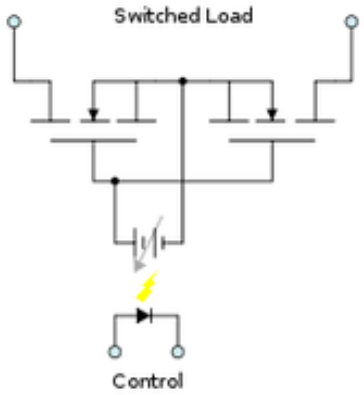


(b) Voltage step down followed by bridge rectifier

(e) ZigBee modules



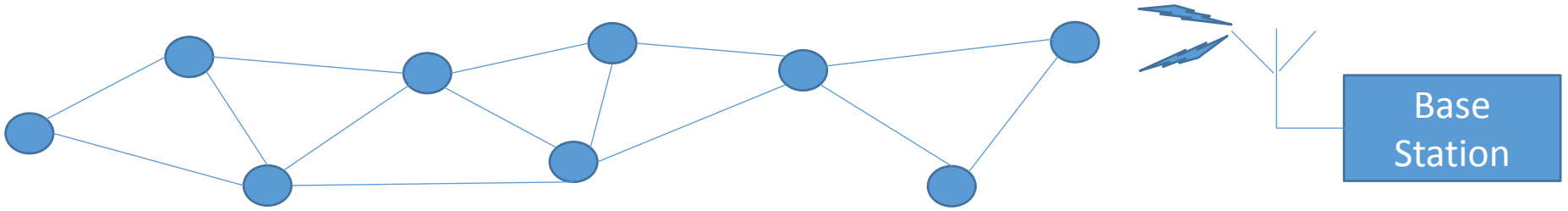
(c) Electromechanical Relay



(d) Solid state Relay

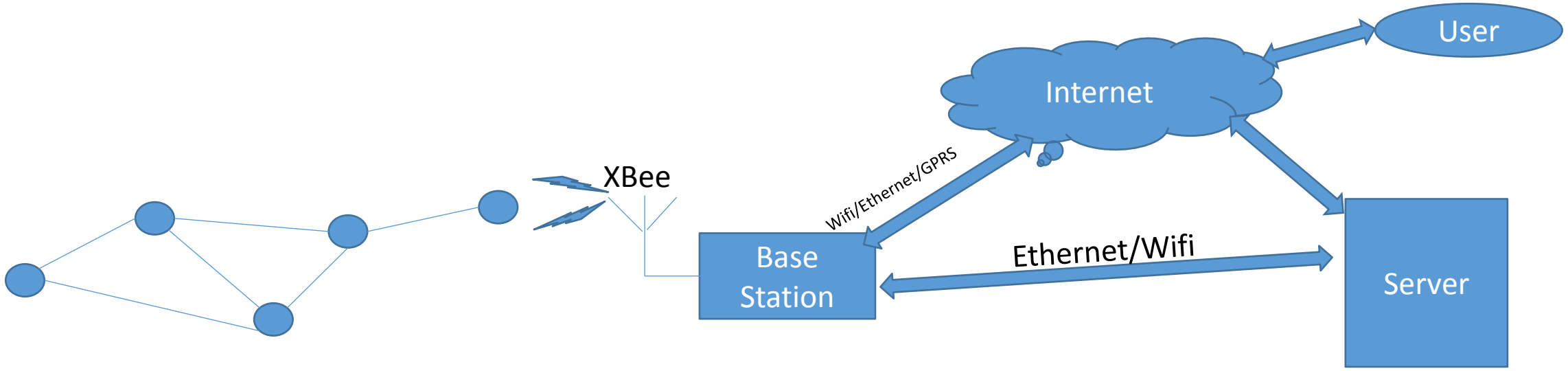
Wireless AdHoc network architecture

- Plug loads are spatially distributed in a de-centralized way
- Scalability and network reliability are key aspects
- Calls for a AdHoc network architecture that can handle such decentralized deployments and have sufficient redundancies to ensure against disruptions in network
- If area of deployment is large multihop routing is a good design choice



Base Stations

- Base Stations act as network co-ordinator for the rest of the node
- The base station is responsible for routing communication messages to and from the backend building management server
- Base stations are hence equipped with multiple communication interfaces.



Load Monitoring Server

- The base stations will forward live data feeds from SEMs to a Load Monitoring Server
- The server maintains a database of past consumption history of each node
- Simple applications daemons running in the server may respond to critical demand-response events by sending proper actuation commands to the SEMs
- Servers should also authenticate users, and give them access to SEMs which are registered to them for monitoring and controlling purposes

End user interface

- The user interface design should be intuitive and easy
- User accessibility is a major concern and hence user interface is generally implemented as a web interface
- Using the user interface, users should get seamless and secure access to their registered SEMs and view their live status besides accessing the energy consumption history and remote control their SEMs.

Case Study I

Managing Plug-Loads for Demand Response within Buildings

- University of California, San Diego

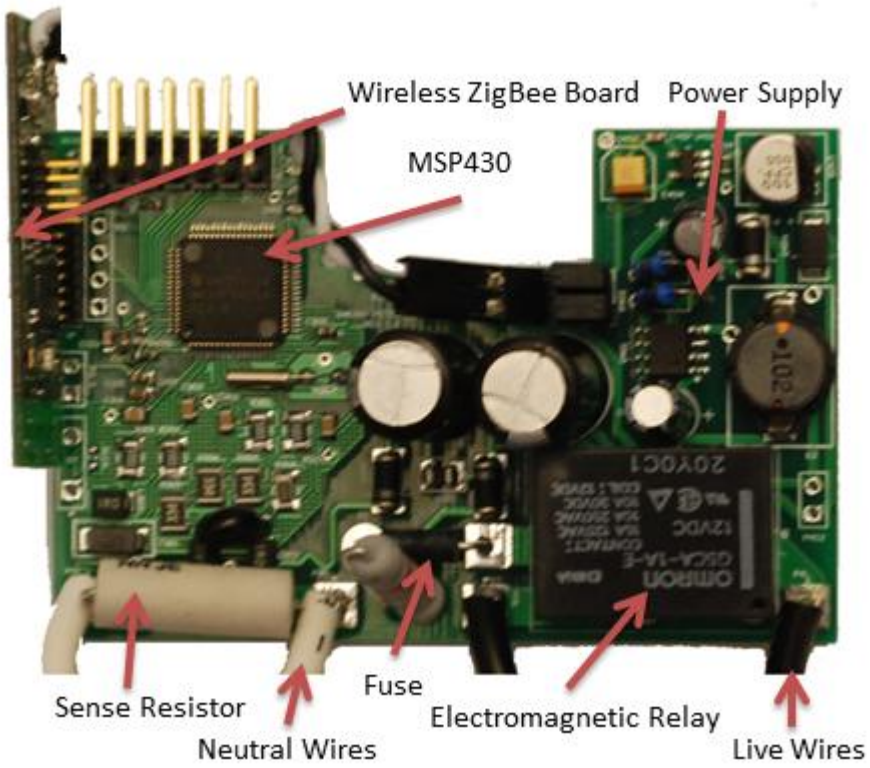
The proposed system consists of these following

- A Wireless smart energy meter with actuation capabilities
- ZigBee – based wireless network infrastructure
- Demand Response Server

Smart Energy Meter

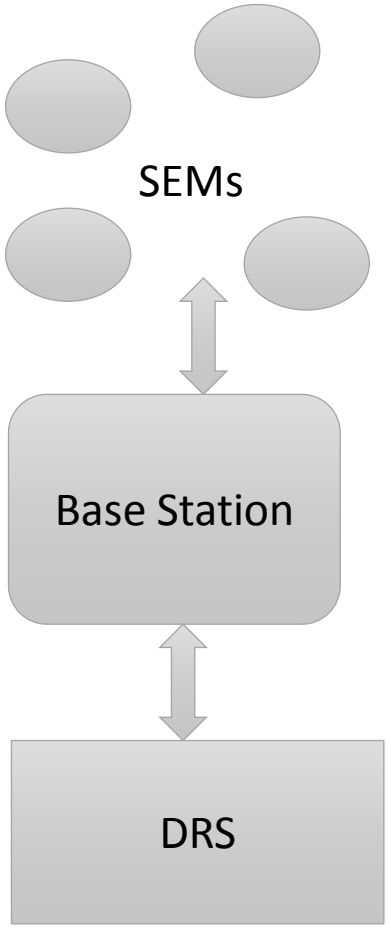
SEM node comprises five components

- Voltage and current circuitry
- Energy measurement unit
- Power supply
- Wireless Radio
- Relay for switching loads on or off



Wireless Data Collection Network

- The network architecture is tiered with SEMs sending data to base stations which relay the information to the DRS.
- SEMs equipped with ZigBee Interface
- Base Stations is equipped with both ZigBee and Ethernet interface
- A number of security protocols like AES, trust centre authentication and key establishment ensure messages and nodes are authenticated



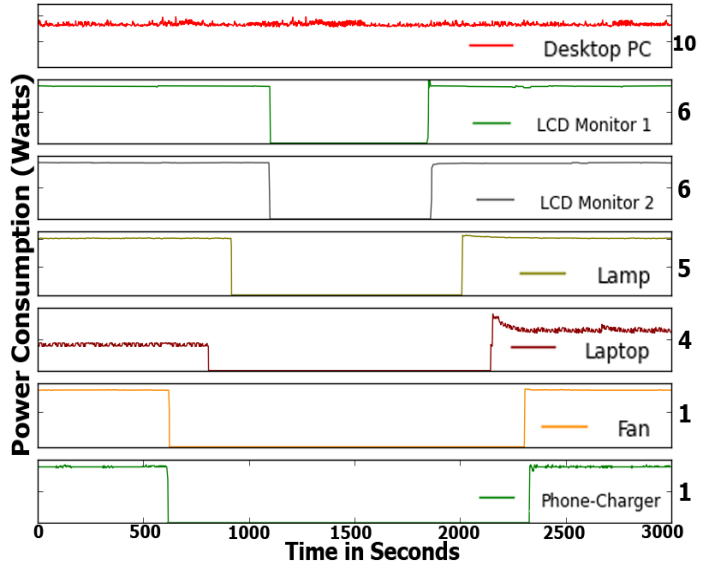
Demand Response Server

- The DRS collects the energy data from the base stations and stores it in a database. The database records energy measurements as well as metadata about all SEMs.
- DRS has a web-based interface for both end-users
  - My dashboard(users can add their energy meter to the site and view them)
  - Building management(Administrative interface allows to view all the connected meters)

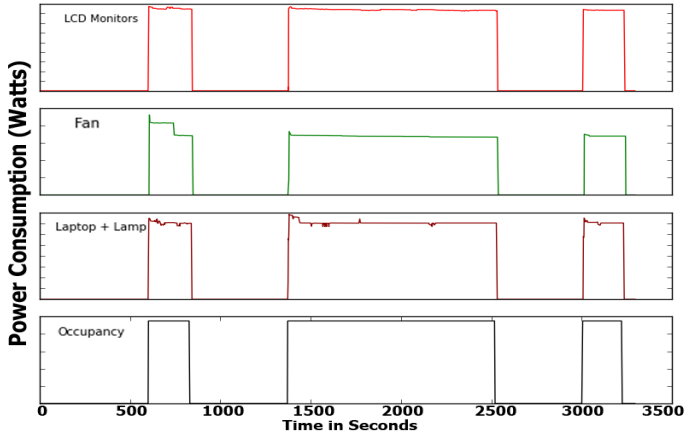
Usage Models

There are several methods that BMs can use to enact DR events.

- Direct actuation
  - The device parameters allow BMs to send a single command to all the SEMs for actuation based on device type or priority levels etc
  - Turning off a device inconveniences users who might be present in the DR event
  - Turning off all the devices might cause an unwanted spike, especially if there are many devices
- Using Occupancy Information
  - incorporating information from occupancy sensors to augment our demand response load shedding system.



Priority level actuation

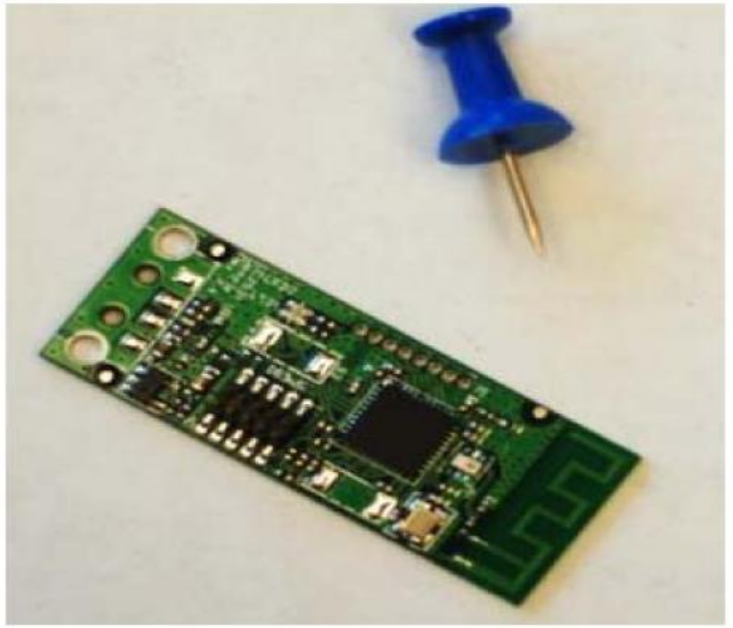


Results of using occupancy information along with priority levels

Snaps of the working model

(a) Plug based meter

(b) Base station and energy meters.



(c) The CC2530-based wireless module

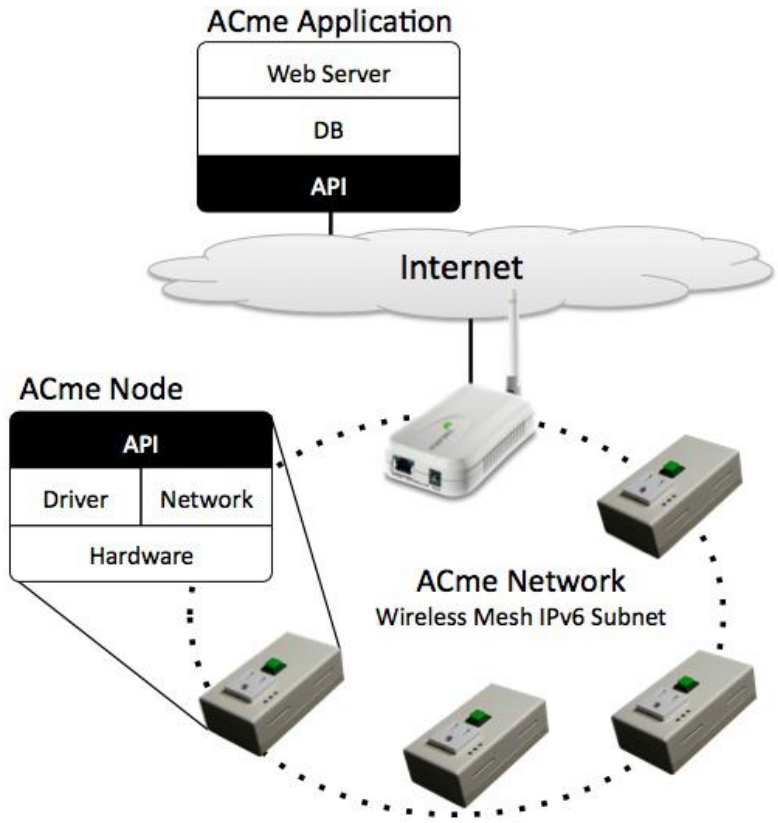
Case Study II

Design and Implementation of a High-Fidelity AC Metering Network

- University of California, Berkeley

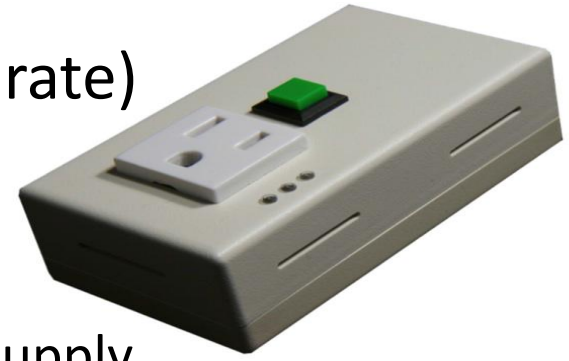
The proposed system consists of these following

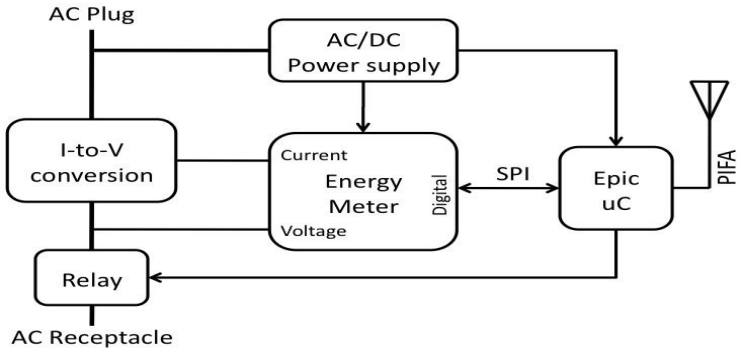
- Acme nodes with dedicated energy metering IC
- Network with IPv6 stack on every node and edge router
- Acme Application



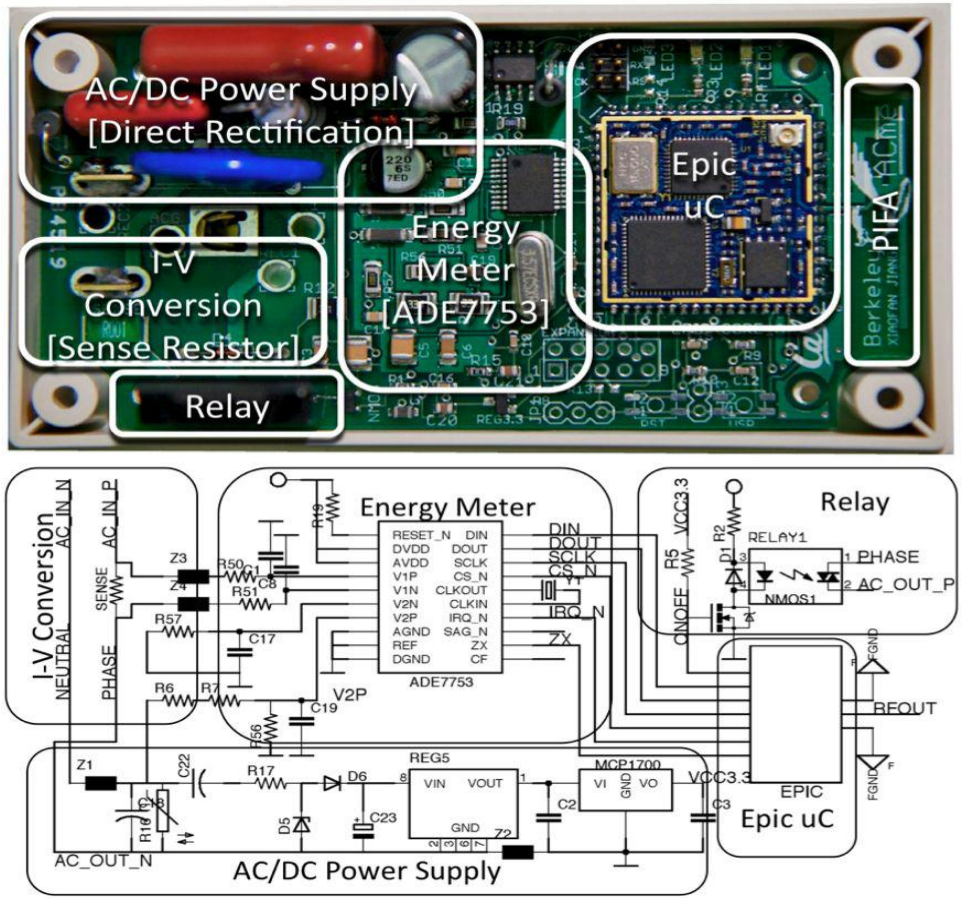
ACme NODE

- An integrated, small form-factor device with energy metering, control, and networking in one package
- The ACme node supports a set of sampling and control operations such as read_energy(), switch(state), and report(ip_addr, rate)
- An Acme node consists of following components
  - current-to-voltage conversion, energy metering, AC/DC power supply, microcontroller with radio, and solid state AC relay

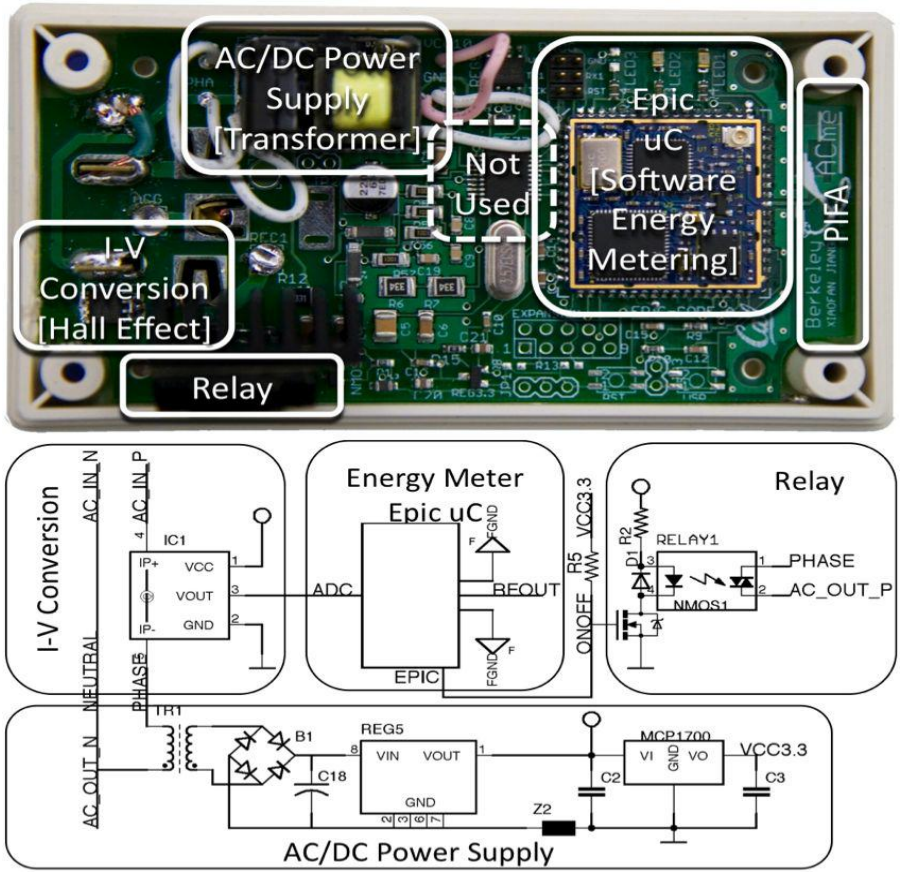




Two different ACme node hardwares



(a) ACme-A uses shunt resistor as I-V conversion, direct rectication as AC/DC power supply, and ADE7753 as the energy metering IC.



(b) ACme-B uses an in-line Hall Effect sensor as I-V conversion, a step-down transformer followed by a bridge rectifier as the AC/DC power supply, and performs energy calculation in software using the microcontroller.

ACme NETWORK

- Ad-hoc IEEE 802.15.4 network layer that provides IP connectivity
- The network provides connectivity between the sensor nodes and other networks using a dual-interface router.

Routing:

provide reliable, multi-hop communication within the subnet of ACme nodes.

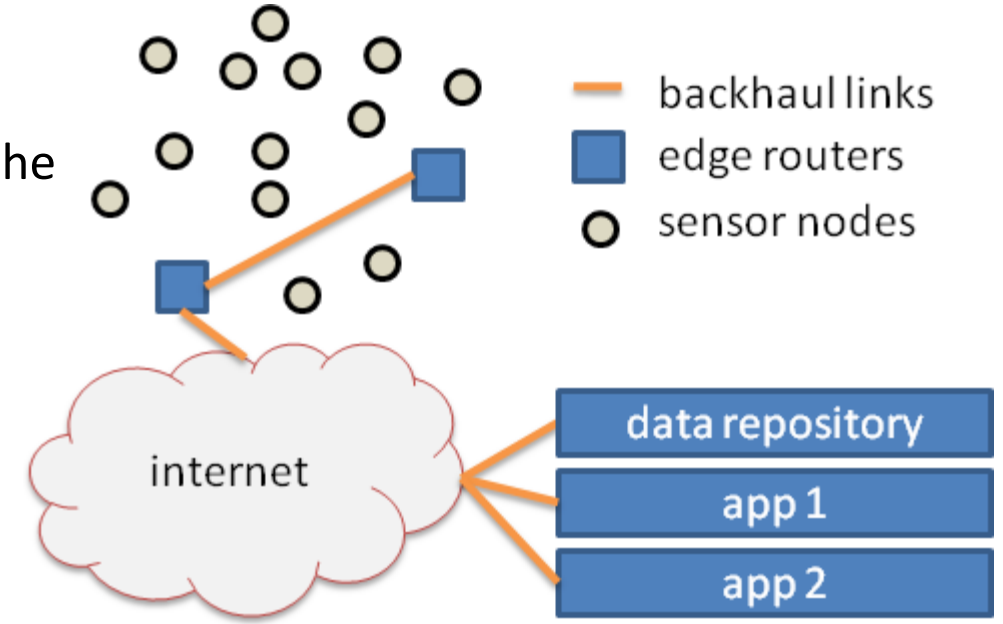
Edge Router:

provide good network coverage and reliability.

The edge routers also act as an Internet router for the subnet assigned to the ACme network.

Transport:

blip on the ACme nodes provides TCP and UDP as available transport protocols.



Sensor nodes are connected to the Internet through IP routers. Acme nodes are the sensors and edge routers are Linux-class devices.

ACme APPLICATION TIER

- The ACme application consists of a web front-end, a database back-end, and a daemon process.
- ACME Nodes are typically configured to report energy readings once per minute via UDP to simple Python application daemon running on a server.
- The Daemon parses the UDP packets and inserts relevant data in database
- Based on this data Usage profiles are monitored on cloud.

Comparative Study

SheevaPlug(UC,San Diego)

VS

ACme(UC,Berkeley)

Comparative Study contd

Sheeva Plug

Design objective

- Demand Response Severs for BM

Application Tier

- Command Based Broadcasting

Smart Meter Design

- Only Software based energy metering

Wireless Communication Protocol

- ZigBee based Adhoc Network

ACme

Design objective

- Explore IPv6 implementation aspects

Application Tier

- RPC features over the Network

Smart Meter Design

- Both software and hardware methods of Energy Metering

Wireless Communication Protocol

- Used an open source IPv6 network stack(Blip) over ZigBee Protocol

Conclusion

- There are multiple ways to reduce plug loads, ranging from purchase of energy efficient equipment to raising employee awareness about turning off devices when not in use.
- Managing plug loads is a quick, cost-effective way to save on energy costs and to boost your bottom line.

Queries and Suggestions