Wireless Sensor Networks in the Smart Power Grid

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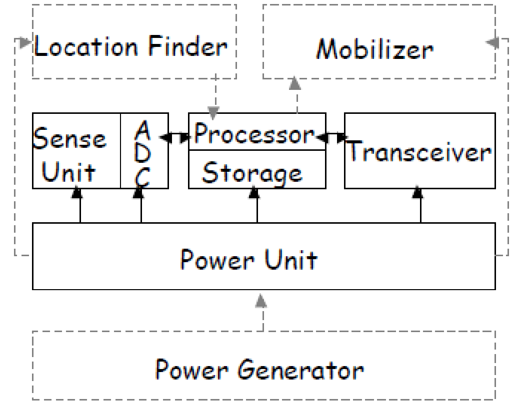
IEEE Ottawa Section Seminar, November 22, 2010

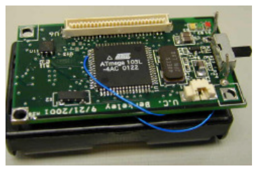
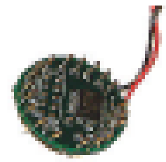
Outline

- Wireless Sensor Networks
- Smart Grid and WSNs in the Smart Grid
- Residential Energy Management
  - TOU-Aware Residential Energy Management
- Prediction Based PHEV Charging for Real-Time Pricing
- Conclusions and Future Perspectives

Sensors



- Sensor nodes

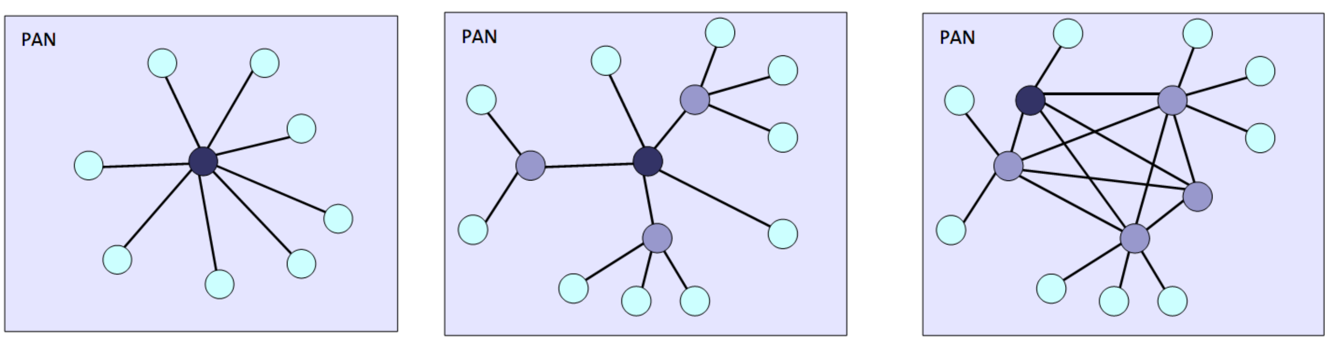





- Sensors: accelerometer, temperature sensor, light sensor, camera, ...
- Cost: ~ $100

- SunSpot Sensor:
  - Processor: 180MHz
  - RAM: 512KB
  - Flash memory: 4MB
  - CMOS camera can be mounted
- Mica Mote:
  - Processor: 4 MHz
  - RAM: 4 KB
  - Flash memory: 512 KB

Wireless Sensor Network

- Communication via Zigbee protocol stack
  - IEEE 802.15.4 standard
- Low power
  - Duty cycles
- Low data rate
  - Data rates of 250 kbps, 100kbps, 40 kbps and 20 kbps
- Zigbee utilizes three ISM bands
  - 2.4GHz ISM band worldwide , 915MHz band in North America, 868MHz band in Europe
- Zigbee uses 16-bit and 64-bit addressing modes
  - 6lowpan for IP integration
- Star, cluster-tree or mesh topologies



Electrical Power Grid

What's wrong?

- Growing demand
- Fossil fuel reserves are diminishing
- Costs are increasing
- Renewable energy resources are not widely used
- Demand management is weak
- Aging infrastructure
- Reliability
  - Major blackouts

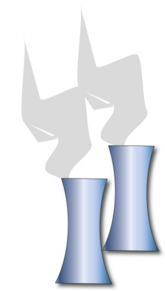
Smart Power Grid

What's new?

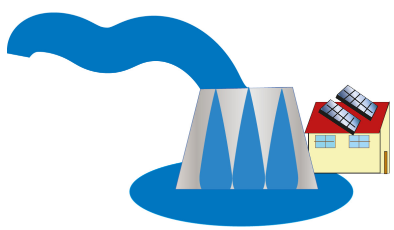
The electrical power grid meets ICT

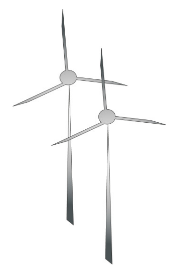
Smart Power Grid - Generation

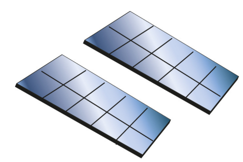
– Traditional thermal power plants: Coal, nuclear, natural gas



– Renewable generation: hydro, solar, wind, ocean thermal energy conversion, …





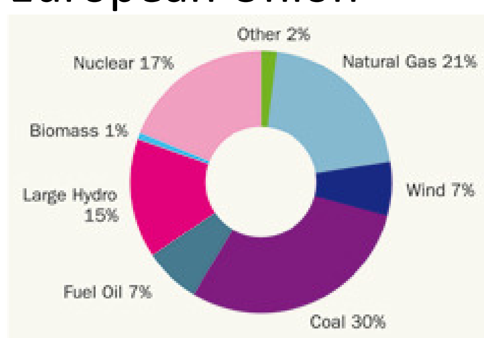


– Energy Generation Mix

Ontario

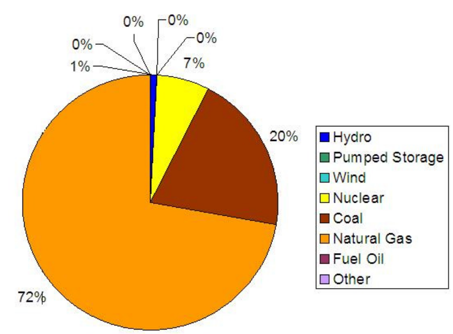
Sources: IESO of Ontario

European Union



EWEA and Platts (2008)

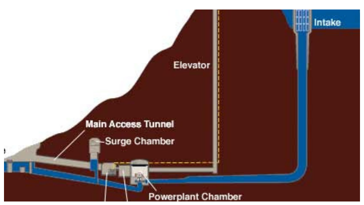
US- ERCOT (Houston)

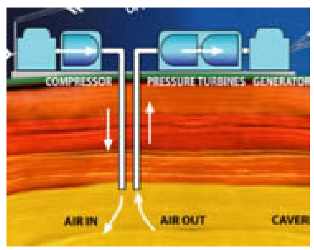


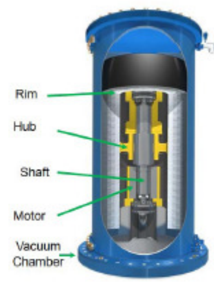
Exelon

Smart Power Grid - Storage

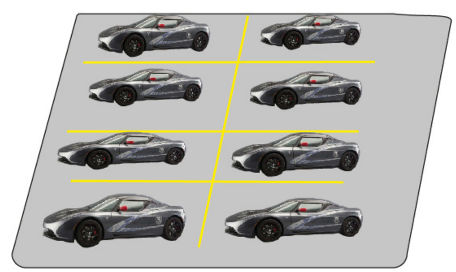
- Energy storage
  - Pumped hydro, compressed air, flywheel and sodium-sulfur (Na_2S) battery







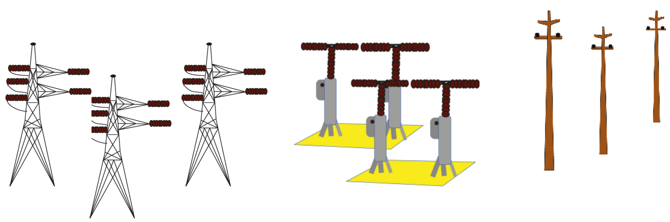
  - Li-Ion batteries and PHEVs as smart grid storage

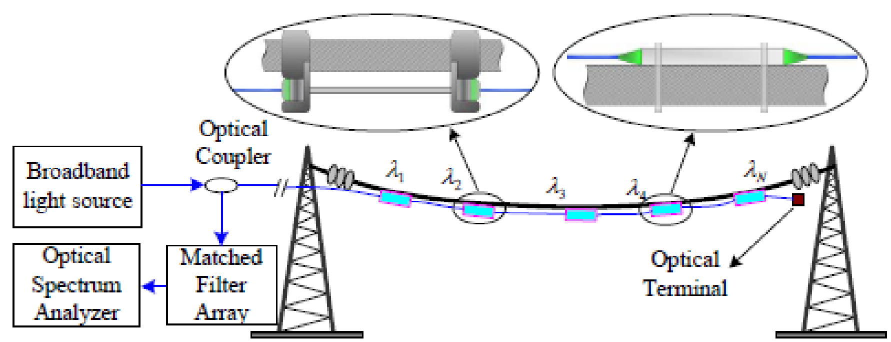


~ 0.5kWh/kg 5-50kWh ~MWh

Smart Power Grid – Transmission & Distribution

- Reliable and self-healing
  - Real-time asset monitoring



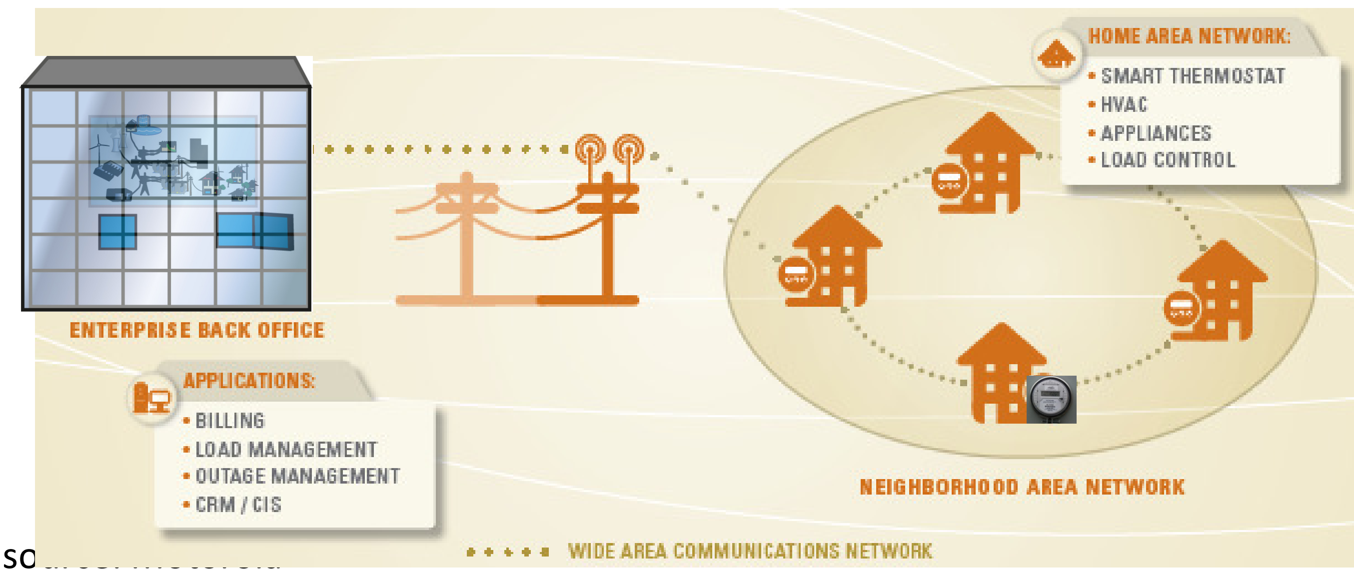


- Security
  - Resilient to physical and cyber attacks

M. Erol-Kantarci, H. T. Mouftah, “Wireless multimedia sensor and actor networks for the next generation power grid,” to appear in Elsevier Ad Hoc Networks journal, 2011.
Q. Huang, C. Zhang, Q. Liu; Y. Ning, Y. Cao, “New Type of Fiber Optic Sensor Network for Smart Grid Interface of Transmission System,” Power and Energy Society General Meeting, 2010.

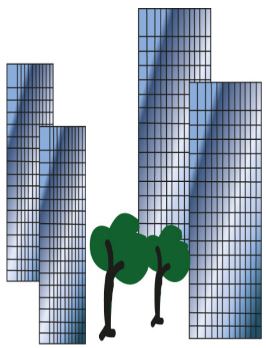
Smart Power Grid - AMI

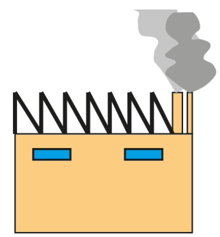
- Enable two-way flow of information and electricity
  - Smart meters
  - Advanced Metering Infrastructure (AMI)



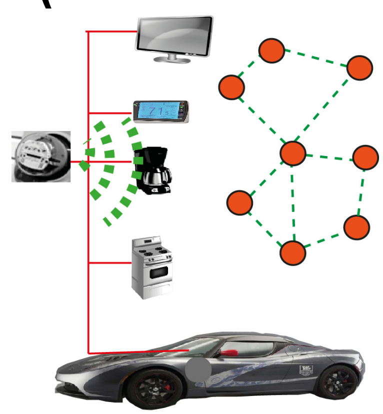
Smart Power Grid - Demand

- Demand response and energy management
  - Commercial and industrial consumers





  - Residential consumers (Smart demand)



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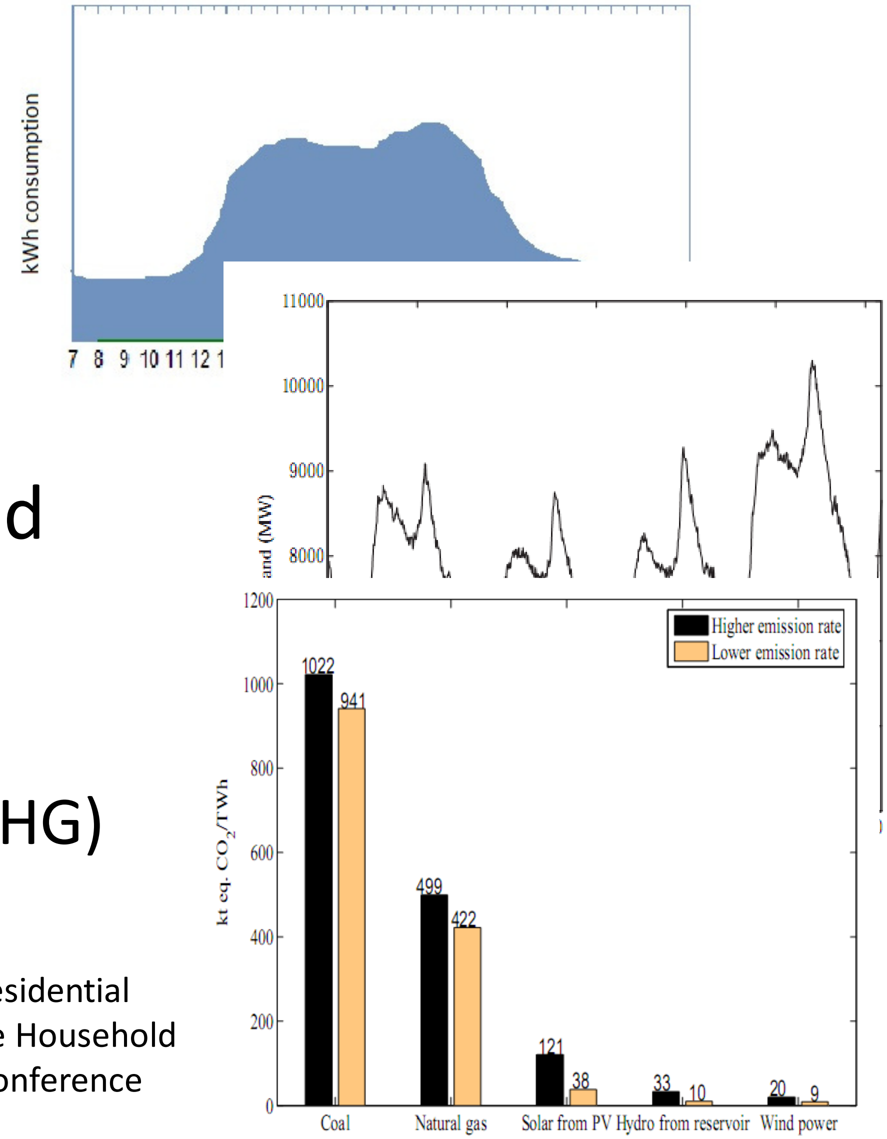
Motivation - Peak Demand

- Demand profile
  - Appliances, lights, TV, thermostat, PHEV ...

- Load on the electricity grid

- Peaker Plants
  - More Green House Gas (GHG) emissions

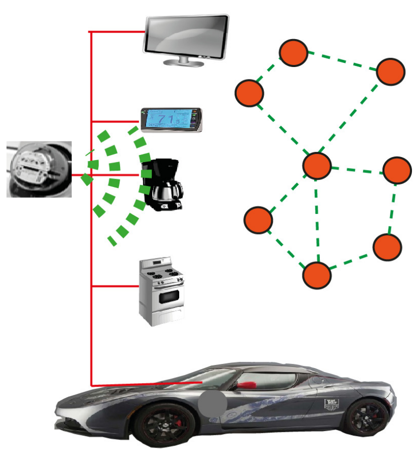


M. Erol-Kantarci, H. T. Mouftah, "The Impact of Smart Grid Residential Energy Management Schemes on the Carbon Footprint of the Household Electricity Consumption,'' IEEE Electrical Power and Energy Conference (EPEC), Halifax, NS, Canada, August 25-27, 2010.

Motivation - TOU

- Reduce electricity consumption of the appliances during peak hours
  - Shift flexible demands to off-peak hours
- Reduce the CO_2 emissions of the residential users
- Time of Use (TOU) tariff
  - Electricity is more expensive during peak hours

Solution: : Use TOU rates and WSNs to coordinate consumption and use of local resources



TOU-aware Residential Energy Management

- Consumer turns on an appliance
  - The appliance generates a START-REQ packet and sends it to Energy Management Unit (EMU)

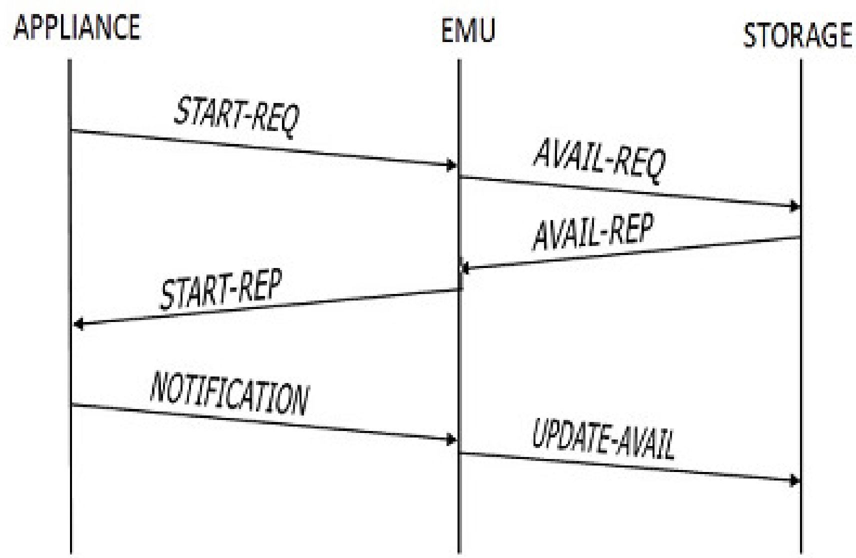
Octets: 4	1	4	1
Appliance ID	Seq. No	Start Time	Duration

- EMU computes a ‘recommended start-time’ according to:
  - TOU rates
- EMU sends a START-REP to the appliance with the waiting time
- Consumer:
  - Turn on the appliance immediately
  - Turn on the appliance at the suggested time
- Appliance sends consumer decisions in the NOTIFICATION packet
- WSN relays the packets of the application

M. Erol-Kantarci, H. T. Mouftah, “TOU-Aware Energy Management and Wireless Sensor Networks for Reducing Peak Load in Smart Grids,” Green Wireless Communications and Networks Workshop (GreeNet) in IEEE VTC2010-Fall, Ottawa, ON, Canada, September 6-9, 2010.

TOU-aware and micro Feed In Tariff (microFIT) Residential Energy Management

- MicroFIT compatible home:
  - Local renewable energy resource
    - PV, wind tribune, etc.
  - Energy storage unit
    - Fuel-cell, PHEVs, etc.
- EMU computes a ‘recommended start-time’ according to:
  - TOU
  - Availability of local energy sources

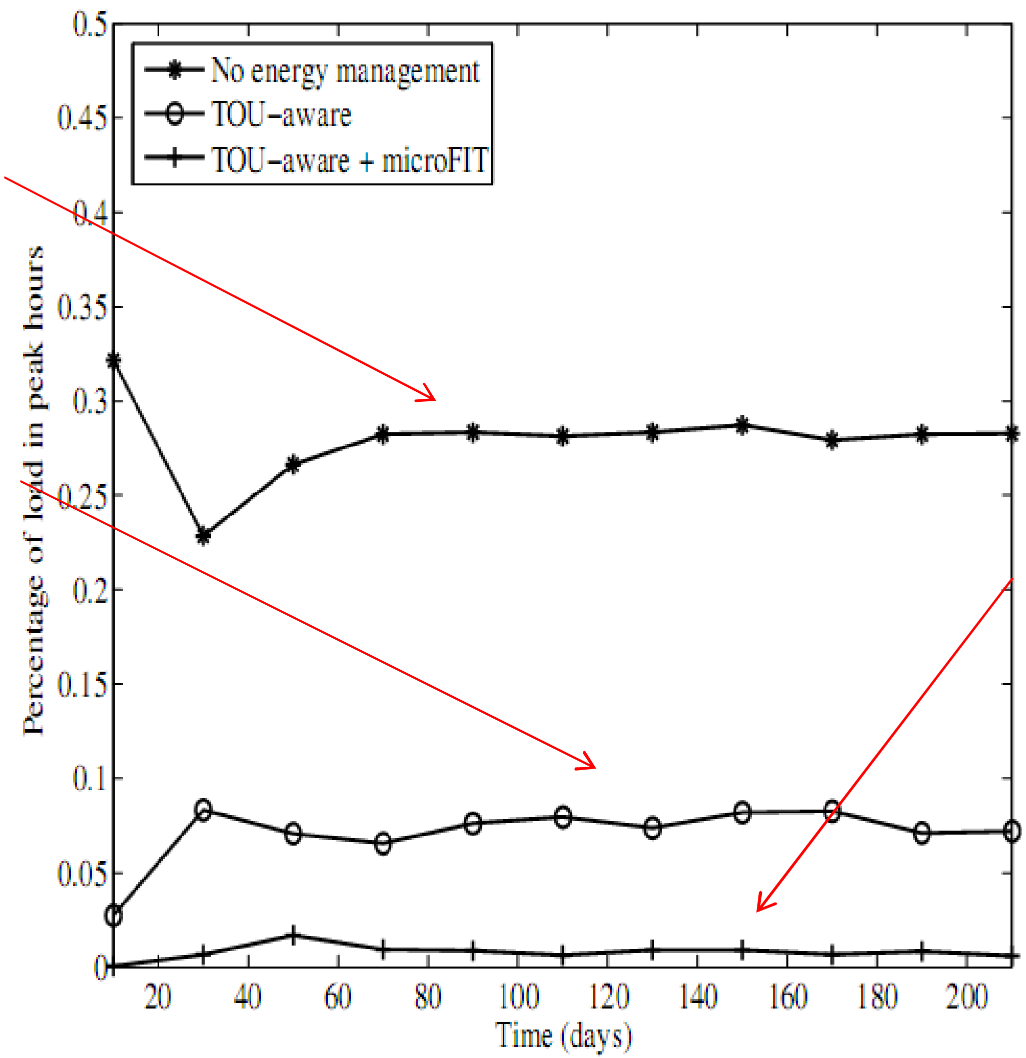


Simulation Results

Percentage of the load on peak hours

No EM, 30% of the demand occurs in peak hours

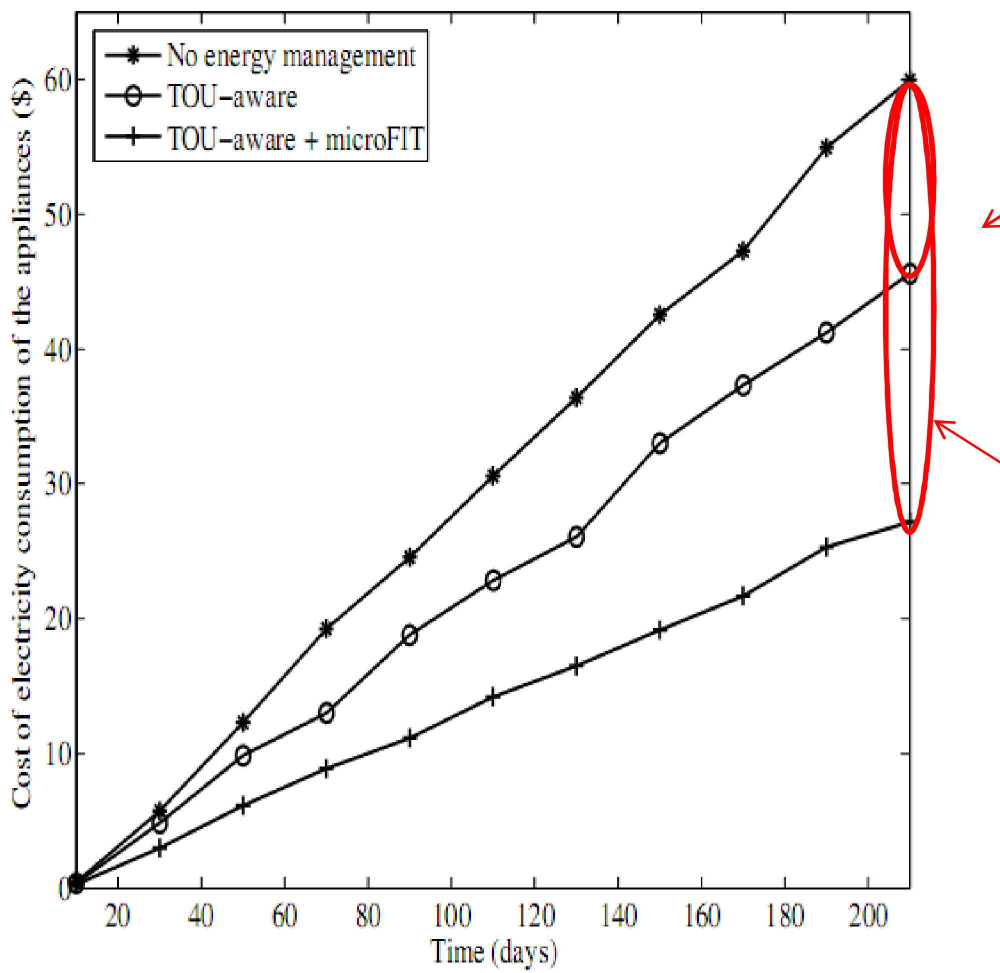
TOU-aware, 10% of the load is left in the peak hours



TOU-aware + microFIT, 1% of the load is left in the peak hours only

Simulation Results

Total cost of electricity consumption of the appliances



TOU-aware:
the contribution of the appliances on the energy bill is reduced by almost 25%

TOU-aware + microFIT:
contribution of the appliances on the energy bill is reduced more than 50%

Trade-off: Delay
TOU-aware + microFIT ->2 hrs
TOU-aware -> 4 hrs

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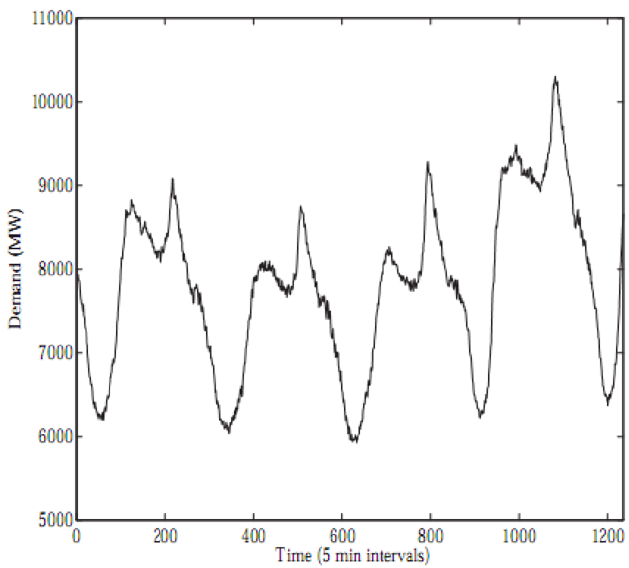
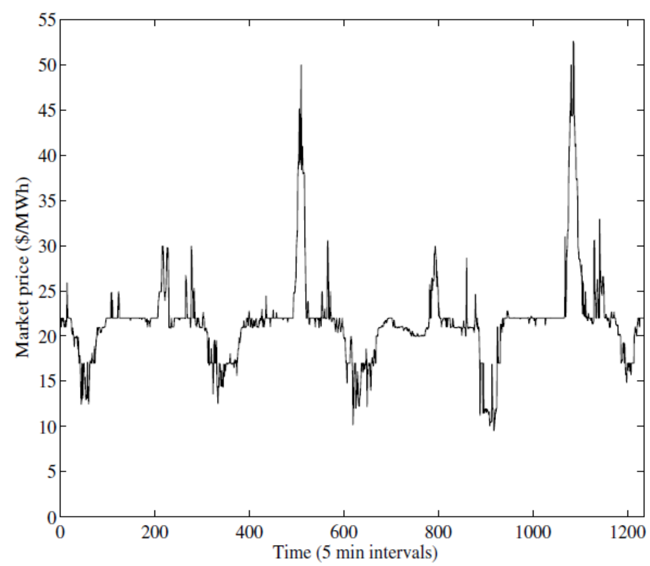
Real-Time Pricing

- Real-Time (dynamic) pricing
  - The price of electricity is determined by the regional independent system operator (ISO) in deregulated markets
  - Price = Raw market price of the electricity + regulatory charges + transmission & distribution charges + taxes + other fees





Prediction-based PHEV Charging for Real-Time Pricing

- By 2030, the annual PHEV market is estimated to be over 5 million new sales in the U.S.
- Light weight Li-ion batteries
  - Capacities reaching 50kWh
  - Can be charged from a household electrical outlet or a charging station
  - The maximum power level determines the duration required to fully charge the batteries
- PHEVs:
  - If powered during critical periods they may cause failure of the grid
  - If powered duri ay more
  - Best strategy: c ys possible

Solution:

- Prediction of dyna ciding the best Time of Charge (TOC)

M. Erol-Kantarci, H. T. Mouftah, "Prediction-Based Charging of PHEVs from the Smart Grid with Dynamic Pricing," First Workshop on Smart Grid Networking Infrastructure in LCN 2010, Denver, Colorado, U.S.A, October 2010.

Prediction-Based Charging

Prediction scheme is based on k-nearest neighbours algorithm

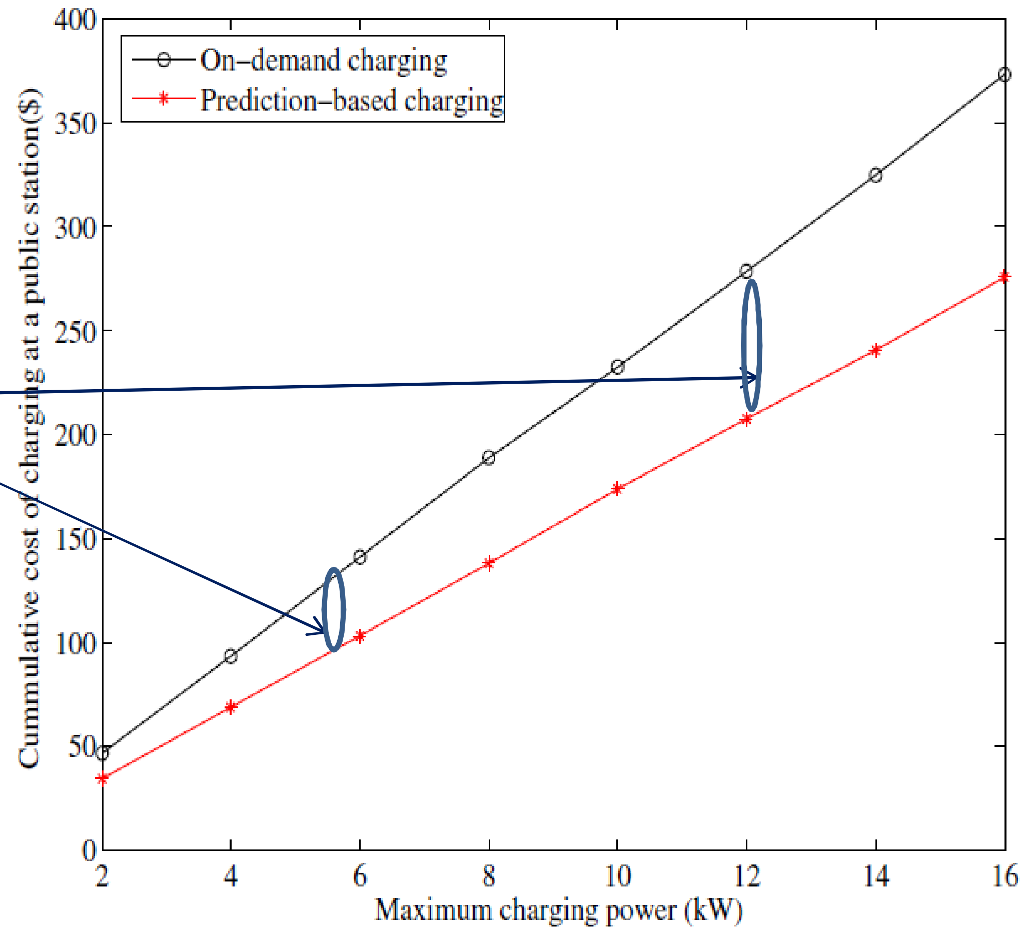
- Training set
  - Time series of hourly price signals
    - P_i: the hourly average price for time slot i
  - Price signals recorded in the previous D_t days
  - We employ a sliding window of size W_s
- If the predicted price is greater than the price threshold, $Pr_j > T_p$
    - Charging is delayed
    - Otherwise, PHEV starts charging

Simulation Results

Cost of charging the PHEV batteries in a public charging station (July 2009)

- Savings of the consumers are higher with prediction based charging

Prediction-based scheme has almost 25% lower monthly cost than on-demand charging at the maximum charging power



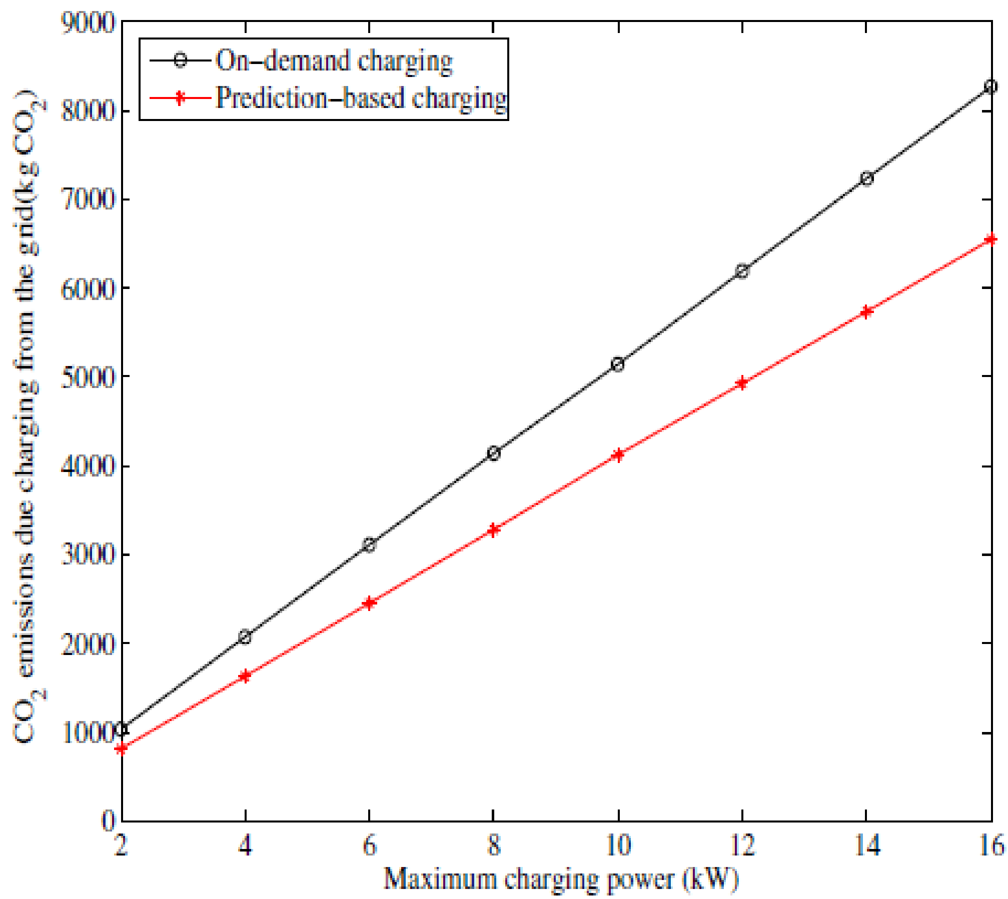
Simulation Results

CO_2 emission of the PHEVs (electric range)

- During peak hours, power plants with higher emission rates are generally utilized

- Prediction-based charging can reduce the emissions by almost 18%

  - Emission rate depends on
    - PHEV's battery usage settings, e.g. charge-depleting, blended mode
    - The energy supply of the regional grid, e.g. nuclear, hydro, coal



Conclusions

- Use of WSNs in the smart grid is promising
- Residential energy management schemes can reduce
  - Electricity expenses
  - Peak hour load
  - CO_2 emissions
- The negative impacts of PHEV charging can be avoided by smart charging strategies
- Prediction-based charging scheme
  - reduces the operating cost of PHEVs
  - reduces the CO_2 emissions

Future Work

- Future work for residential energy management schemes
  - Integrate learning systems to increase consumer comfort
  - Incorporate PHEVs and develop V2H applications
- Future work for PBC
  - Realistic driving and charging models
  - State of Charge (SOC) of each vehicle and owner settings

- Smart pumps can provide a mix of gas and electricity
  - Following the fuel prices, electricity prices and emission rates from the web and minimize the cost and emissions by choosing the appropriate charging strategy and fuel type
- Vehicle to the grid (V2G) scenarios can also be considered
  - A fleet of PHEVs can be contracted to provide ancillary services
    - spinning reserves and regulation services

Publications on Smart Grids

- M. Erol-Kantarci, H. T. Mouftah, "Wireless Multimedia Sensor and Actor Networks for the Next-Generation Power Grid," accepted for publication, Elsevier Ad Hoc Networks Journal, 2011. DOI 10.1016/j.adhoc.2010.08.005.
- O. Asad, M. Erol-Kantarci, H. T. Mouftah, "Sensor Network Web Services for Demand-Side Energy Management Applications in the Smart Grid," IEEE Consumer Communications and Networking Conference (CCNC'11), Las Vegas, USA, January 2011.
- M. Erol-Kantarci, H. T. Mouftah, "Prediction-Based Charging of PHEVs from the Smart Grid with Dynamic Pricing," First Workshop on Smart Grid Networking Infrastructure in LCN 2010, Denver, Colorado, U.S.A, October 2010.
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- M. Erol-Kantarci, H. T. Mouftah, "Using Wireless Sensor Networks for Energy-Aware Homes in Smart Grids" IEEE symposium on Computers and Communications (ISCC), Riccioni, Italy, June 22-25, 2010.
- M. Erol-Kantarci, H. T. Mouftah, "Wireless Sensor Networks for Domestic Energy Management in Smart Grids", 25th Biennial Symposium on Communications, Kingston, ON, Canada, May 12-14, 2010.

Thank you

Questions?

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