Wireless Sensor Networks in the Smart Power Grid

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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**
  - Nuclear: 9293 MW
  - Hydro: 4318 MW
  - Gas: 3064 MW
  - Coal: 1160 MW
  - Wind: 808 MW
  - Other: 95 MW

  Sources: IESO of Ontario

  **European Union**
  - Nuclear: 17%
  - Hydro: 10%
  - Large Hydro: 10%
  - Gas: 30%
  - Fuel Oil: 7%
  - Coal: 30%
  - Other: 2%

  Sources: EWEA and Platts (2008)

  **US- ERCOT (Houston)**
  - Hydro: 72%
  - Nuclear: 1%
  - Wind: 0%
  - Natural Gas: 0%
  - Coal: 7%
  - Fuel Oil: 0%
  - Other: 0%

  Sources: Exelon
Smart Power Grid - Storage

• Energy storage
  – Pumped hydro, compressed air, flywheel and sodium-sulfur (Na$_2$S) battery
  – Li-Ion batteries and PHEVs as smart grid storage

$\sim 0.5\text{kWh/kg}$  $5\text{-}50\text{kWh}$  $\sim\text{MWh}$
Smart Power Grid – Transmission & Distribution

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

• Security
  – Resilient to physical and cyber attacks

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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• Prediction based charging for PHEVs

• Conclusions and Future Work
Motivation - Peak Demand

• Demand profile
  – Appliances, lights, TV, thermostat, PHEV ...

• Load on the electricity grid

• Peaker Plants
  – More Green House Gas (GHG) emissions

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)

• 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

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 $\rightarrow$ 2 hrs
- TOU-aware $\rightarrow$ 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 during peak hours customers pay more
  - Best strategy: charge at night but not always possible

Solution:
- Prediction of dynamic price signals and deciding the best Time of Charge (TOC)

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
  – CO₂ 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 CO₂ 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


Thank you

Questions?

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