POSTECH
Division of IT Convergence Engineering

IT CONVERGENCE ENGINEERING
SINCE 2009

Optimal Demand-Side Energy Management Under Real-time Demand-Response Pricing

Jin Xiao[1], Jae Yoon Chung[2], Jian Li[2], Raouf Boutaba[1,3], and James Won-Ki Hong[1,2]

[1] IT Convergence Engineering, POSTECH, Pohang, Korea
[2] Dept. of Computer Science and Engineering, POSTECH, Pohang, Korea
[3] School of Computer Science, University of Waterloo, Canada

Introduction and Motivation

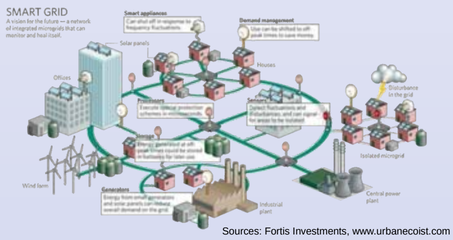
The ability to reduce electricity usage and wastage through better demand-side management and control is considered a key solution ingredient to the global energy crisis. One effective measure that has been put into place in many countries around the globe is the Demand Response (DR) program.

➢ Key Deterring Factors of Current Grid

- Lack of information
- Lack of smart planning
- Customers are risk-averse

➢ Research Goals

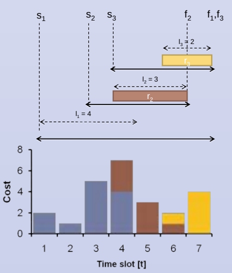
- Design and Implement Green-Home Service (GHS) architecture to provide advanced metering and control
- Design scheduling algorithm to provide decision making capabilities



Sources: Fortis Investments, www.urbanecoist.com

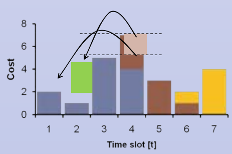
Demand-side Energy Management

➢ minMax Algorithm Overview



- Request d with a starting time s and a ending time f
- Schedule d to somewhere within the specified time frame
- Assign d to the time-slots with the lowest cost among the candidate timeslots

➢ Algorithm Improvement using Battery



- Input: the schedule produced by the minMax algorithm
- Find the peak cumulative cost
- Shifts part of its demand forward in time filling in the time slots that are under-utilized
- Repeat operation 2) and 3) until no shifting can be performed.

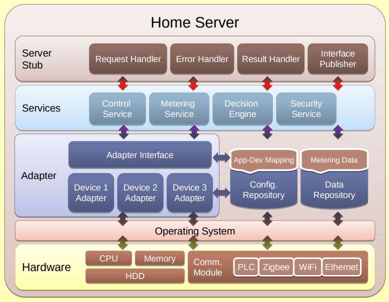
minMax Algorithm

Algorithm 1 minMax Scheduling

Input:
n number of time slots, m number of demands
Time slot $t \in T$ where $1 \le t \le n$
Consumer demand $d_j = (s_j, f_j, r_j, l_j) \in D$ where $1 \le j \le m$
$s \in T$ is start time, $f \in T$ is finish time, r is consuming rate, l is number of time slots of demand.
Cost for demand rate r at time slot t $P_t(r)$
Output:
$scheduleMatrix[n][m]$ such that $scheduleMatrix[i][j]$ is the energy cost of j-th demand at time slot t

Initialize $scheduleMatrix[n][m]$ to zeros
Initialize $c_{1..n}$ to zeros
Assign tasks in D with fixed schedules (i.e. $f - t + 1 = l$) to timeslots, and adjust c accordingly
Sort D based on r as the major key in descending order
Sort D based on l as the minor key in descending order
for $i = 1$ to m **do**
  $minMax \leftarrow \infty$
  $schedulingSlot \leftarrow 0$
  for $t = s_i$ to $f_i - l_i + 1$ **do**
    $minMaxAtT = maximum(c_t + P_t(r_i), c_{t+1} + P_{t+1}(r_i), \ldots, c_{t+l-1} + P_{t+l-1}(r_i))$
    if $minMaxAtT < minMax$ **then**
      $minMax \leftarrow minMaxAtT$
      $schedulingSlot \leftarrow t$
    end if
  end for
  for $j = schedulingSlot$ to $l - 1$ **do**
    $scheduleMatrix[i][j] \leftarrow P_j(r_i)$
  end for
end for

GHS Implementation

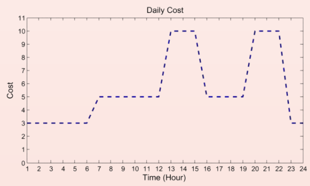


➢ GHS Components

- **Server Stub:** Web service interface to the client applications and power utility
- **Services:** a collection of GHS services such as metering, decision engine, security service, etc
- **Repository:** manages metering data as well as device specific information such as the adaptor-to-appliance mapping.
- **Adapter:** generates communication messages depending on the manufacturer's message format and data model. Multitude of communication technologies are enabled through the use of appliance specific adapters.

Simulation Study

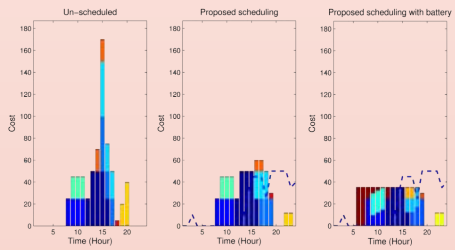
➢ Daily Energy Price from Utility



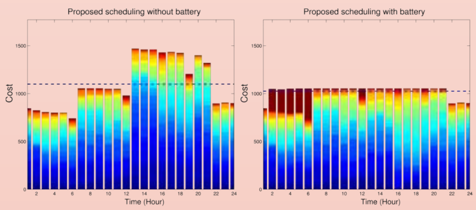
➢ Variables Defined for Simulation

Variable	Value	Description
Energy Demand	1 ~ 5	Energy that is required by each task per hour
Task Length	1 ~ 5	The contiguous running time of each task
Shift Time	1 ~ 5	Shift time range of each task
Daily Energy Price	3 ~ 10	Energy price per one power unit in each hour

➢ Scheduling Result with 10 Tasks



➢ Scheduling Result with 1000 Tasks



Conclusion & Future Work

➢ Conclusion

- Designed and implemented GHS
- Modeled the demand-side energy management problem (NP-hard)
- Designed a scheduling algorithm for demand side energy management
- Showed that our algorithm can find near-optimal
- Showed the effect of battery on demand smoothing

➢ Future Work

- Integrate the minMax algorithm in the Green-Home Service implementation
- Conduct field-test experiment in real home and large enterprise settings.