

# Managing End-User Preferences in the Smart Grid

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April 14, 2010



# Outline

- Background
- Automate Energy Service in a Three-tier Electricity Market
- How to Handle User Preferences?
- How to Balance the Load by Taking Preferences into Account?
- Evaluation
- Related Work
- Conclusion

# Background

- Demand response<sup>[1]</sup>
  - A tariff or program established to **motivate changes in electric use by end-use customers** in response to changes in the price of electricity over time, or to give incentive payments designed to induce lower electricity use at times of high market prices or when grid reliability is jeopardized.
- Smart Grid<sup>[2]</sup>
  - Having all supply and demand resources dynamically managed via a combination of data, communications and controls, whereby the operation of the grid for reasons of economics, security, reliability, emissions, etc., can be optimized in real time.
- The Impact of People's Awareness to Energy Efficiency
  - Saving ranges 5-15%<sup>[3]</sup> from meters showing clearly-understood reference points for improving billing

[1] U.S. Department of Energy. Benefits of demand response in electricity markets and recommendations for achieving them. 2006.

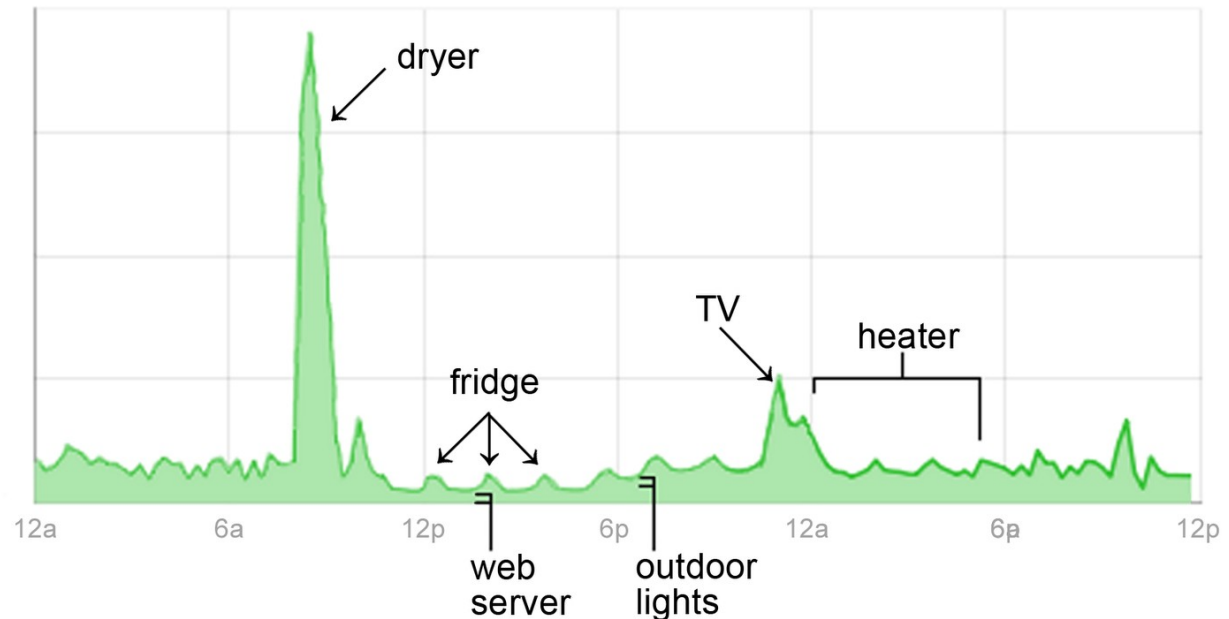
[2] Demand Response and Smart Grid Coalition: Accelerating the Use of Demand Response and Smart Grid Technologies is an Essential Part of the Solution to America's Energy, Economic and Environmental Problems, *Policy Recommendations for the Obama Administration and 111th Congress*, Nov 2008.

[3] S. Darby: The Effectiveness of Feedback on Energy Consumption, *Environmental Change Institute, University of Oxford*, April 2006.

# Tools for Direct Feedback

- Smart Meter
  - Real-time electricity consumption measurement
  - Passing collected measurements to a central location
  - Some enable remote control of power consumption
- Google PowerMeter

## Home Electricity Use



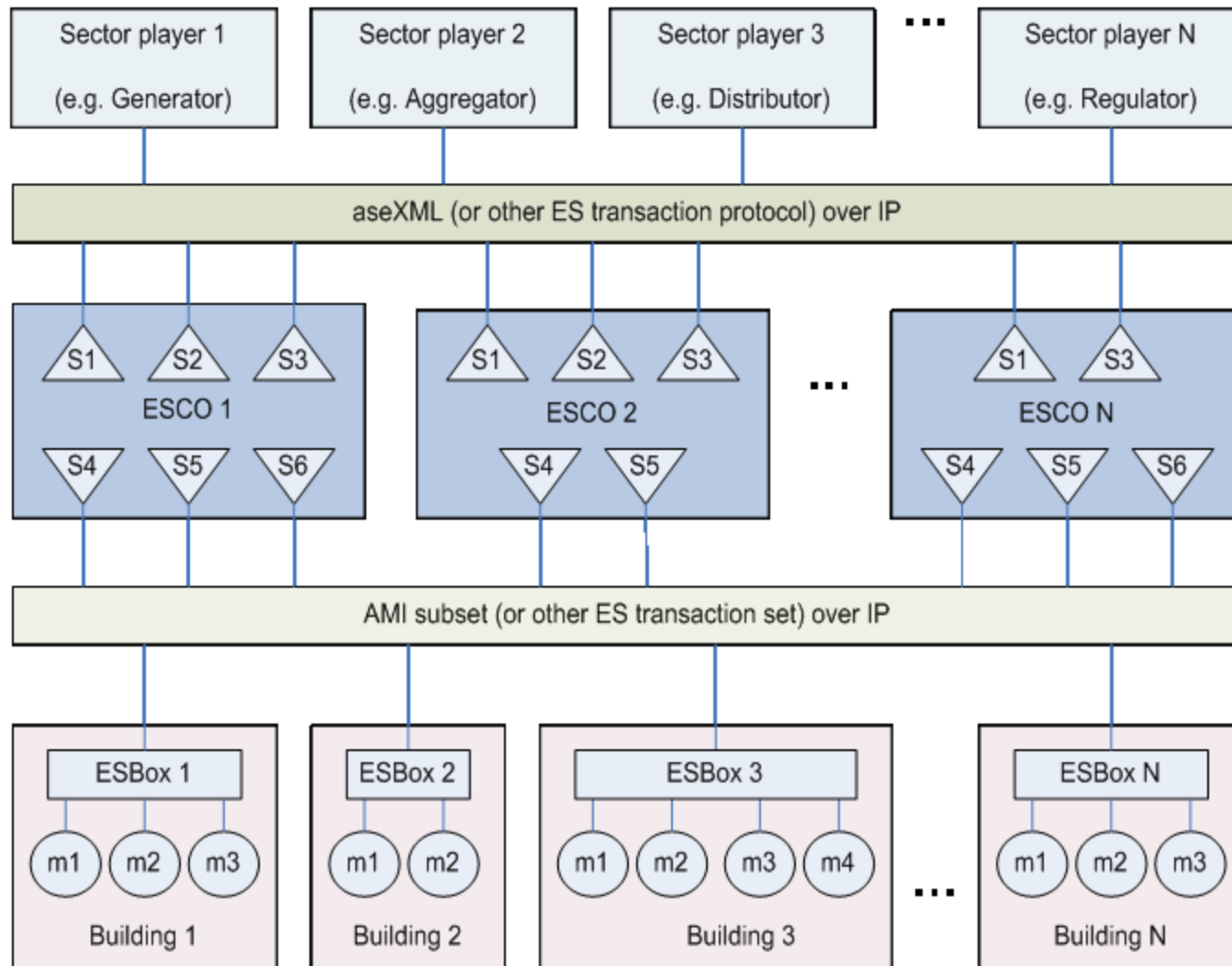
Source: <http://googleblog.blogspot.com/2009/02/power-to-people.html>

# These tools are not enough

- **Peak Time Consumption Management is Complicated**
  - What other users are doing matters
  - It requires coordination and understanding of use patterns
- **Real Time Pricing is Complicated to End Users**
  - Utilities have their own goals to optimize their operations
    - profit margins
    - power grid reliability
    - green house gas emissions
    - ...
  - It is difficult for end-users to optimize their energy use under this context
- **Solution: Automated it by using value-added Web Services?**



# Our Proposal: Automated Energy Service in a Three-tier Electricity Market [ICWS'09]



# Middle Tier (ESCO)'s Centric Role

- **Current practice**
  - Large energy consumers, employ staff and contract consultants to better manage their energy consumption
    - big industrial sites, shopping malls and data centres
  - Small energy consumers do not have the same opportunity
    - the cost savings would not offset the consultant fees
    - most people do not have sufficient technical knowledge to implement the advice given...
- **The value of ESCOs**
  - understanding of users' behaviours
  - understanding of utilities and electricity market
- **The values can be realised in an automated manner**
  - constructing services over aggregated information

# Issues we tackle in this paper

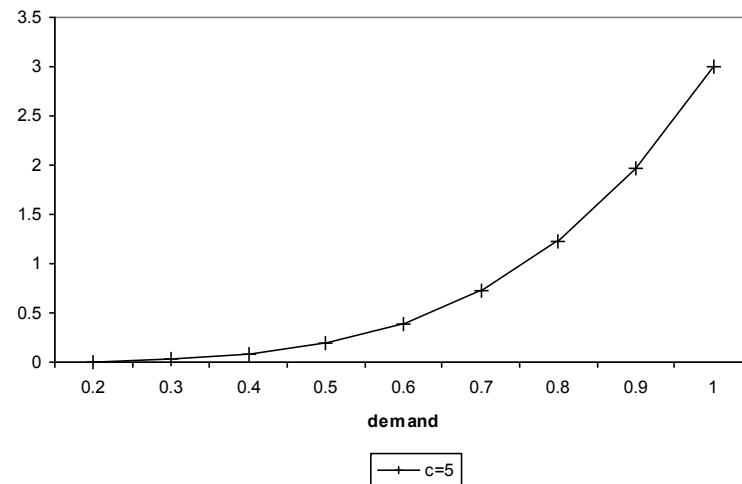
- The willingness of end-users to respond to a DR signal
  - Traditional DR usually involves large energy consumers for whom cost is the dominant factor.
  - The convenience of making changes to energy use patterns becomes an important factor.
- Investigating how to optimize the overall energy consumption with multiple ESCOs in the market
  - Each optimizes its customers' DR strategies in a selfish manner.
  - Similar problem exists in transportation networks, communication networks and large scale distributed systems.



# The Problem Settings

- Electricity pricing is based on equal-length time slice
  - The price to a time slice is dynamic and related to the supply-demand ratio

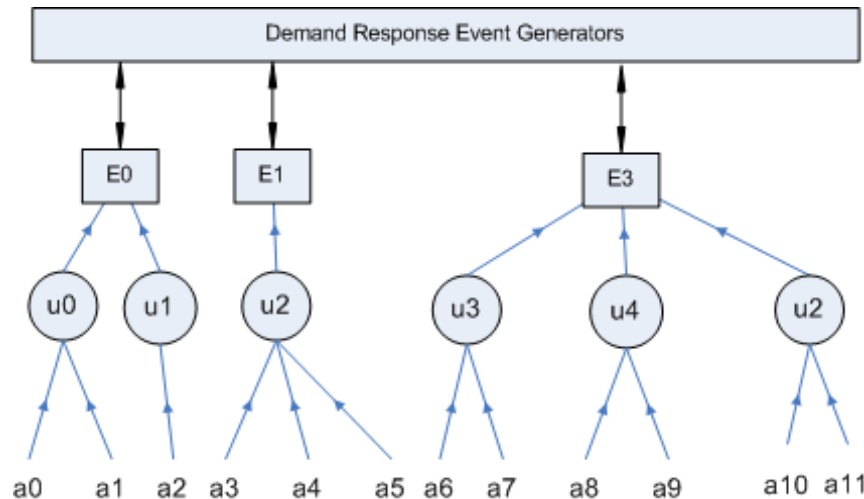
$$P = a(D/C)^{c-1}$$



- The overall electricity cost is minimal when energy consumption is **balanced** in each time slice
- A user has a set of smart meter connected appliances
  - Such an appliance is capable of responding to signals from its ESCO.
  - The response is driven by the **user preference**.

# The Optimization Goals of an ESCO

- An ESCO optimizes energy use of subscribed end-users when receiving a DR event



- **Two optimization objectives:**
  - Balance the load in a given time frame for all end-users subscribing to its service → reduce the peak energy use and therefore reduce the unit energy price for each end-user;
  - Minimize the overall changes to users' preferred energy consumption patterns → reduce the inconvenience caused by scheduling.

# How to deal with user preferences?

- Representation

Appliance	Preference	$t_0 - t_1$	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$
$a_0$	1	1kW			
	2		1kW		
	3			1kW	
$a_1$	1	2kW	2kW	2kW	2kW
	2	2kW		2kW	
	3	1kW	1kW	1kW	1kW

A time series on a sequence of time slice  $\langle t_0 - t_1, t_1 - t_2, \dots, t_{n-1} - t_n \rangle$

- Comparison of two preferences (dynamic time warping based)

$$P = \langle p_0, p_1, \dots, p_{n-1} \rangle$$

$$Q = \langle q_0, q_1, \dots, q_{n-1} \rangle$$

$$DTW(i, j) = |p_i - q_j| + \min \begin{pmatrix} DTW(i-1, j) \\ DTW(i, j-1) \\ DTW(i-1, j-1) \end{pmatrix}$$

# Load Balancing within Single ESCO

- **Maximum Slice Demand(MSD):**
  - Let a vector  $\langle d_0, d_1, \dots, d_{n-1} \rangle$  represent the demand of appliance at time slice  $\langle t_0 - t_1, t_1 - t_2, \dots, t_{n-1} - t_n \rangle$ , the maximum slice demand of this appliance is  $\max\{d_0, d_1, \dots, d_{n-1}\}$ .
- **Discomfort Level (DCL)**
  - The DCL of an alternative electricity use plan during a sequence of time slices is the overall DTW distance between the users' top preferences and their corresponding preferences in the alternative plan.

# The Algorithm Description

1. Sort preferences using comparator **PreferenceComp** in a non-descending order;
  2. **While** not all appliances are scheduled **do**
  3.     find the preference from the sorted list that minimizes the overall demand according to **PreferenceComp**;
  4.     mark the corresponding appliance as scheduled;
  5.     update the overall demand;
  6. **End while**;
- The algorithm gives priority to appliances with small energy consumption rate and preferences with low DCL.
    - Avoid the situation where a large number of users with small appliances are discomforted.

# The Comparator

```
11: int PreferenceComp( $p_1$ ,  $p_2$ ) {the function returns a
    positive number if  $p_1 > p_2$ , a negative number if  $p_1 < p_2$ 
    and 0 if  $p_1 == p_2$ }
12: if  $p_1.msd < p_2.msd$  then
13:     if  $p_1.dcl - p_2.dcl \geq dcl\_thr$  and  $\frac{p_2.msd}{p_1.msd} < msd\_thr$ 
        then
14:         return 1
15:     else
16:         return -1
17:     end if
18: end if
19: if  $p_1.msd > p_2.msd$  then
20:     if  $p_2.dcl - p_1.dcl \geq dcl\_thr$  and  $\frac{p_1.msd}{p_2.msd} < msd\_thr$ 
        then
21:         return -1
22:     else
23:         return 1
24:     end if
25: end if
26: return  $p_1.dcl - p_2.dcl$ 
```

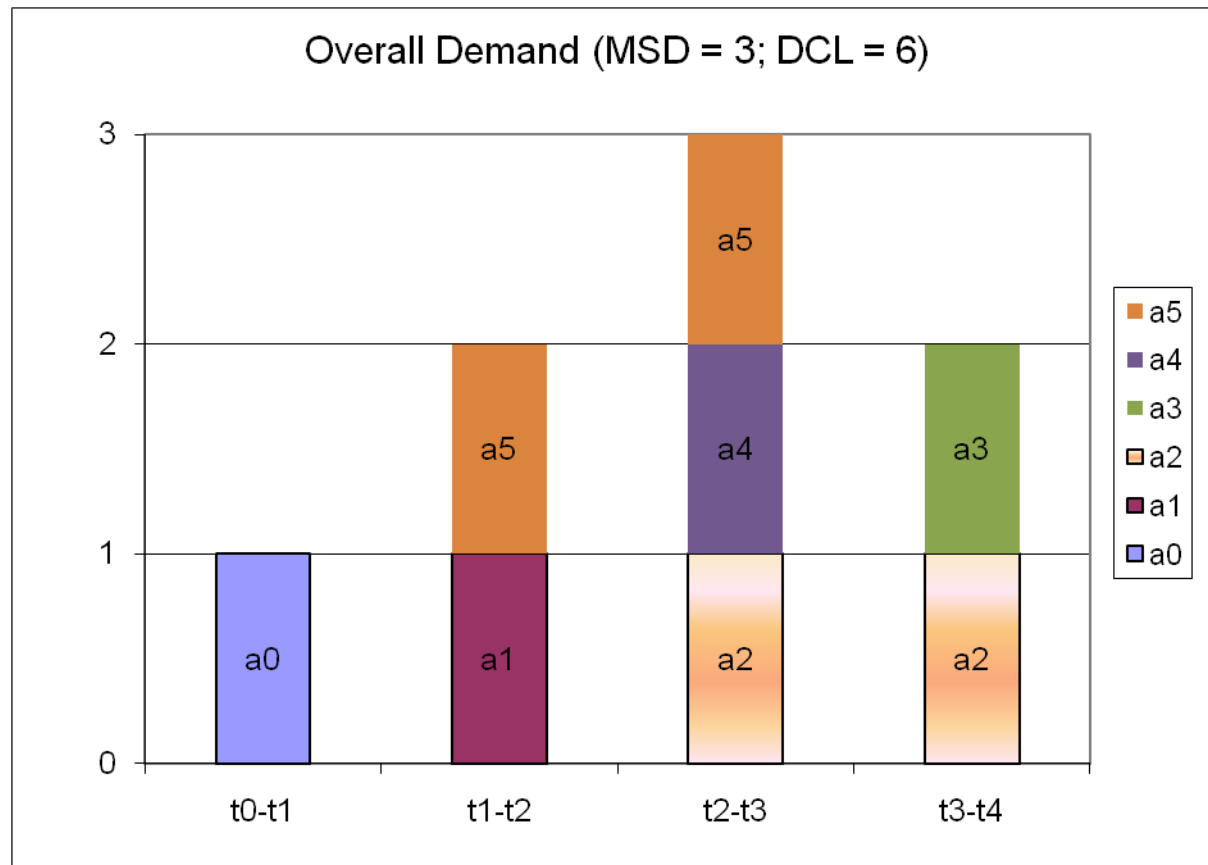


# Example: A Market with Multiple ESCOs

ESCO	Meter	Preference	$t_0 - t_1$	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$
$E_0$	$a_0$	1	1kW			
		2		1kW		
		3			1kW	
	$a_1$	1		1kW		
		2			1kW	
		3				1kW
	$a_2$	1	1kW	1kW		
		2		1kW	1kW	
		3			1kW	1kW
$E_1$	$a_3$	1				1kW
		2			1kW	
	$a_4$	1				1kW
		2			1kW	
		3		1kW		
	$a_5$	1		1kW	1kW	
		2			1kW	1kW

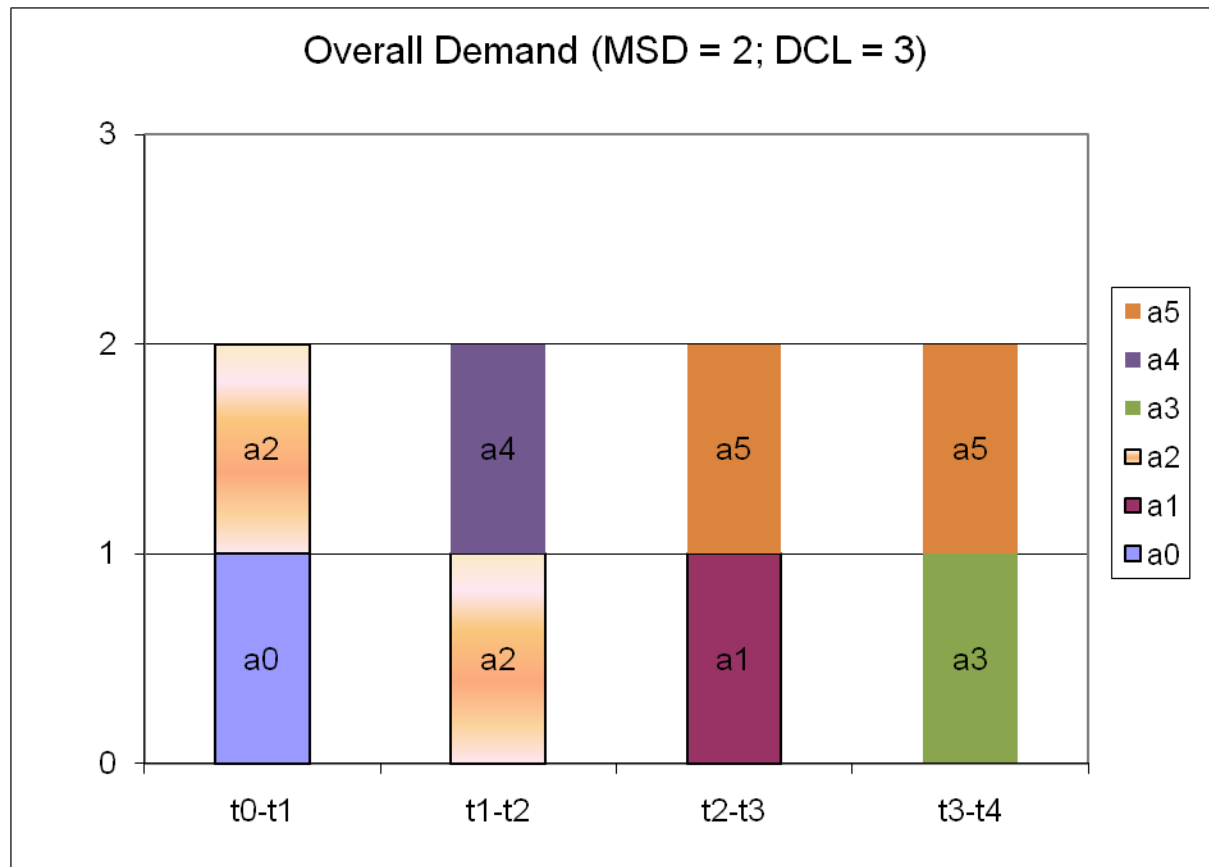
# Example (cont)

- E0 and E1 balance their consumptions independently



# Example (cont)

- E0 and E1 coordinates with each other



# Load Balancing among Multiple ESCOs

- Exploit Demand Response signals (DR events) generated by the market
  - The communication between ESCOs and the market is based on the emerging Demand Response standards
- A decentralized algorithm that allows each individual ESCO to further optimize its schedule based on market signals
  - Incentives for an ESCO to participate such a market can be the rewards for stabilizing the power grid, or the better schedule to offer to its customers.

# Load Balancing among Multiple ESCOs (cont)

- **ESCO**: produces a local schedule that optimizes users' energy consumption;
- **ESCO**: submits the time slice demands as well as the overall DCL to the market based on the optimized schedule;
- **The upstream DR automation system (DRAS)**: calculates the overall demand from all participating ESCOs and notifies them via DR events of prices for the requested time slices
- **ESCO**: if the schedule can be improved based on the current prices compared with the previous schedules, the ESCO revises its schedule and resubmits the updated demand;
- **DRAS**: selects the ESCO that minimizes the overall makespan and DCL, and then notifies the ESCOs the changed prices.
  - if no adjusted demand is received or the new demand cannot improve the overall makespan and DCL further, the DRAS notifies ESCOs the final time slice prices of this round;

# Example

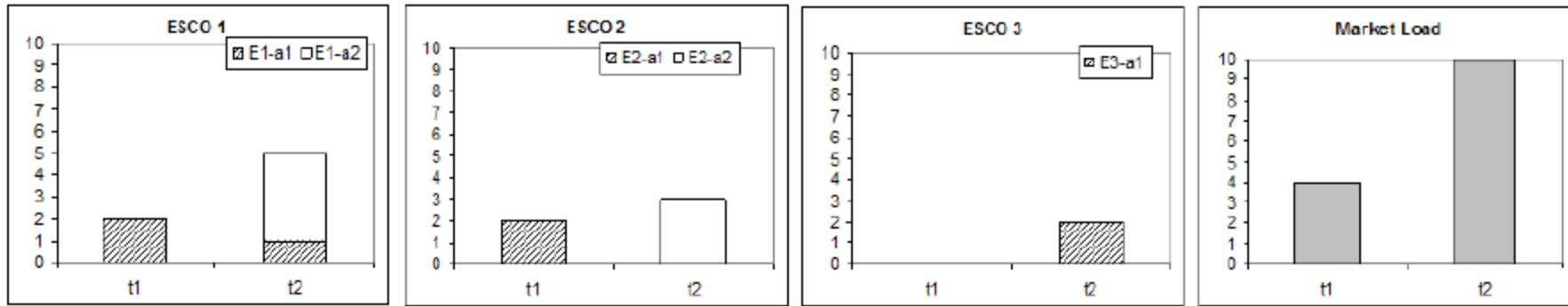
- Three ESCOs in a market
  - Two time slices:  $t_1$  and  $t_2$
  - Each appliance is flexible to shift between the two time slices

ESCO	Appliance	$t_1$	$t_2$
$E_1$	a1	2kW	1kW
	a2		4kW
$E_2$	a1	2kW	
	a2		3kW
$E_3$	a1		2kW

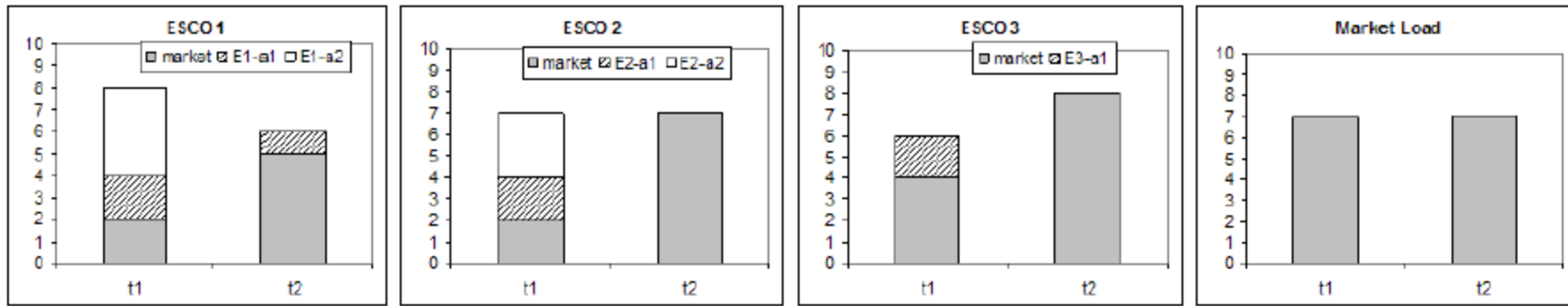


# Example (cont)

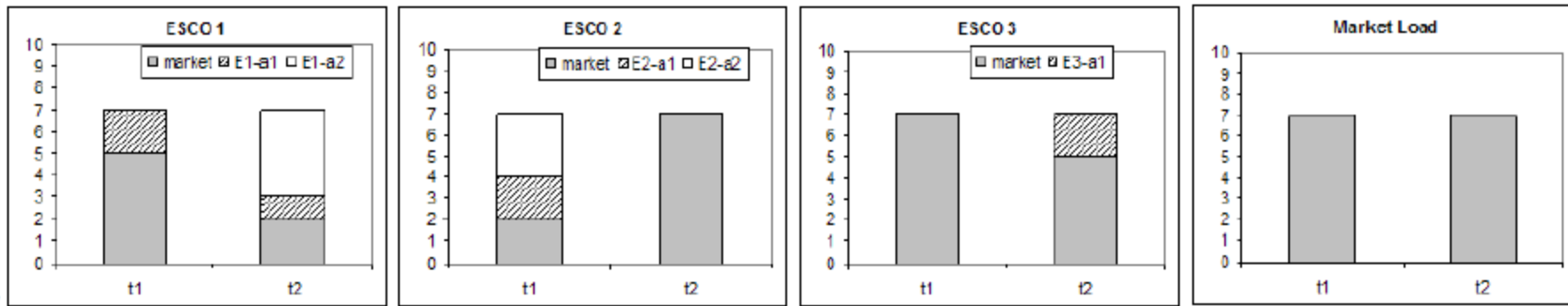
R0:



R1:



R2:



# Characteristics of the Algorithm

- Each ESCO behaves “selfishly” to optimize its own makespan and discomfort level
  - ESCOs do not explicitly coordinate with each other; instead it is done through DR events generated by the market.
  - The upstream DRAS only plays a role of sharing the market load.
- The algorithm leads the ESCOs in a market to a global schedule that is a Nash Equilibrium in a finite number of steps.

# Evaluation: Settings

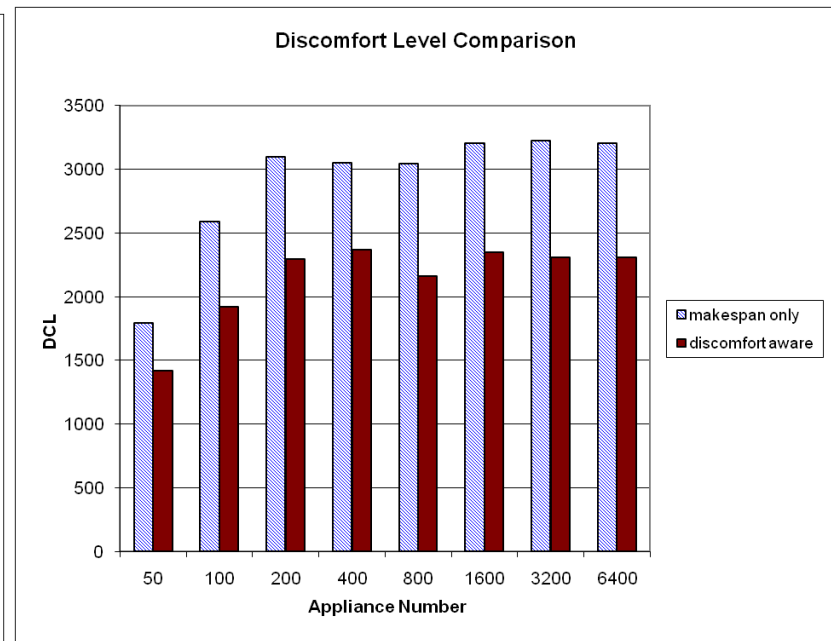
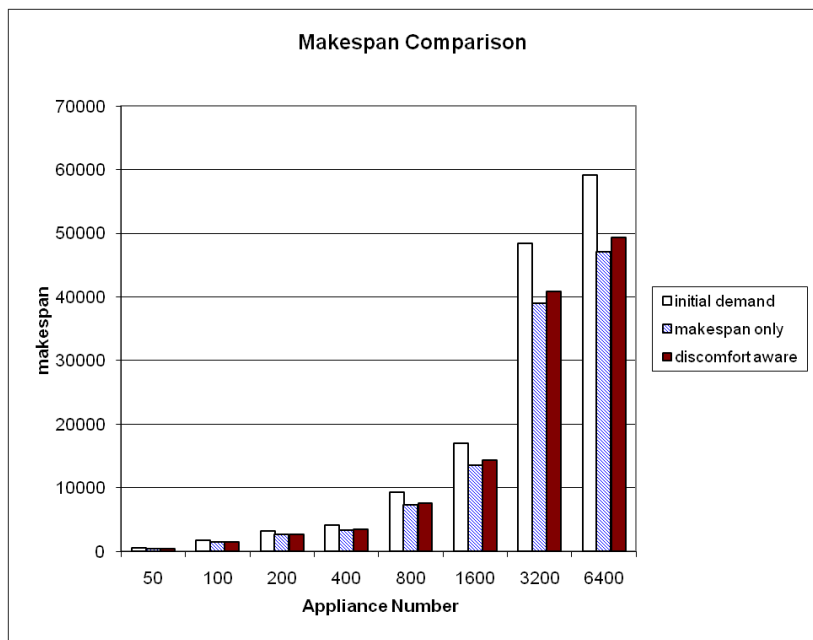
- 24 time slices
- Each user has a randomly generated number of appliances
- Each user selects the starting time for using an appliance according to Zipf distribution with the exponent equal to 1.0
  - A large number of end-users have similar patterns of using appliances
- An appliance keeps on for a randomized number of time slices once turned on
- We pre-define a set of appliance types with each type has a given mean electricity consumption rate varying from 10 to 100. An appliance is randomly assigned a type based on Zipf distribution with  $\alpha = 1.2$ 
  - a large number of appliances belonging to the same type.
- The number of preferences of an appliance is uniformly randomized between 1 and 5.
- Each preference is derived either by **demand shift** or **demand stretch**

# Evaluation: Single ESCO

## Makespan reduction:

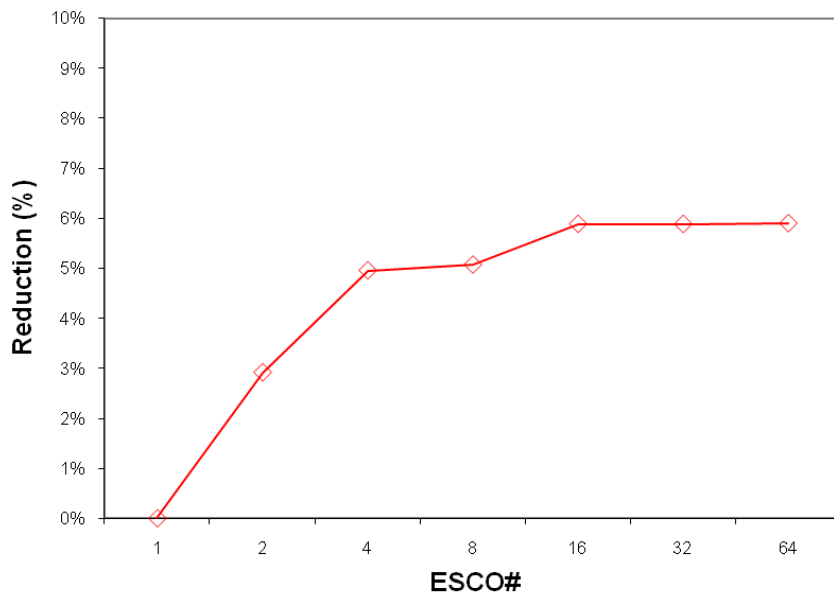
the discomfort aware algorithm – from 13.8% to 17.4%.

the makespan only algorithm – from 16.5% to 21.6%, but 40% more discomfort level

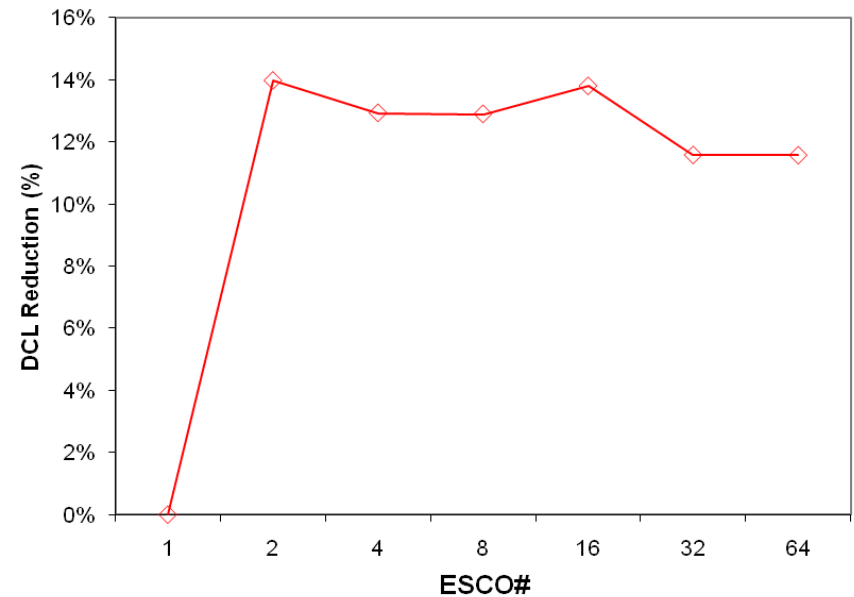


# Evaluation: Multiple ESCOs

## Makespan Reduction Rate



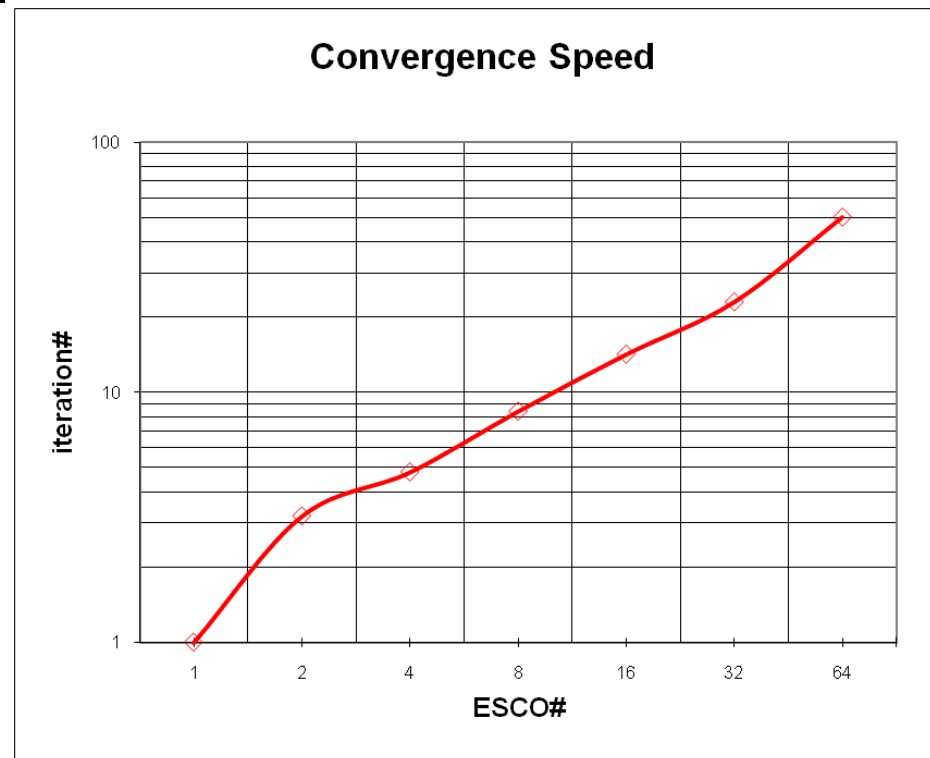
## DCL Reduction Rate



The percentage of makespan reduction increases when the ESCOs participating in the market increases to a certain number.

# Evaluation: Convergence Speed

- Measured by the number of iterations that DR events for scheduling adjustment are sent out.
  - under our experiment settings, the convergence speed is roughly proportional to the number of ESCOs participating in the market.





# Related Work

- **Simple pricing strategies**
  - provided by utilities in an attempt to make people better manage their electricity use [20]
- **Some Web services for energy consumption monitoring**
  - Energy Tracking and Google PowerMeter provide energy consumption data collection and analysis services.
  - We focus on how to use of the obtained data and preference management
- **“smart” houses [11]**
  - allow remote monitoring and controlling of appliances
  - We focus on mechanisms for adding values on top of the remote monitoring and controlling capability
- **Load balancing algorithms [17, 9, 15]**
  - We deal with load balancing across contiguous time slices
  - User preferences are taken into account in our load balancing design
  - Selfish load balancing [7,8]

# Conclusions

- Existing research has revealed that end-users' awareness alone results in significant energy saving
- We developed a mechanism to further exploit the awareness of end-users in a three-tier energy market
  - It uses the middle tier (ESCO level) to aggregate the flexible electricity consumption patterns from individual users and reduce the peak energy consumption through load-balancing.
  - It takes end-users' preferences into account.
- We gave a method for multiple ESCOs to improve their schedules iteratively via Demand Response events
  - It fits the emerging ADR standards well.