Control Mechanisms for Residential Electricity Demand in Smart Grids

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\section*{Introduction}

\subsection*{Demand Response}
- Most electricity grids sized to meet peak demand.
- Demand Response (DR) programs aim to reduce peak usage.
- Why?
  - 5\% reduction in peak demand would eliminate 625 combustion turbines, save \$3B/year.
  - Other benefits: Reduced cost (to utility and customer), improved grid stability, fewer blackouts/brownouts, increased renewable integration.
- DR programs can be based on pricing
- Customers cannot react to frequently changing pricing signals.
- Energy Management Controller (EMC) needed.

\subsection*{Our Contributions}
- Optimization Models and algorithms for EMC decision-making.
- Negative aggregate impact of off-peak pricing model if consumers are "smart" (use EMCs).
- Novel communication protocol for energy allocation among local EMCs.

\section*{Simple EMC Optimization Algorithm}

\subsection*{Appliance Timing Optimization}
- Determine optimal start times of (deferrable) appliances.
- \textbf{T} : Planning Horizon
- \textbf{d}_{\text{max}} : Maximum allowable number of periods of delay
- \textbf{\psi}_n : Delay penalty, per period
- \textbf{\psi}^1_{\text{max}} : 
- \textbf{\psi}^0_{\text{max}}

- \textbf{\psi}^0_{\text{max}} : 
- \textbf{\psi}^1_{\text{max}}

\begin{itemize}
  \item Appliance \textit{n} requested at time \textit{t}. When to turn on?
  \end{itemize}

\begin{itemize}
  \item \textbf{Objective:} Choose \textbf{\psi} set of appliances to turn on based on
  \end{itemize}

\begin{itemize}
  \item Decision: Choose \textbf{\psi} set of appliances to turn on based on
  \end{itemize}

\begin{itemize}
  \item Expected cost of peak demand reduction with minimal inconvenience/cost to consumer
  \end{itemize}

\begin{itemize}
  \item Reduced by 40\%.
  \item Significant reductions in peak demand possible with minimal inconvenience/cost to consumer
  \end{itemize}

\begin{itemize}
  \item Peak reduced by 40\%.
  \item Significant reductions in peak demand possible with minimal inconvenience/cost to consumer
  \end{itemize}

\begin{itemize}
  \item Approach executes very quickly \textbf{O}(\textbf{T}^2)
  \end{itemize}

\begin{itemize}
  \item Makes restrictive assumptions (linear pricing, no constraints)
  \item Dynamic Programming model will be more flexible.
  \end{itemize}

\section*{Simulation}

\begin{itemize}
  \item 50 homes, 3 smart appliances each
  \item Arrival rate of appliances peak around 6PM.
  \item Electricity prices (ConEd time-of-user) (21\textcent\textit{kWh} during peak and 1.4\textcent\textit{kWh} during off-peak).
\end{itemize}

\begin{itemize}
  \item Shaded regions represent peak periods.
  \item \textbf{Rebound Peak:}
    \begin{itemize}
      \item Peak shifts from 6PM to 10PM
      \item Becomes larger (83.2 kW vs. 68 kW)
    \end{itemize}
  \item Load is more variable
  \item Off-peak pricing fails to reduce peak load.
\end{itemize}

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