Communicating Appliances

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Not All Appliances are the Same

- Reducing the duty cycle of an air conditioner
  - Decreases the power consumed
  - Raises the room temperature
  - Turning most appliances on and off during an interval of minutes is not acceptable
- Delaying the power to charge an electric vehicle and controlling the amount of power to each vehicle
  - Is acceptable, sometimes
  - Delaying power for an electric light is not acceptable
  - Decreasing the power to a motor or florescent light can make them inoperable

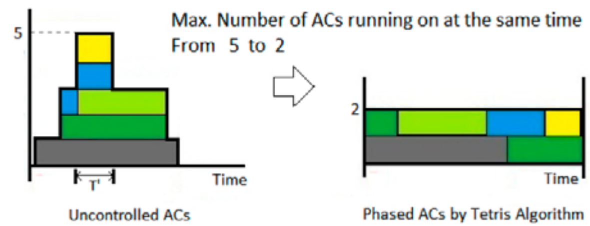
Communicating Air Conditioners

1) Types of information and control
2) Reducing Peak Power – scheduling
3) Fairness – definitions
4) Water filling algorithm based on room temperature

- Alternatives
  - Advertise higher rates during peak usage
  - Win/win
    - The utilities charge more, though it costs less to produce
    - The rich and powerful are “cooler”

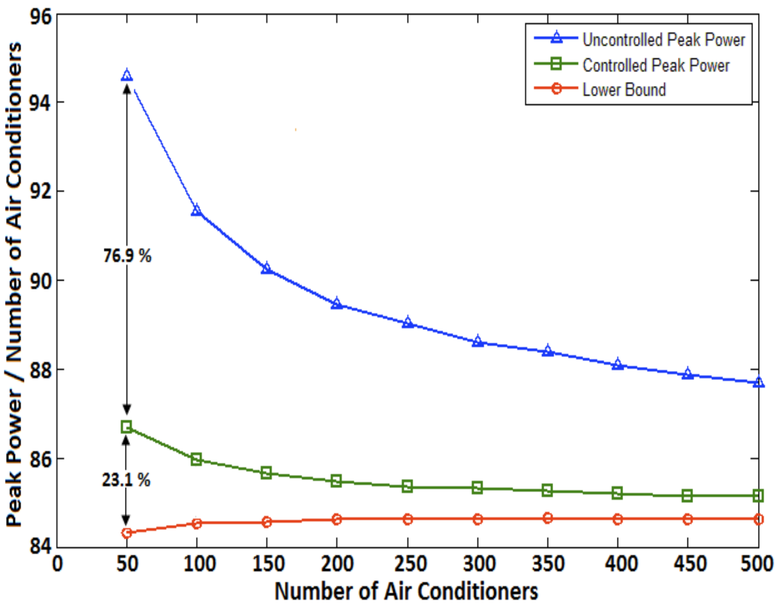
Types of Information and Control

- Duty Cycle
  - Standard period, schedule start of cycles to minimize peak power, also reduces I^2R losses



  - Fraction of the time on, control power consumption
- House Temperature
  - Decreasing “on” time increases temperature

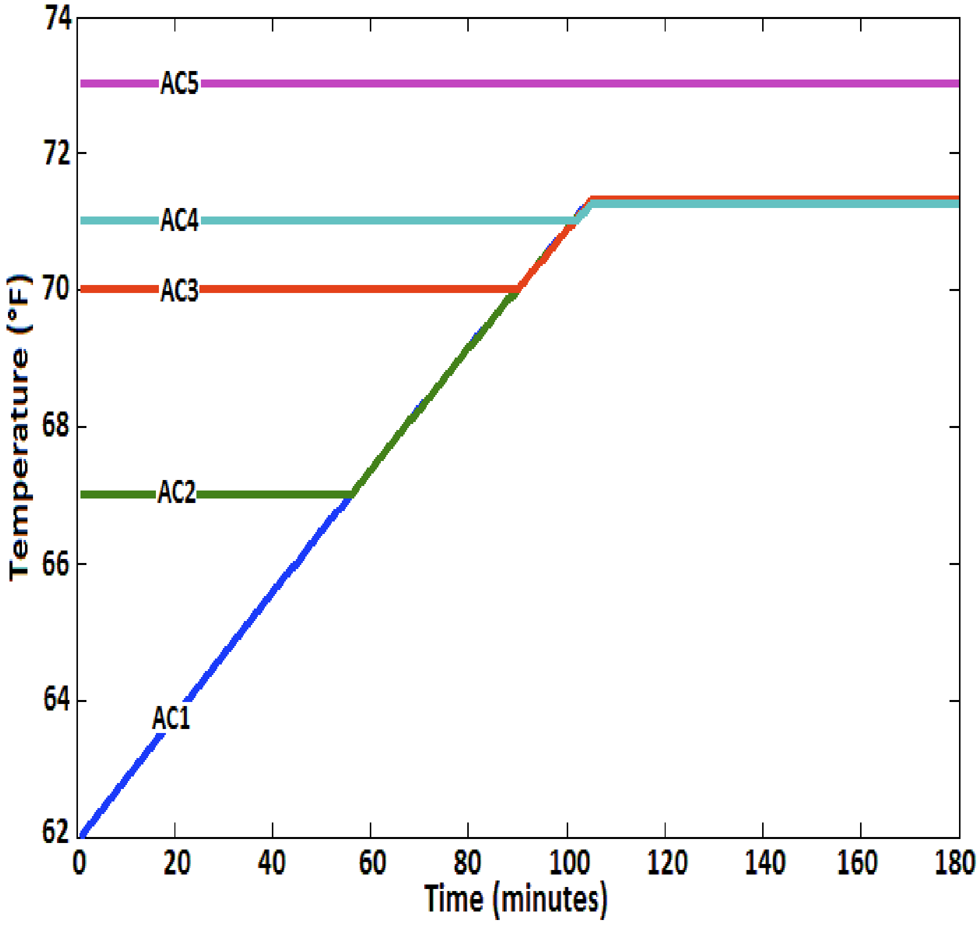
Reducing Peak Power



- In the experiment:
  - the average duty cycle is about 1/3.
    - Higher duty cycles result in smaller improvements
  - ½ of the power is consumed by air conditioners
    - Power to other appliances is a Gaussian distribution
- As the number of air conditioners becomes large, the improvement from scheduling becomes small
  - Law of large numbers
  - There will be a small change in the demand on the generating facilities
- With a small number of air conditioners there may be a significant change in the peak (8-10%)
- Also reduce heating losses on feeder cables or at a substation (I^2R losses)

Fairness

- Max-Min Fairness based on room temperature
- Reduce duty cycle of coolest homes every 15 minutes
- Continuous operation with safeguard



To Be Done

1) Calculate I^2R losses with and without scheduling
2) Other Fairness Criteria
    - Energy used by home
    - Energy per square foot - efficiency
3) Distributed Rather Than Centralized Flow Control
    - Objective: Change duty cycles as air conditioners are added or removed
    - Bandwidth Balancing (with power consumption as fairness)
        - Transmit residual power to each air conditioner in turn
        - Each air conditioner increases or decreases its duty cycle so that it takes up to α of the available power (it takes less if it meets its temperature goal)
        - Trade-off between convergence rate and fraction of power unused
    - Apply BWB to Temperature, rather than power

Recharging Electric vehicles

- Types of information and Control
- Definition of Fairness
- 3 Techniques dependent on information
- Alternative:
  - Charge less to use power in the middle of the night
    - Excess power that is available during other times may be unused
    - Overloads may still occur during the middle of the night – they just won’t be noticed until the next morning

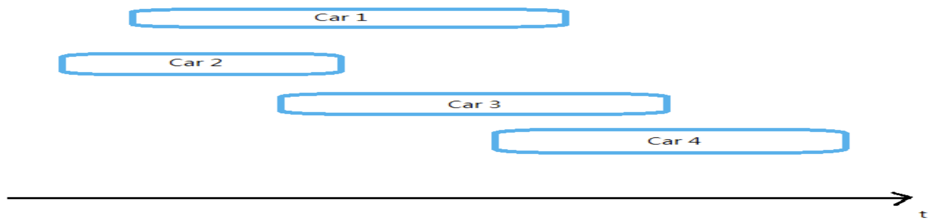
Types of information and Control

Assign the available power dependent on:

1. The number of vehicles being charged
2. The battery level in each vehicle
3. The expected departure time of each vehicle

Fairness

- Fairness is a only a concern when there isn't sufficient power to charge all vehicle completely
- A system is unfair when a vehicle that is charging at the same time as another vehicle
  - Receives power that could have been given to that vehicle, and
  - Leaves with more charge in its battery



- Fairness = $(D_{12} + D_{13} + D_{14} + D_{23} + D_{34})/5$
  - D_{ij} is the magnitude of the difference in % charge when the vehicles leave
  - This does not exactly match the definition

3 Techniques dependent on information

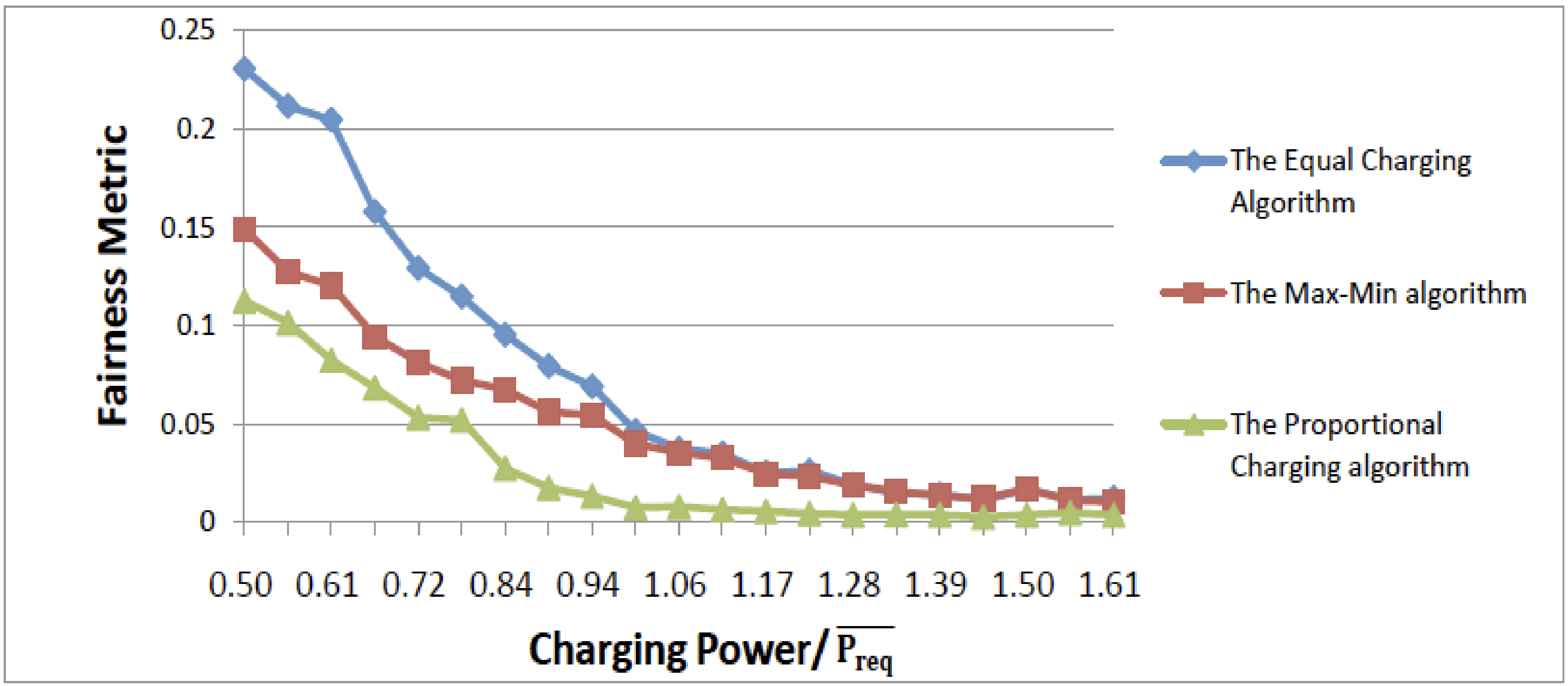
1. Given the number of vehicles being charged
    - Give each an equal share of the available power
2. The battery level of each vehicle
    - Use water filling algorithm to charge the lowest batteries first
3. The expected departure time of each vehicle
    - Proportional charging

$K_i = C_i \bullet (1 - R_i)/(T_{di} - t)$, C=Capacity of battery, R=% remaining, T_d=departure time

Fraction of $\text{power}_i = K_i/\Sigma_i(K_i)$

Simulation

Fairness as a function of the available power



Remaining Work

- Refine fairness metric
  - The current metric only considers differences in battery levels and not whether or not the difference could be reduced
    - Ie: In water filling algorithm if one vehicle receives all of the power for its time in the station and leaves early, the other vehicles that were in the station could not have given it more power
- Include maximum charging rate for vehicles
  - One vehicle may not be able to accept all of the available power
- Complete analysis of proportional fairness
  - The current work picks ratios that provide improvement, but may not be the best that can be done