An Autonomous Decentralized Mechanism for Energy Interchanges with Accelerated Diffusion Based on MCMC

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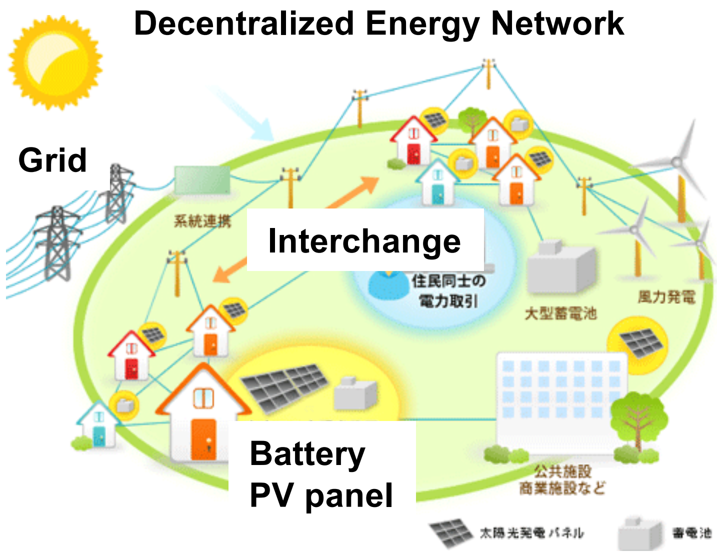
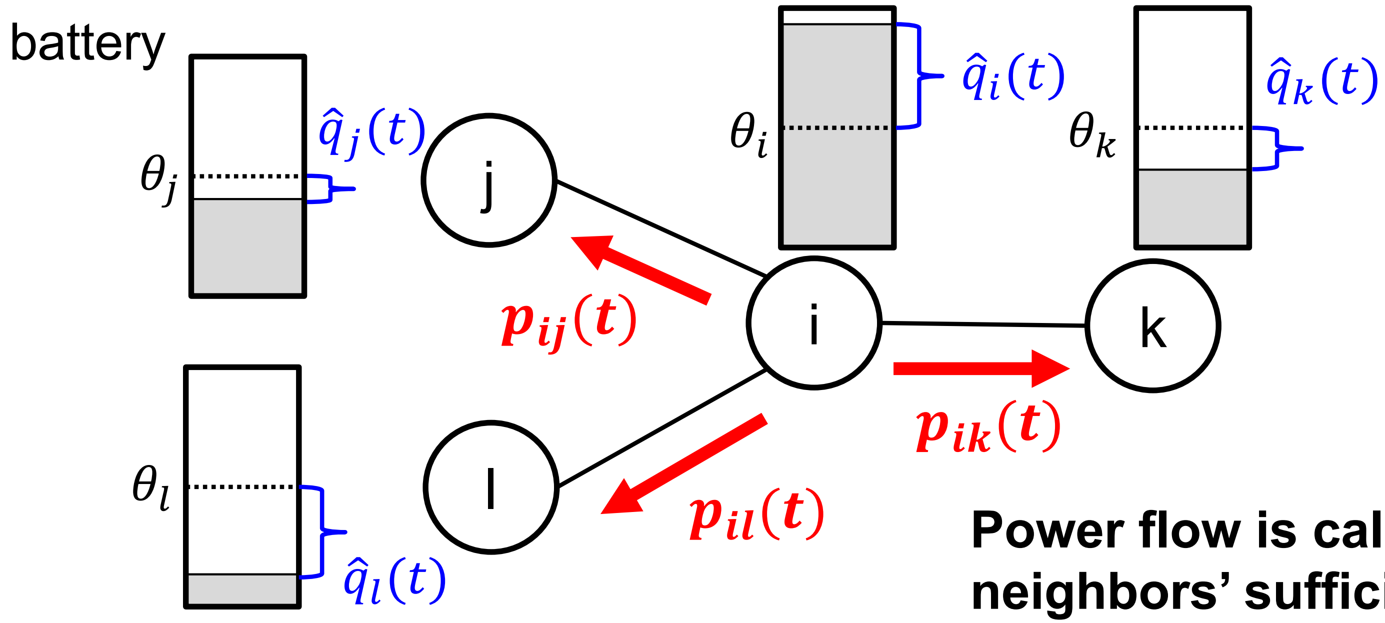
Introduction

- Background
  - Research on decentralized energy network
    - Houses with PV panel and battery
    - Local energy network for energy interchange
  - Effective utilization of renewable energy
    - Energy interchange mechanism to fill in the spatial and temporal gaps
- This work
  - Design of autonomous decentralized mechanism for energy interchange
    - Diffusion equation
    - MCMC (Markov Chain Monte Carlo)



System Model

- Battery network $G = (V, E)$
  - V: set of nodes with battery, E: set of edges
- Battery sufficiency level $\hat{q}_i(t) := q_i(t) - \theta_i$
  - $q_i(t)$: remaining amount, θ_i: target level



Power flow is calculated based on neighbors' sufficiency level

Goal: equalize the battery sufficiency level $\hat{q}_i(t)$
Approach: diffusion equation and MCMC

Basic Idea to Design Energy Interchange Mechanism

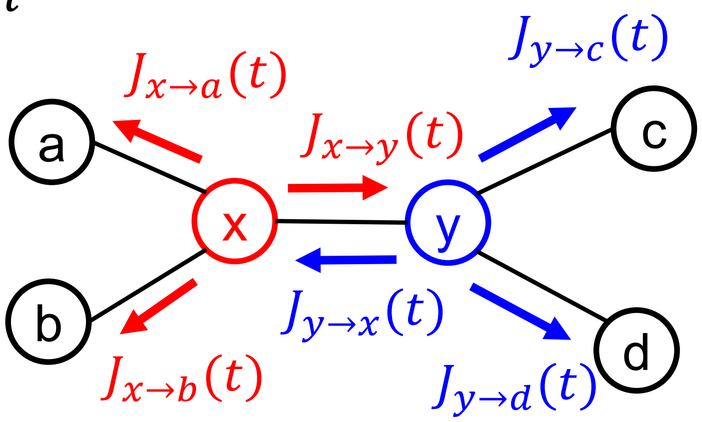
- Discrete diffusion equation

$$\hat{q}_i(t+\Delta t) - \hat{q}_i(t) = k'\Delta t \sum_{\forall j \in a_i} \left(\hat{q}_j(t) - \hat{q}_i(t)\right)$$

  - k': diffusion coefficient, a_i: set of node i's adjacent nodes
- Energy transmission amount from node i to each adjacent node j

$$\forall j \in a_i \quad J_{i\to j}(t) = k'\Delta t \cdot \hat{q}_i(t)$$

  - Only depends on sufficiency level of node i
  - Actual flow is calculated by sum of energy transmission $J_{i\to j}(t)$
  - **Long time for equalization**
- Energy transmission can be regarded as the diffusion of the energy particles
  - Movement of each energy particle is modeled by Markov chain
  - Opportunity to apply MCMC for fast equalization



$$\begin{cases} J_{x\to y}(t) = J_{x\to a}(t) = J_{x\to b}(t) \\ J_{y\to x}(t) = J_{y\to c}(t) = J_{y\to d}(t) \end{cases}$$

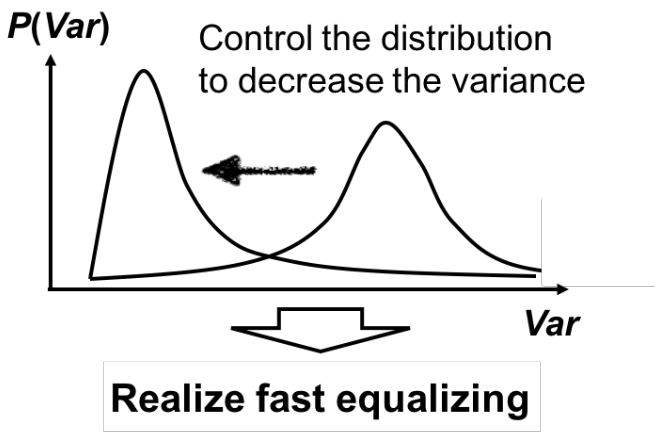
Acceleration of the Equalizing based on MCMC

- MCMC (Markov Chain Monte Carlo)
  - Method to design the Markov chain with probability distribution of the metric
- Proposed metric
  - Variance of battery sufficiency levels $\hat{q}_t(t)$

$$\mathrm{Var}(\hat{Q}(t)) = \frac{1}{|V|}\sum_{i=1}^{|V|}\left(\hat{q}_i(t) - \mathrm{E}(\hat{Q}(t))\right)^2$$

where

$$\mathrm{E}(\hat{Q}(t)) = \frac{1}{|V|}\sum_{i=1}^{|V|}\hat{q}_i(t)$$

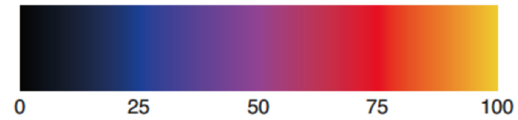


Calculation of $J_{i\to j}(t)$ is updated based on MCMC
→Fast equalization is realized!

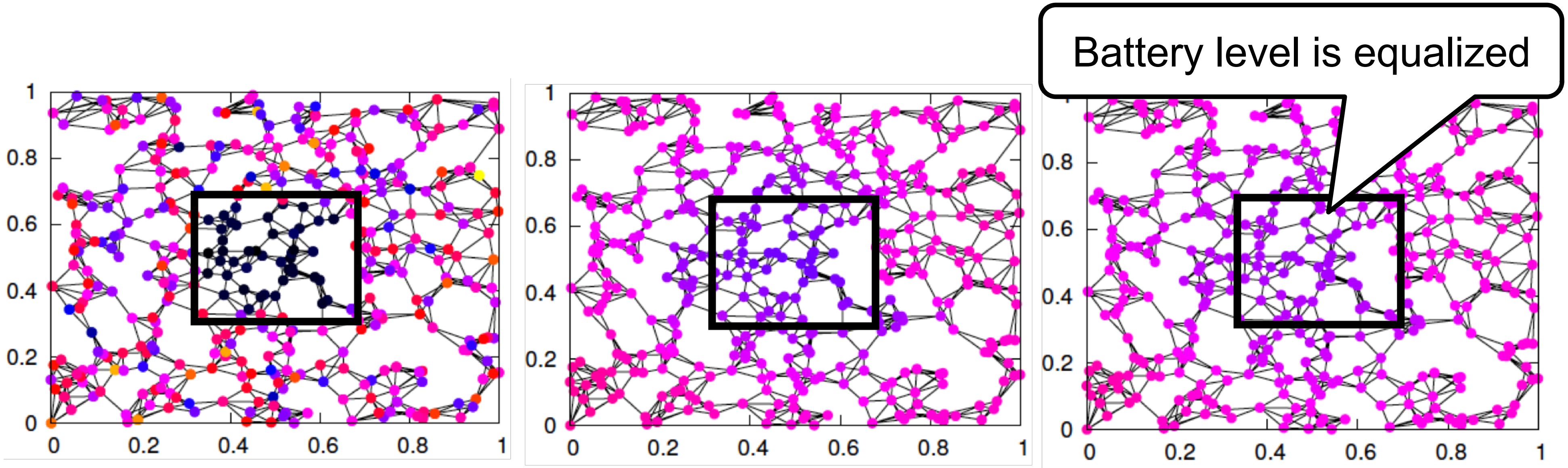
***Detail formulation can be found in [Y. Sakumoto, et al., ASP-DAC'15]**

Simulation Result: Sufficiency Level Equalization

- Time evolution of battery remaining amount $q_i(t)$
  - Target level θ_i for all nodes: 50
  - Average of $q_i(0) = 5$ in the center region
  - Average of $q_i(0) = 50$ in the other region



color map

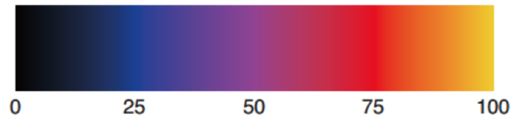


t=0 [unit time] → t=250 [unit time] → t=500 [unit time]

Battery remaining amount $q_i(t)$

Simulation Result: Demand-aware Sufficiency Level Equalization

- Time evolution of battery remaining amount
  - Target level θ_i of a few nodes: 75
  - Target level θ_i of the others: 50



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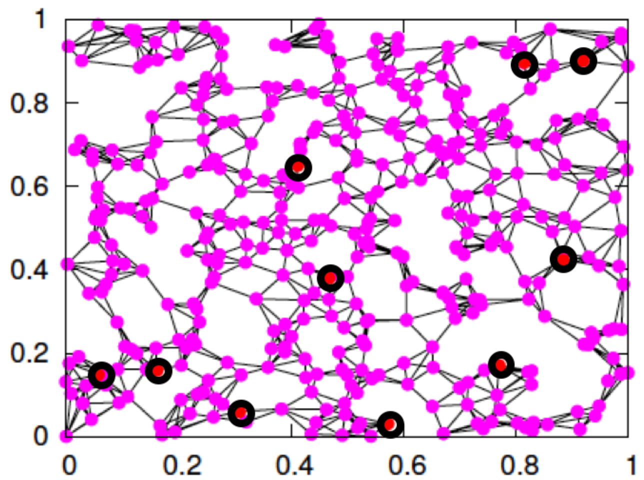
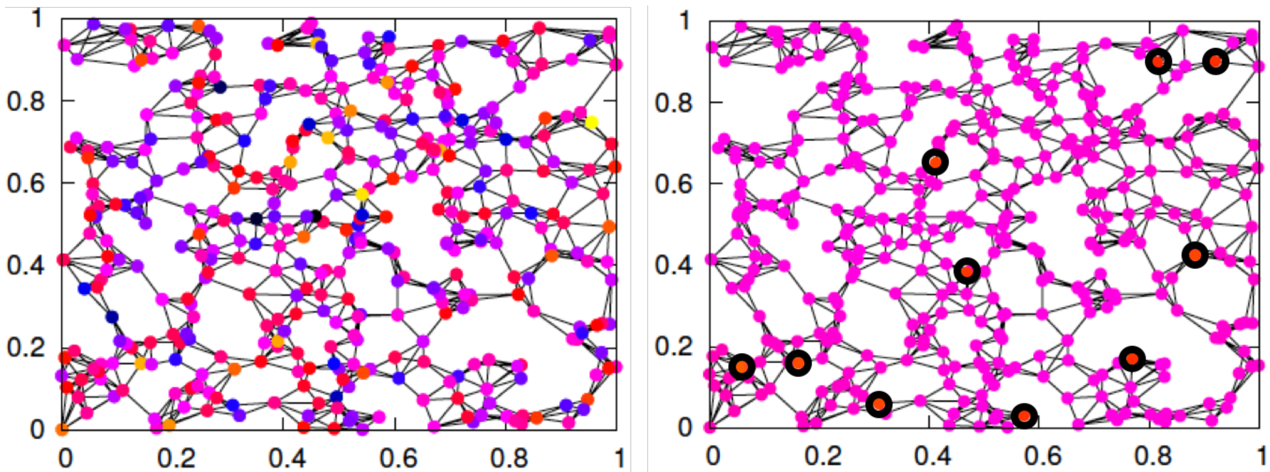


Target level θ_i

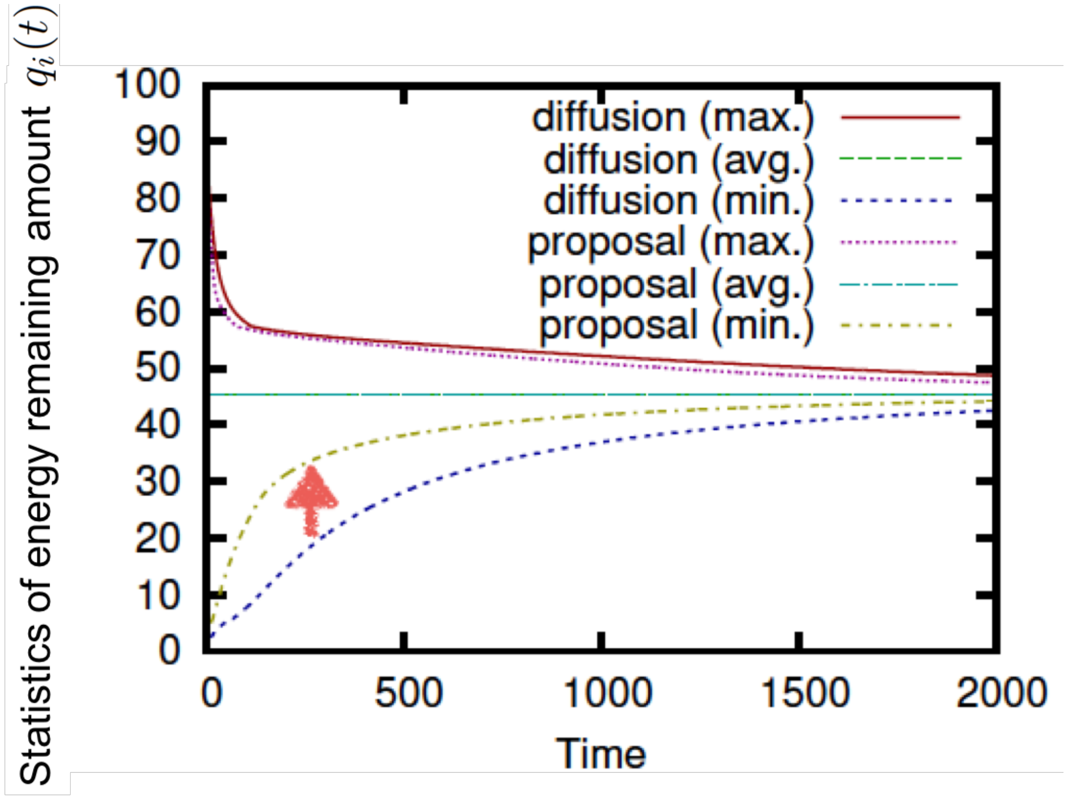


t = 0 [unit time] → t = 500[unit time]

Battery remaining amount $q_i(t)$

Simulation Result: Convergence Property in the Equalizing

- Time evolution of statistics of energy remaining amount $q_i(t)$
  - Target level θ_i for all nodes: 50
  - Average of $q_i(0) = 50$



Proposed mechanism achieved **faster energy supply** for nodes

Conclusion and Future Work

- Conclusion
  - Autonomous decentralized mechanism of the energy interchanges
    - Derived the expression of energy interchange from the diffusion equation
    - Improved the derived expression by using MCMC for fast equalizing
  - Clarified the fundamental property of the proposed mechanism on ideal scenario
- Future work
  - Evaluation on more practical scenario