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

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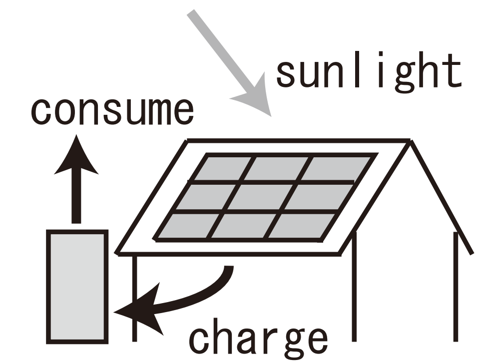
Outline

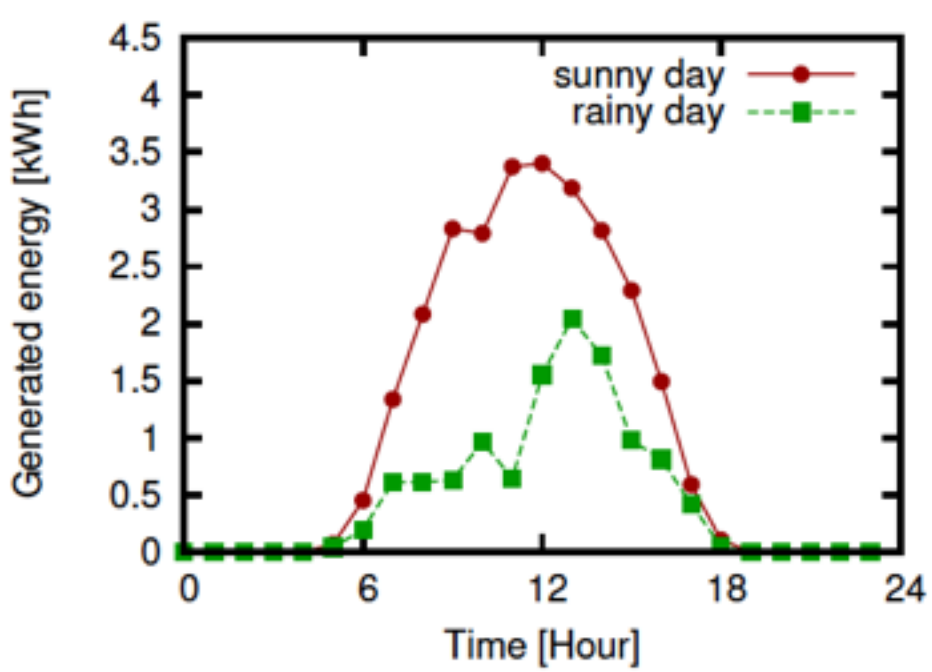
- Background
  - Renewable energy and large-scale microgrid
- Objective
  - To propose an autonomous decentralized mechanism for promoting effective use of renewable energy
    - Use of energy interchange between distributed batteries
- Design
  - Basic idea: diffusion equation and MCMC
  - Expression of energy interchange amount
- Evaluation
  - Effectiveness of our proposed mechanism
- Summary

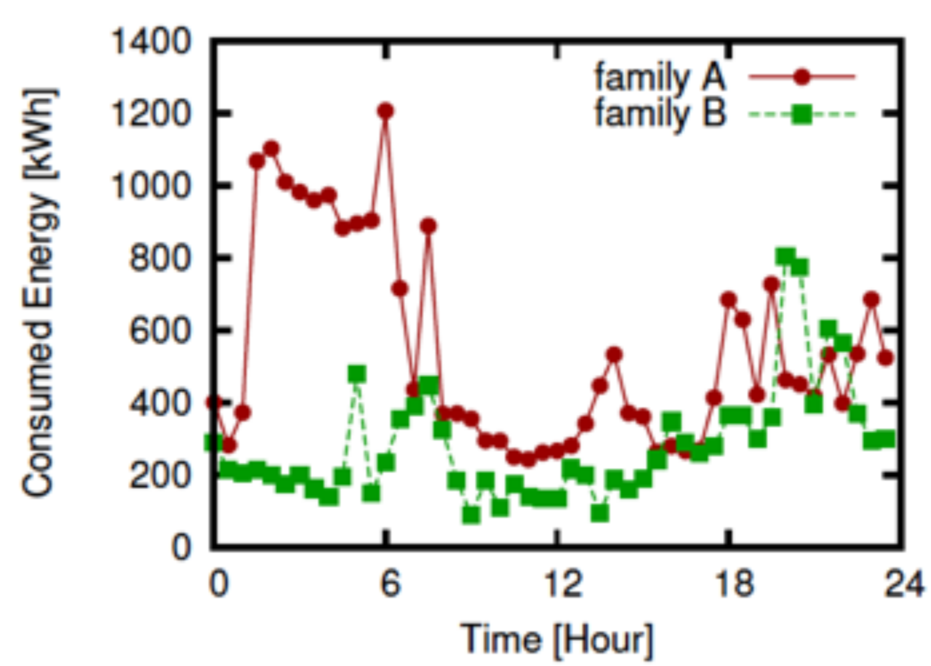
Background



- Renewable energy (e.g., sunlight and wind)
  - Is clean and inexhaustible
    → to be alternative energy of conventional fuels
  - Depends on geographical conditions and time of day
    → Difficulty supplying energy appropriately for energy demand
      → Major obstacle for the growing availability

We are attempting to alleviate this obstacle by utilizing large-scale microgrids

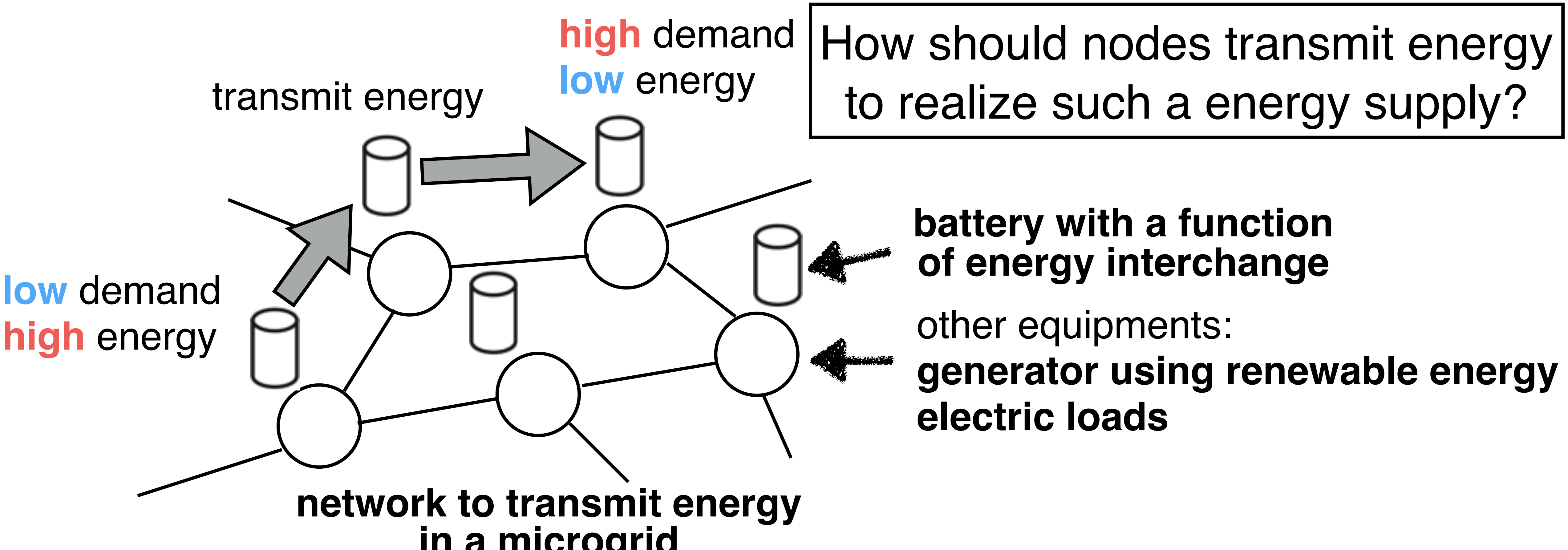




Large-Scale Microgrid

- Is an electricity system interconnecting distributed batteries in a wide area (e.g., island)
- Would be a key technology to provide energy supply appropriately for energy demand
  - By **energy interchange** between batteries

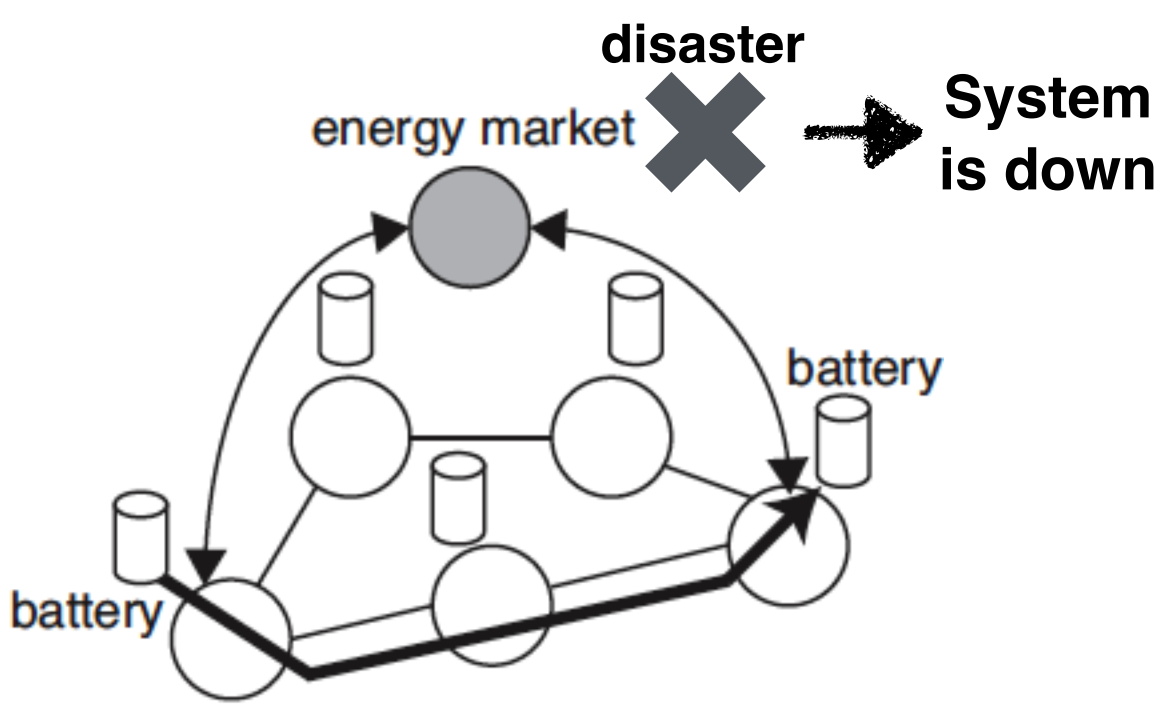
How should nodes transmit energy to realize such a energy supply?



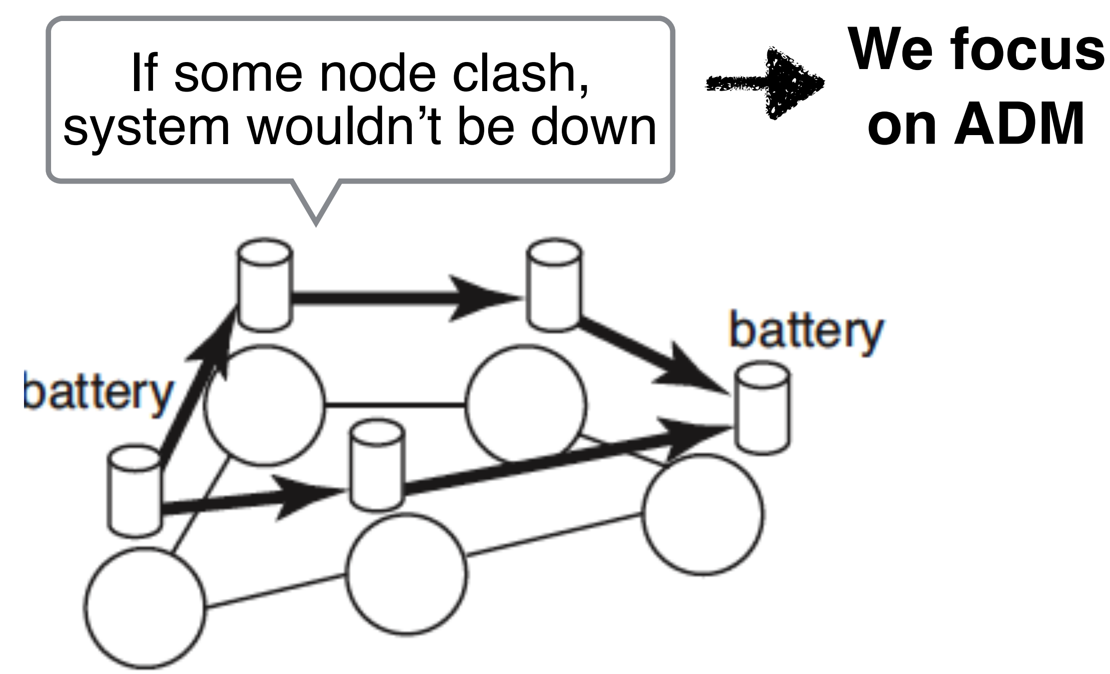
Related Work for the Energy Interchange

[4] T. Taniguchi and S. Yano, "Decentralized trading and demand side response in inter-intelligent renewable energy network," in *Proceedings of SCIS-ISIS 2012*, pp. 645–650, Nov. 2012.

- **An energy trading algorithm** proposed in [4] for energy interchange on the basis of <u>machine learning</u>
  - Supposes **a virtual energy market**
    - To Manage the energy interchange between batteries
    - A kind of centralized mechanism
      → Low robustness for disaster compared with ADM



energy interchanges with energy market and routing **[4]**



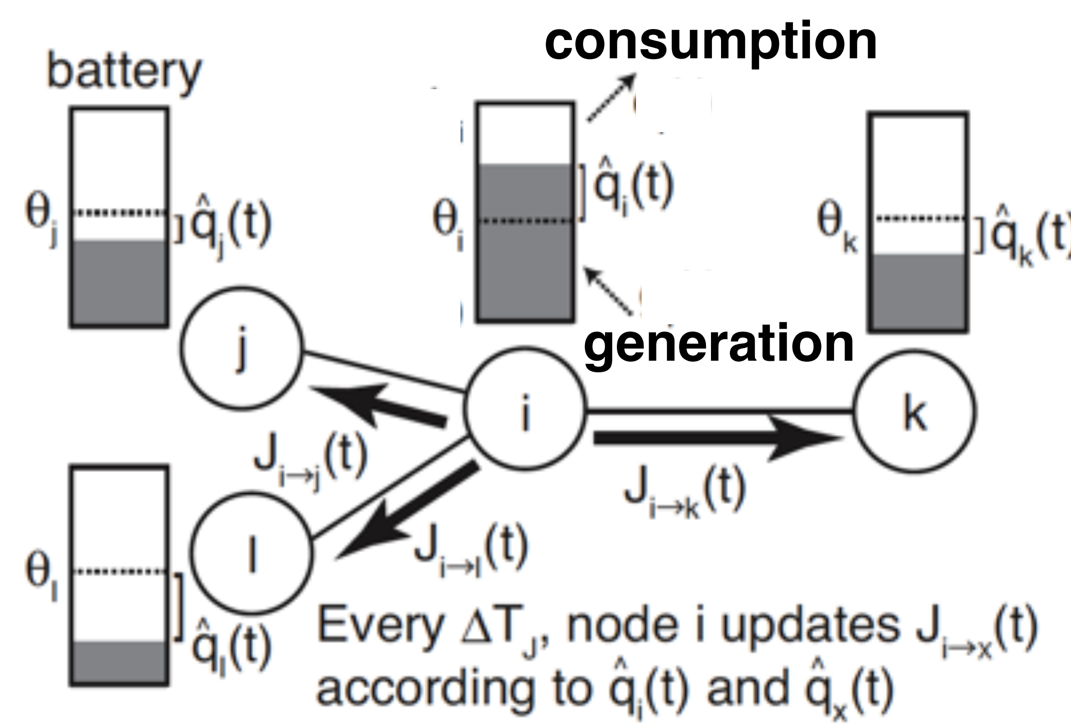
energy interchanges with autonomous decentralized mechanism **(ADM)**

Objective

- Propose an **autonomous decentralized mechanism** of the energy interchanges in large-scale microgrids
    - Goal
        - Energy supply appropriately for energy demand when using renewable energy as main power source
    - Design
        - The energy interchange amount transmitted between batteries on the basis of …
        - **Diffusion equation**
        - **MCMC** (Markov Chain Monte Carlo)
- Clarify the fundamental property of the proposed mechanism
    - Simulation experiment with a simple model

System Model

- Network **G=(V, E)** for energy interchange
  - **V** : set of nodes, **E** : set of links
  - If **(i, j)** ∈ **E**, nodes **i** and **j** can mutually transmit energy
- Node
  - Has battery, generator, load
  - Transmits energy to another node according to sufficiency levels

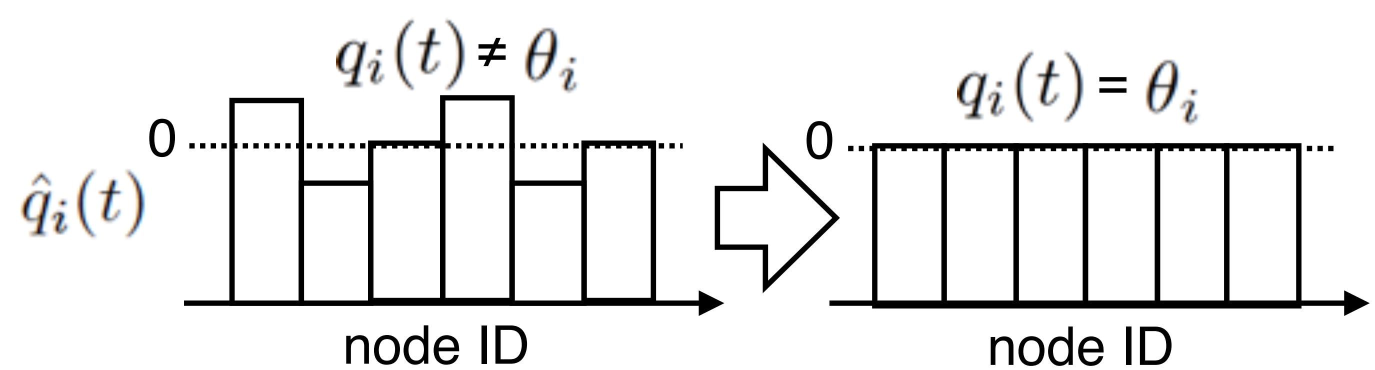


sufficiency level of node i

$$\hat{q}_i(t) := q_i(t) - \theta_i$$

battery remaining amount ($q_i(t)$)

energy demand (θ_i)



Realize energy supply appropriately for energy demand

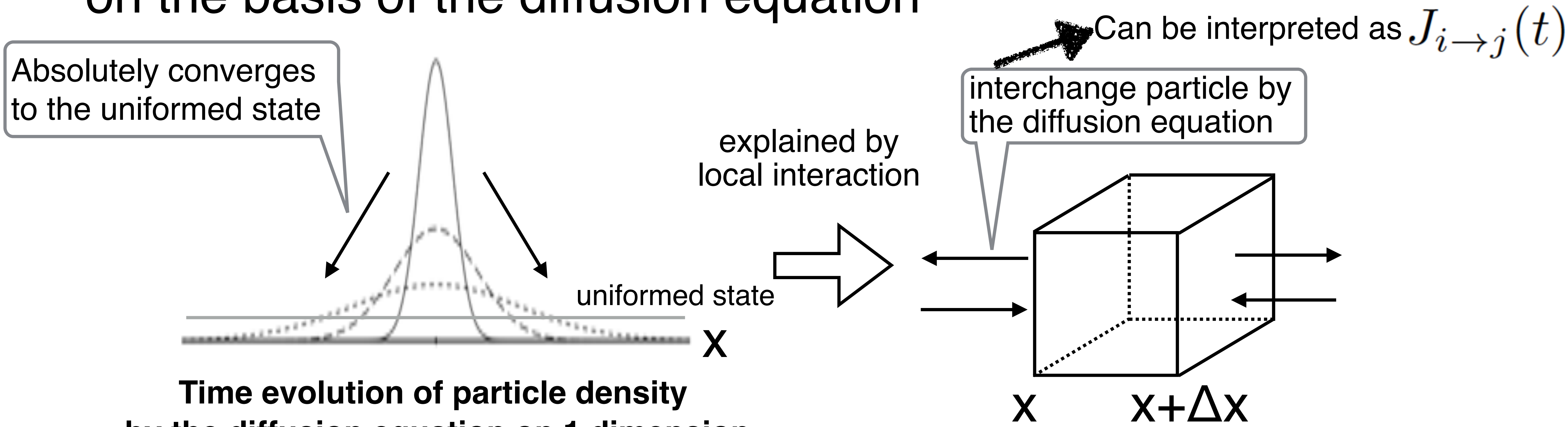
energy interchange amount from node i to node j

$$J_{i\to j}(t)$$

How should we design?

Basic Idea to Degin $J_{i \to j}(t)$

- Derive the expression of energy interchange amount $J_{i \to j}(t)$ on the basis of the diffusion equation



Time evolution of particle density by the diffusion equation on 1 dimension

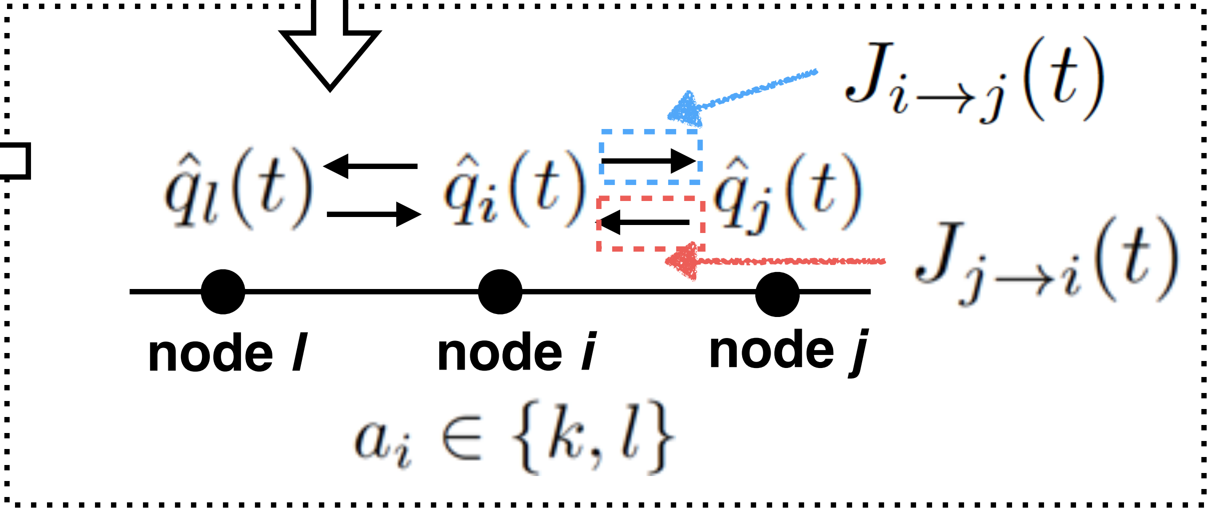
- Use MCMC for accelerating the uniforming speed of $\hat{q}_i(t)$
  - MCMC : Markov Chain Monte Carlo
  - Can fast decrease the variance of sufficiency levels $\hat{q}_i(t)$ by using MCMC

Expression of $J_{i\to j}(t)$ Based on the Diffusion Equation

- Derive expression of $J_{i\to j}(t)$ from the diffusion equation
  1. Consider the discrete diffusion equation

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

  2. Divide into the behavior of each node



$$J_{i\to j}(t) = k' \Delta T_J \hat{q}_i(t)$$

Only depends on $\hat{q}_i(t)$

Cannot preferentially transmit energy to a node with energy shortage

Poses a slow uniforming of $\hat{q}_i(t)$

Acceleration of the Uniforming on the Basis of MCMC[8]

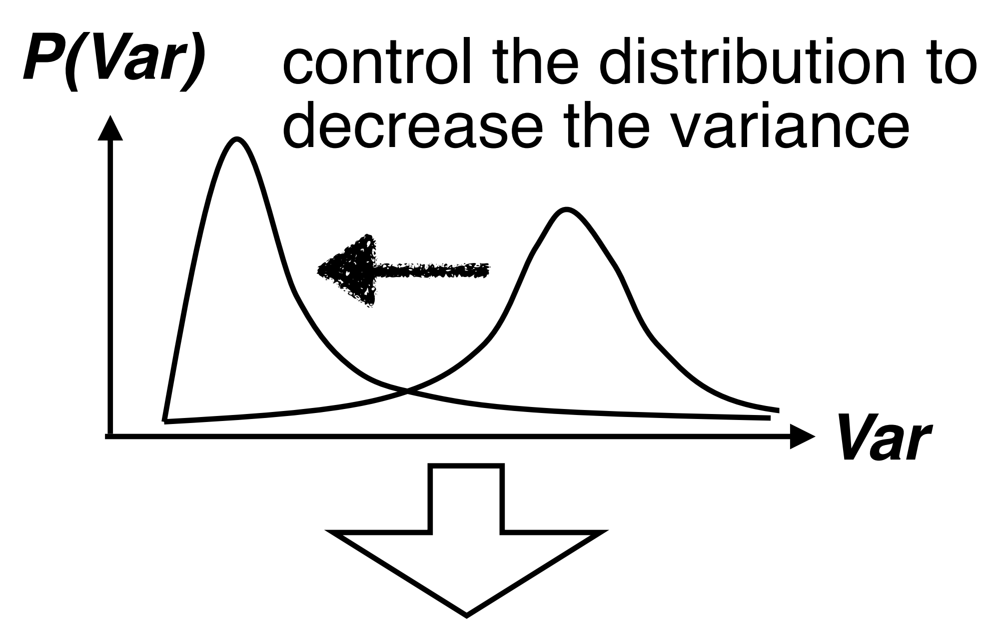
- MCMC (Markov Chain Monte Carlo)
  - A method to control the probability distribution of a metric
- A metric for fast uniforming sufficiency levels $\hat{q}_i(t)$

variance of sufficiency levels $\hat{q}_i(t)$

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

average of sufficiency levels

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



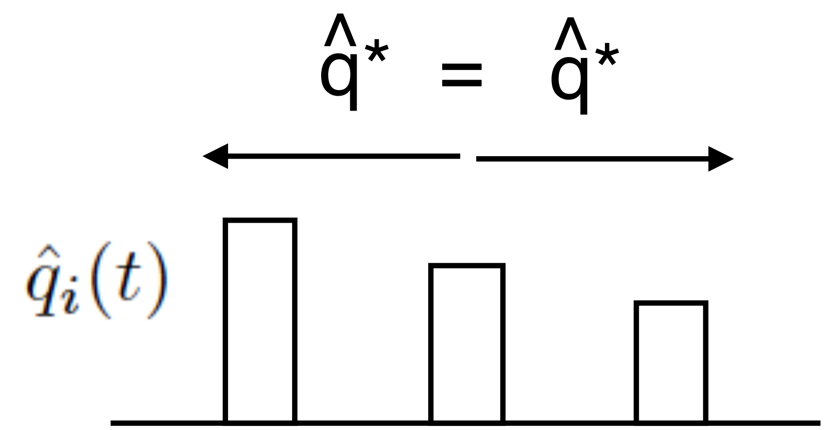
realize fast unifomizing

[8] M. E. Newman, G. T. Barkema, and M. Newman, "Monte carlo methods in statistical physics," *Clarendon Press Oxford*, Apr. 1999.

Expression of $J_{i\to j}(t)$ Based on MCMC

- $J_{i\to j}(t)$ based on the diffusion equation
  - Only depends on $\hat{q}_i(t)$
    → Same value if $\hat{q}_j(t)$ is different

$$J_{i\to j}(t) = k'\,\Delta T_J\,\hat{q}_i(t) \quad \textbf{(5)}$$



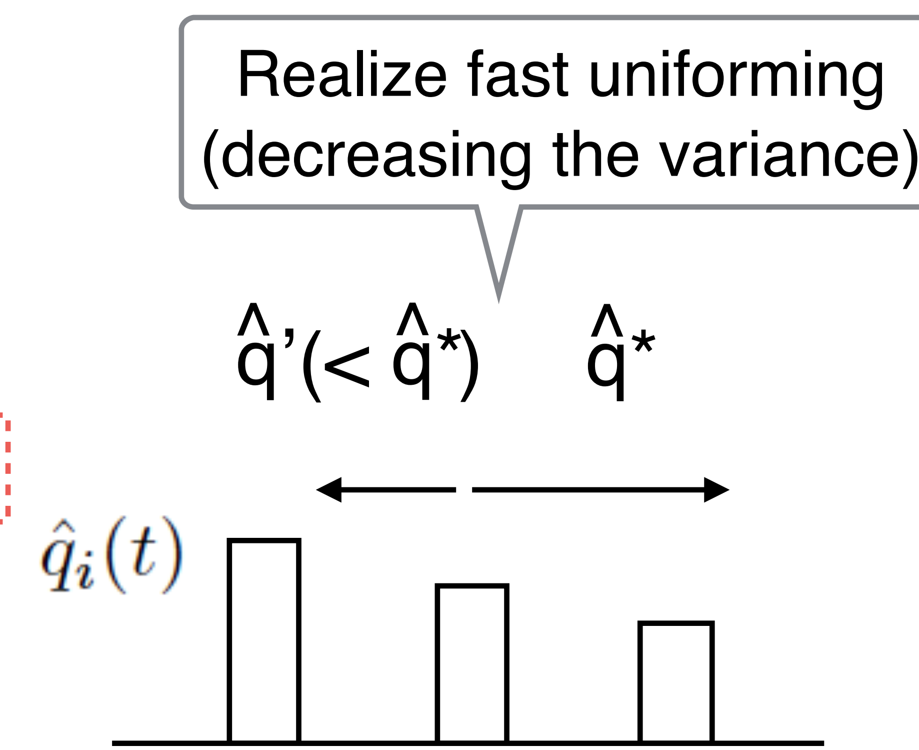
energy interchange by Eq.**(5)**

- $J_{i\to j}(t)$ based on MCMC
  - Depends on $\hat{q}_i(t)$ and $\hat{q}_j(t)$

$$J_{i\to j}(t) = k'\,\Delta T_J\,f_{i\to j}(\hat{q}_i(t), \hat{q}_j(t))\,\hat{q}_i(t) \quad \textbf{(7)}$$

$$f_{i\to j}(\hat{q}_i(t), \hat{q}_j(t)) = 1 - \kappa' |\hat{q}_j(t) - \hat{q}_i(t)|\,[\hat{q}_j(t) - \hat{q}_i(t)]^+$$

where $[x]^+ = \max(0, x)$.



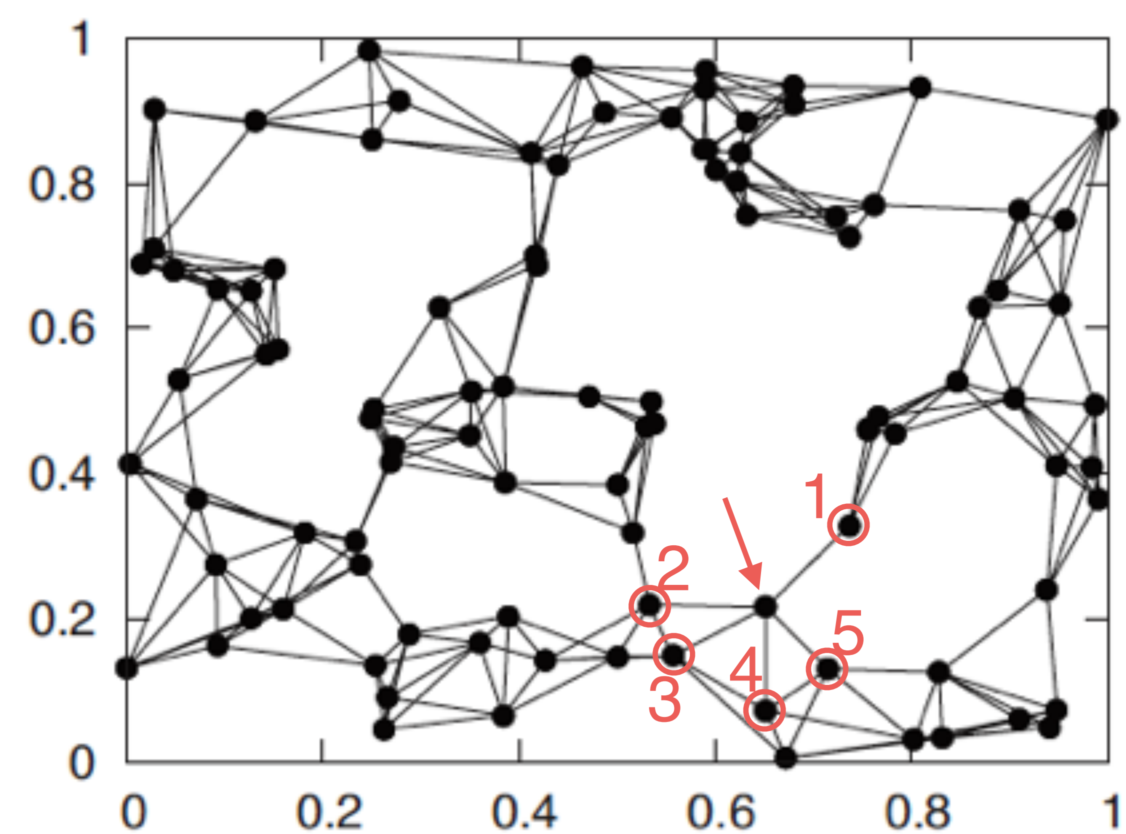
energy interchange by Eq.**(7)**

Evaluation Using Simulation Experiment

- Investigate the **fundamental property** of the proposed mechanism
  - Can it supply energy appropriately for energy demand?
- Use simple simulation model to focus on **uniforming sufficiency levels** $\hat{q}_i(t)$ by the proposed mechanism
  - Assume 'generated energy' = 'consumed energy'
  - Ignore any loss of energy interchanges
  - Set demand amount θ_i to a time-invariant value
- Use the following simulation procedures
  - Randomly set battery remaining amount $q_i(0) \sim \mathrm{N}(\mu_q^{\mathrm{st}}, \sigma_q^{\mathrm{st}})$ at the start of simulation
  - Repeat energy interchange between nodes during simulation

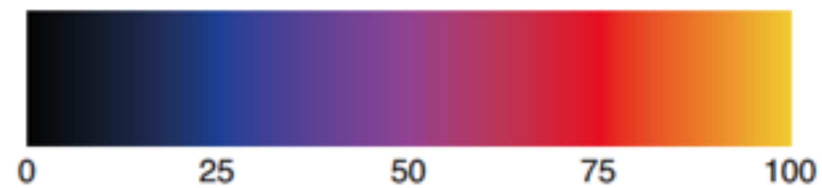
Network Topology: N_k-th Nearest Neighbor Network

- Is generated by the following procedure
  1. N nodes are randomly placed in the 2-dimensional plane
  2. Each node selects N_k-th nearest nodes as its adjacent nodes
- Represents **actual property**
  (a) geographical dispersion of nodes
  (b) wiring const between nodes



An example of N_k=5 and N=100

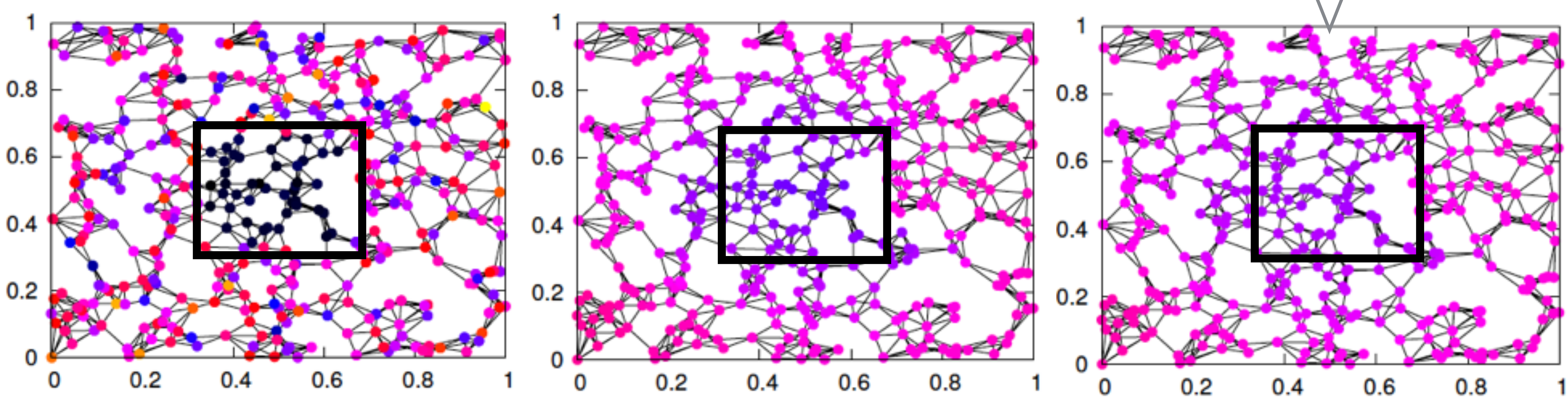
Result to Confirm the Uniforming Sufficiency Levels



color map

- Time evolution of battery remaining amount $q_i(t)$
  - Demand amount θ_i for all node = **50**
  - Average of $q_i(0)$ = **5** in the center region
  - Average of $q_i(0)$ = **50** in the other region

The proposed mechanism can uniform them



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

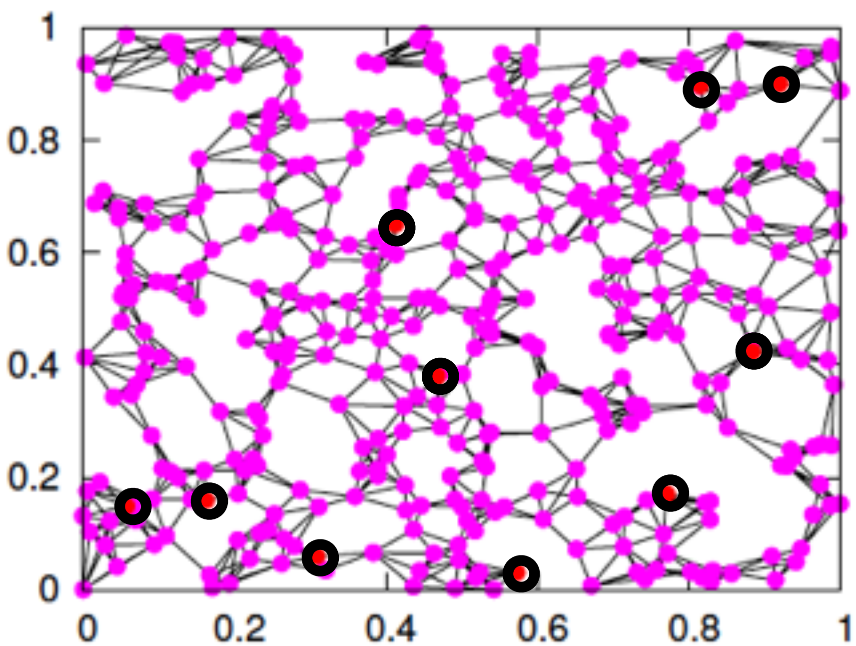
battery remaining amount $q_i(t)$

Result to Confirm Energy Supply Appropriately for Energy Demand

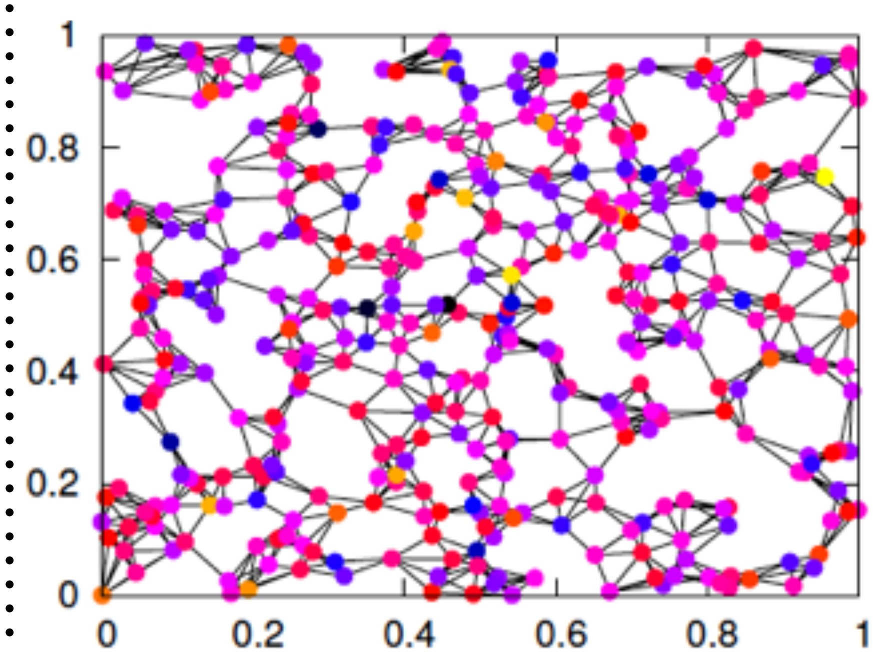
- Time evolution of battery remaining amount
  - Set a few nodes to high demand amount **75**
  - Set other nodes to demand amount **50**

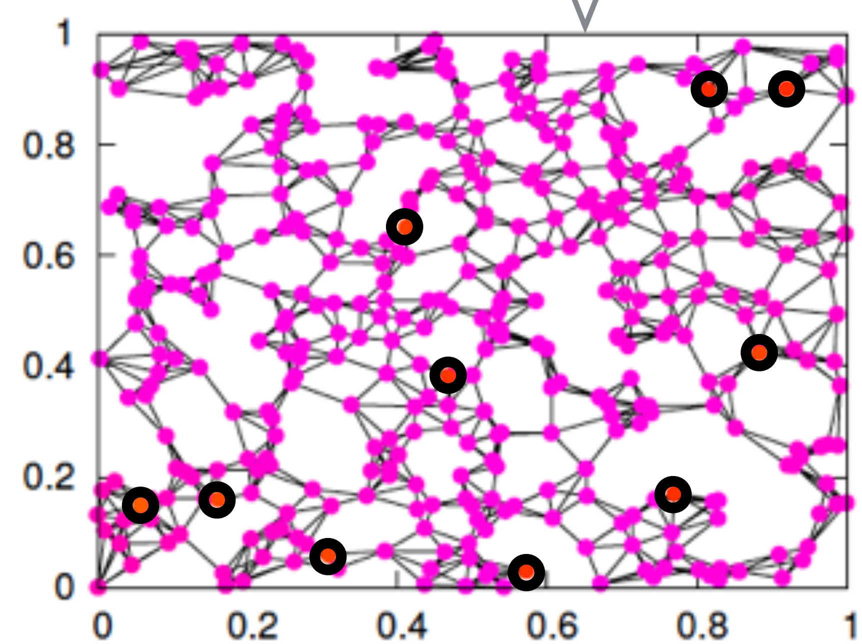
color map

The nodes with high demand θ_i have high $q_i(t)$



demand amount θ_i



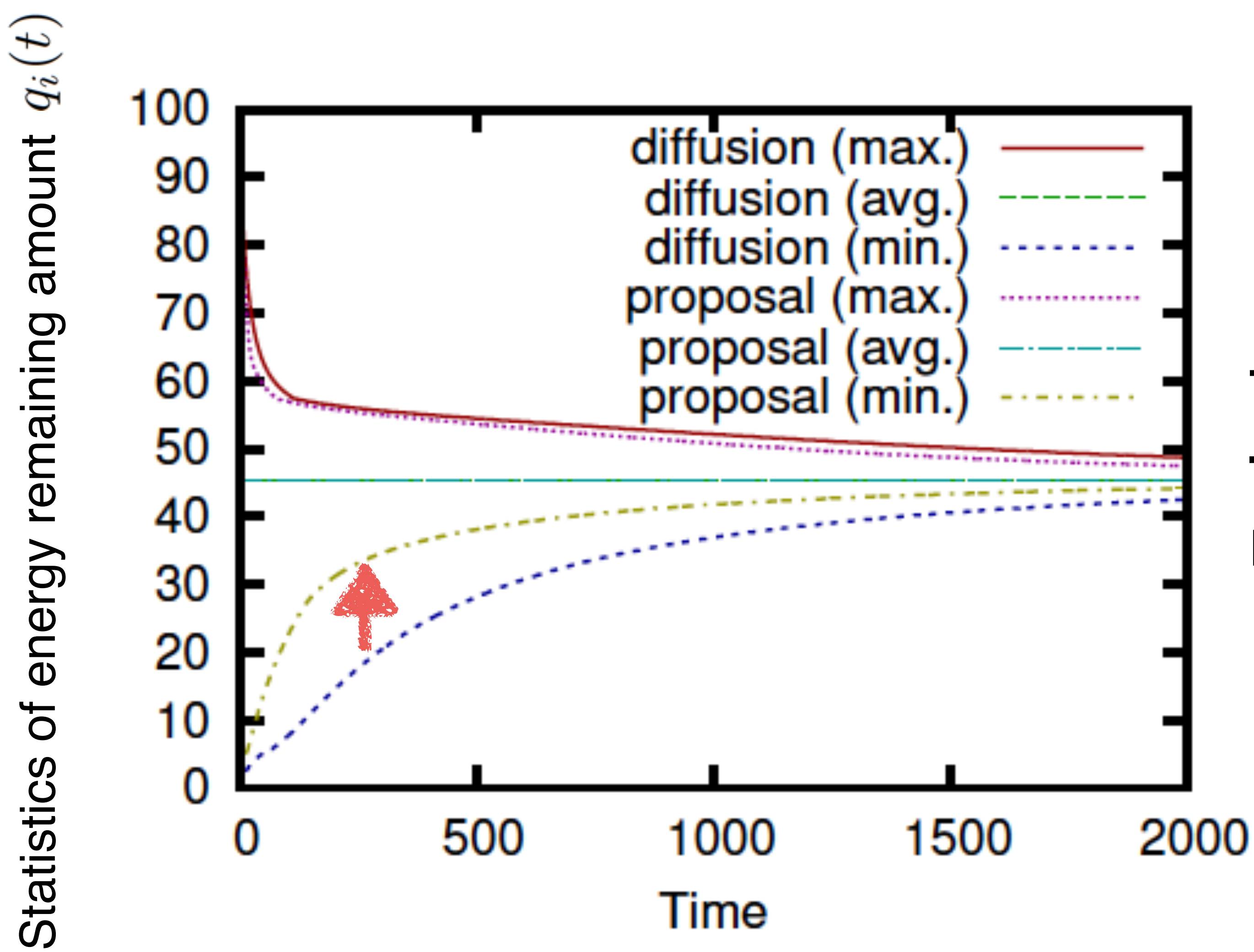


t = 0 [unit time] → t = 500[unit time]

battery remaining amount $q_i(t)$

Result to Confirm Convergence Property in the Uniforming

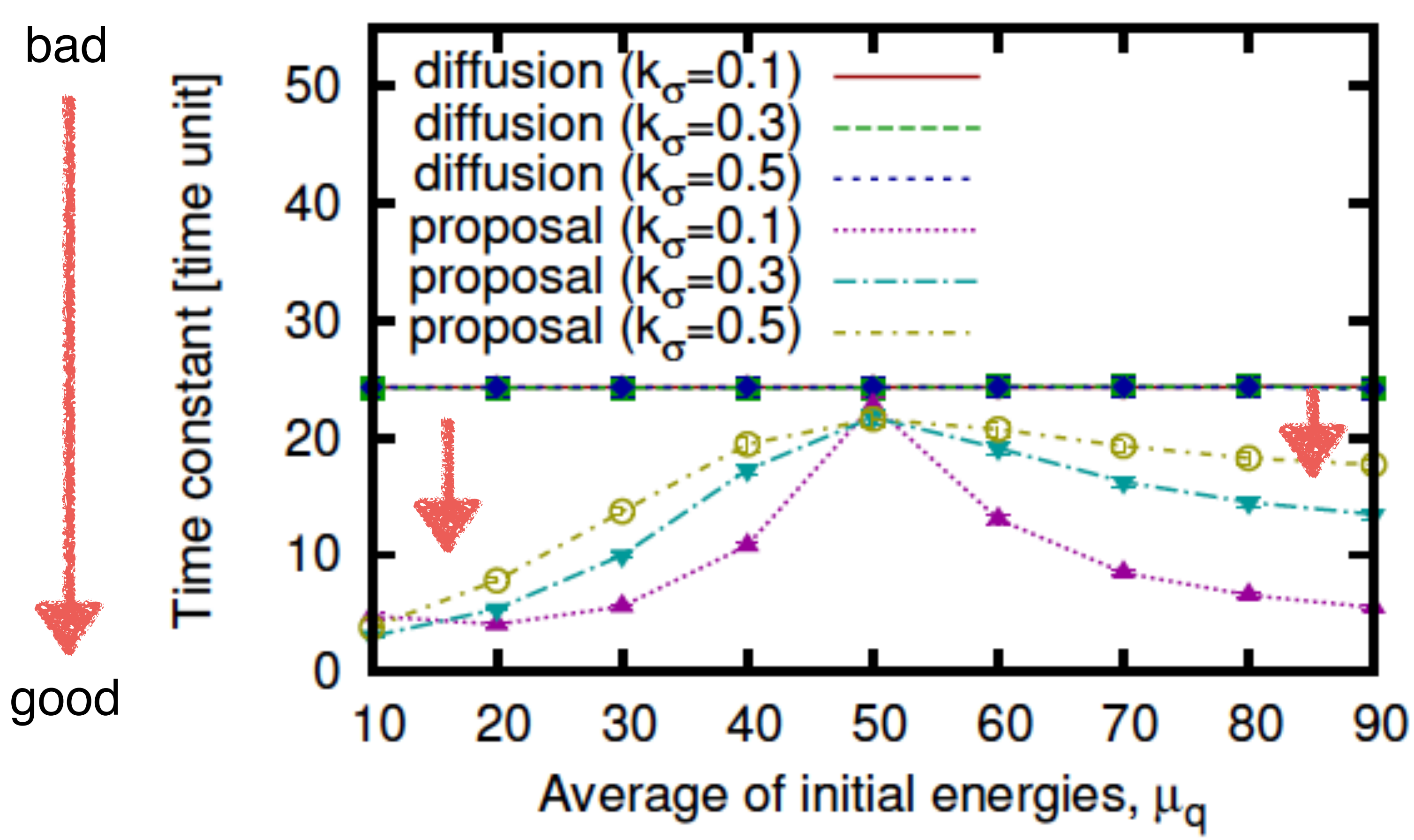
- Time evolution of statistics of energy remaining amount $q_i(t)$
  - Demand amount θ_i for all node = **50**
  - Average of $q_i(0)$ = **50**



The proposed mechanism can **faster energy supply** for nodes with a shortage of energy

Result to Confirm the Uniforming Speed

- Time constant for different average of $q_i(0)$
  - Demand amount θ_i for all node = **50**
  - Time constant is the time required for decreasing initial variance $\mathrm{Var}(\hat{Q}(0))$ (= sqr. of $k_\sigma\,\mu_q^{\mathrm{st}}$) to $e^{-1}\,\mathrm{Var}(\hat{Q}(t))$



The proposed mechanism has high effectiveness for **too energy shortage** and **surplus situations**

Summary

- Proposed an autonomous decentralized mechanism of the energy interchanges in large-scale microgrids
  - Derived the expression of energy interchange amount $J_{i \to j}(t)$ from the diffusion equation
  - Improved the derived expression by using MCMC for fast uniforming $\hat{q}_i(t)$
- Clarified the fundamental property of the proposed mechanism
  - Confirmed the proposed mechanism can fast supply energy appropriately for energy demand

Future Work

- Clarify the performance of the proposed mechanism in a realistic situation with considering …
  - Battery physical properties
    - The rate capacity effect
    - The degrading its performance
  - Energy loss of interchanges
  - Time variability in energy generation and consumption
- Integrate a conventional generator into our proposed mechanism
  - For satisfying energy demand of all nodes in microgrids
- Design the setting policy of energy demand
  - For the efficient use of energy in microgrids

Thank you