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Analysis of Energy Consumption for a Biological Clustering Method in Sensor Networks

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Outline of the Talk

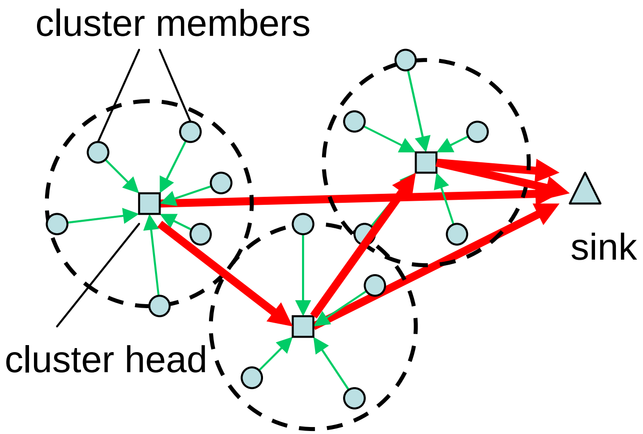
- Introduction
- Clustering in sensor networks
- Biological clustering method
- Analytical model using stochastic geometry
- Numerical evaluation
- Conclusion and outlook

Introduction

- Networks of sensor nodes have become widely available
- Applications include e.g.
  - monitoring of environment conditions (heat, light, ...)
  - localization or tracking

- Sensor nodes contain: sensing device, RF transceiver, battery
- **Main problem**: energy consumption!

Clustering in Sensor Networks



- Nodes logically organized in clusters:
  - cluster heads
  - cluster members
- Cluster heads collect data from members and forward to sink
- Cluster heads use more energy
  ➔ their role is rotated for equalization
- Biologically inspired clustering method based on LEACH

Main Contribution of this Paper

- Evaluate the energy consumption per round of the biological clustering approach
- Apply methods from stochastic geometry in performance analysis of sensor networks
- Find optimal parameters for cluster head candidacy radius R and meeting radius r

J. Kamimura, N. Wakamiya, and M. Murata. Energy efficient clustering method for data gathering in sensor networks. In *First Workshop on Broadband Advanced Sensor Networks (BaseNets)*, San Jose, CA, Oct. 2004.

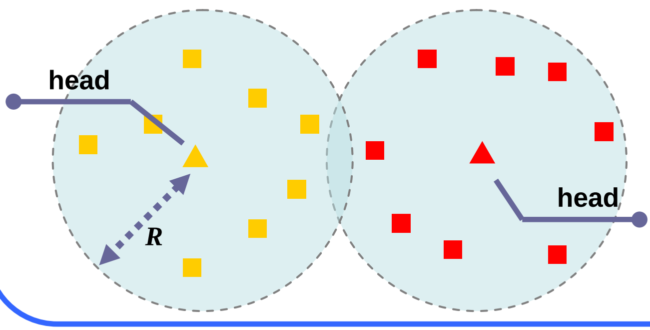
Biological Clustering Method (1)

- Based on behavior of ants (colonial closure)
- Nest mates are recognized by chemical substance ➔ similarity of ants
- **Basic principle:**
  Two randomly chosen objects meet with each other and clusters are created, merged, and discarded through local meetings

Biological Clustering Method (2)

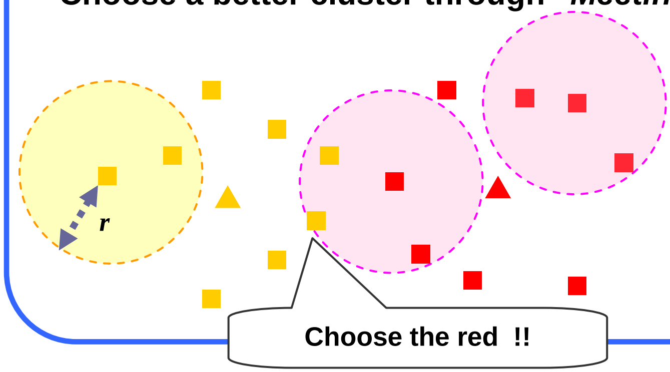
1. Cluster-head Candidacy Phase :

- Candidacy for a cluster-head

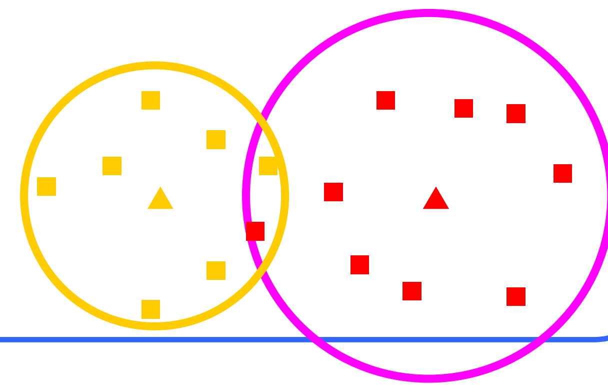


2. Cluster Formation Phase :

- Choose a better cluster through "*Meetings*"

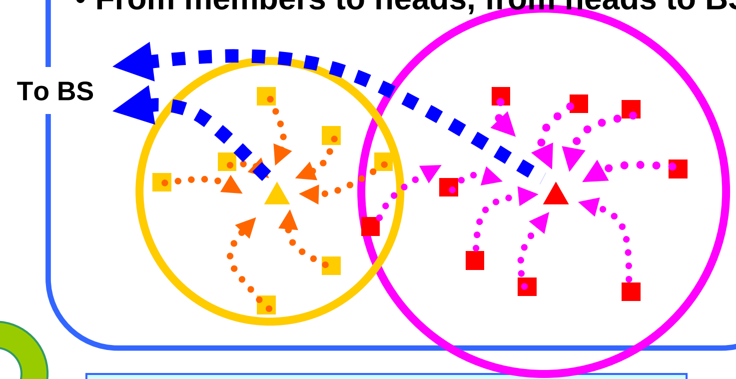


3. Registration Phase :



4. Data Gathering Phase :

- From members to heads, from heads to BS



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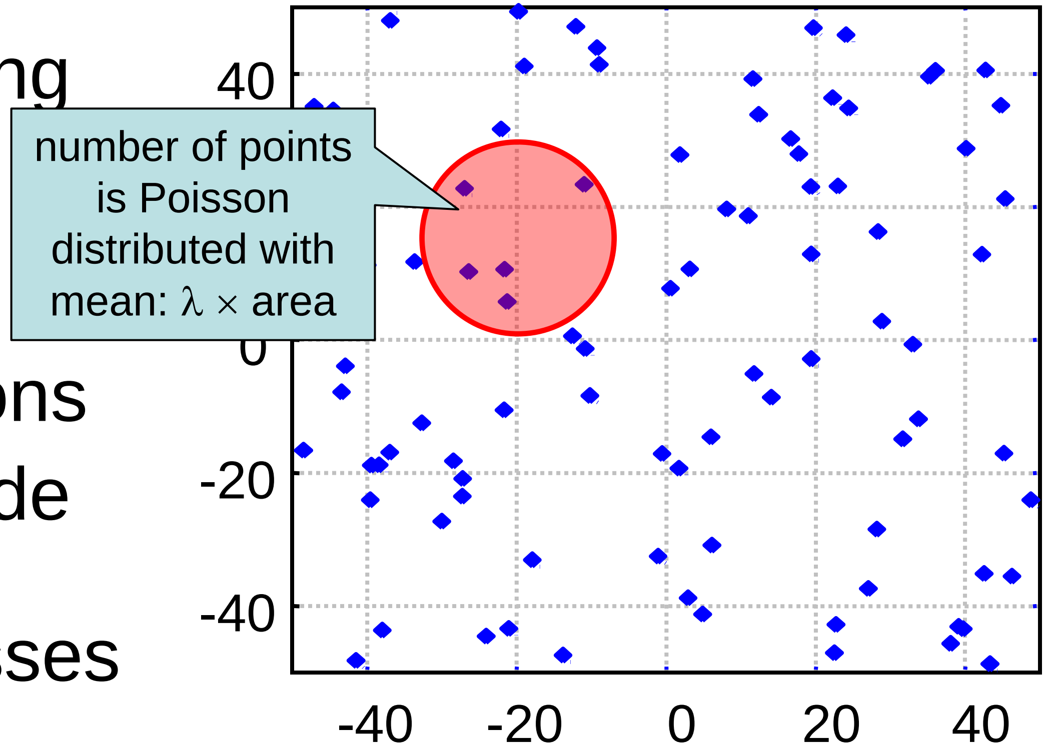
Models from Stochastic Geometry

- Useful for modeling random spatial distributions, e.g. biology, geology, telecommunications
- Description of node distribution by stochastic processes



- **Example:**
  homogeneous Poisson process with density λ, i.e. mean number of points per unit area
  $\Rightarrow N_w = \lambda\pi W^2$ $\quad N_n = \lambda\pi R^2$

Campbell's Theorem

Theorem: Let $\Pi = \{x_1, x_2, \ldots\}$ be a Poisson process with density λ, and let $f: \mathbb{R}^2 \rightarrow \mathbb{R}$, be a measurable function. Let S_A be the following sum

$$S_A = \sum_{x_i \in A \cap \Pi} f(x_i)$$

defined for any compact set A, then

$$E[S_A] = \int_A f(x) \lambda \, dx$$

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Key Points of the Analysis

- Transmission energy from cluster members to CH are calculated with Campbell's Theorem

number of nodes per cluster

energy for transmitting l bits

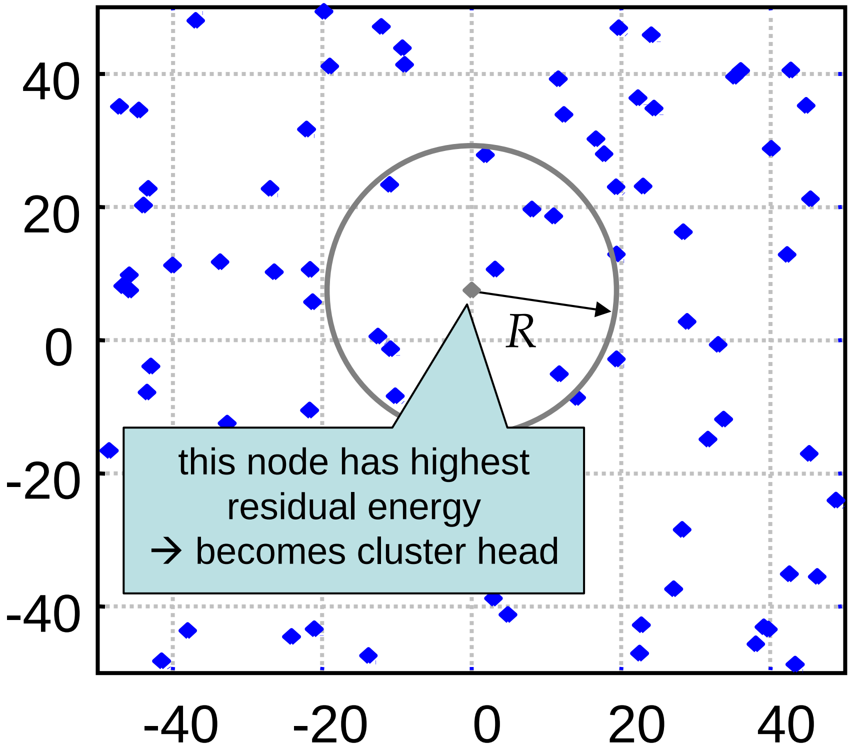
$$E_c(l,R) = \lambda\pi R^2 \times l\left(E_{elec} + \varepsilon_{fs} R^2\right)$$

- Point process for CHs is given by **Matérn hard-core process** (dependent thinning of Poisson process)

$$\lambda_c = \frac{1-\exp\left(-\lambda\pi R^2\right)}{\pi R^2} \qquad N_c = \lambda_c W^2$$

Matérn Hard-Core Process

- **Marked Poisson process**: each point has a random “mark” (residual energy)
- Process consists of points that are greatest compared to the mark of points lying in a circle around this point



Energy Consumption Model

- Energy of four phases of the algorithm is computed for specific layout and density
- Message aggregation:

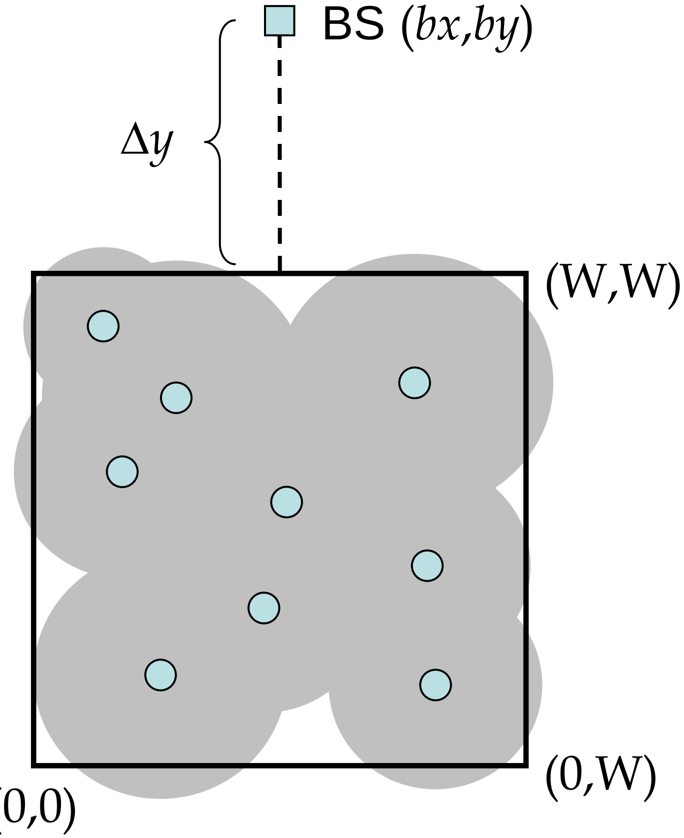
$$\tilde{l}_M = [N - (N-1)\rho]\, l_M$$

compression factor $\rho \in [0,1]$
message length l_M

- "No-Clustering" energy:

$$\hat{E}_{total} = \lambda l_M W^2 \left[2 E_{elec} + \varepsilon_{mp}\, \alpha\right]$$

layout-dependent constant α



Detailed Model

- Phase 1: CH broadcast candidacy

$$E_1 = N_c\, [E_{Tx}(l_B, R) + N_n\, E_{Rx}(l_B)]$$

- Phase 2: Cluster formation

$$E_2 = N_w\, P_{ex}\, [E_{Tx}(l_B, r) + \lambda\pi r^2\, E_{Rx}(l_B)]$$

- Phase 3: Registration

$$E_3 = N_c\, [E_c(l_R, R) + N_n\, E_{Rx}(l_R) + E_{Tx}(l_S, R) + N_n\, E_{Rx}(l_S)]$$

- Phase 4: Data transmission

$$E_4 = N_c\, [E_c(l_M, R) + N_n\, E_{Rx}(l_M) + (N_\mathrm{n}+1)\, l_M\, E_{fuse}] + E_h$$

$$E_h = \lambda_c \int_0^W \int_0^W E_{Tx}\left(\tilde{l}_M, d_{BS}(\{x,y\})\right) dx\, dy$$

energy from all CH to BS using Campbell's Theorem

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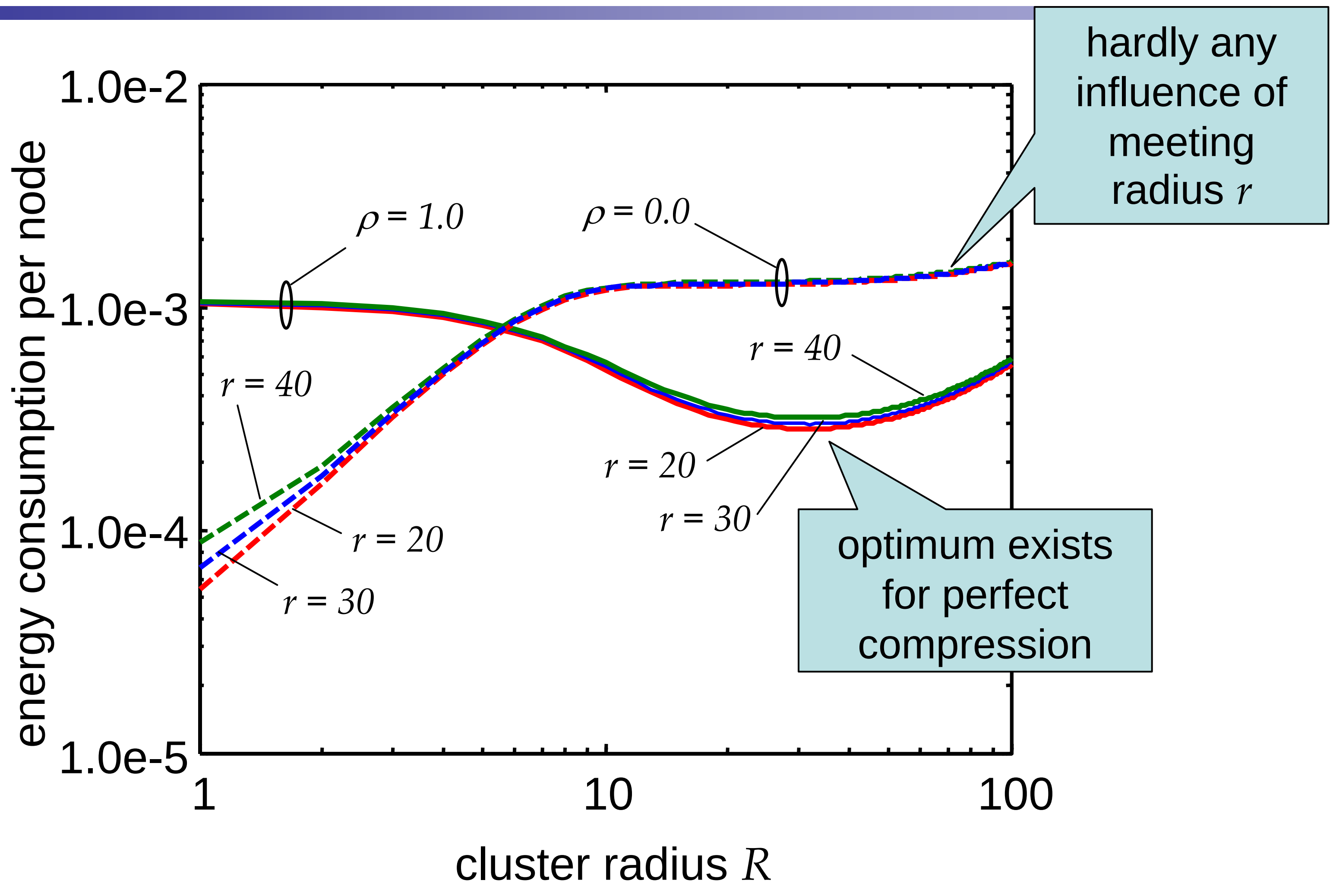
Energy Consumption over R



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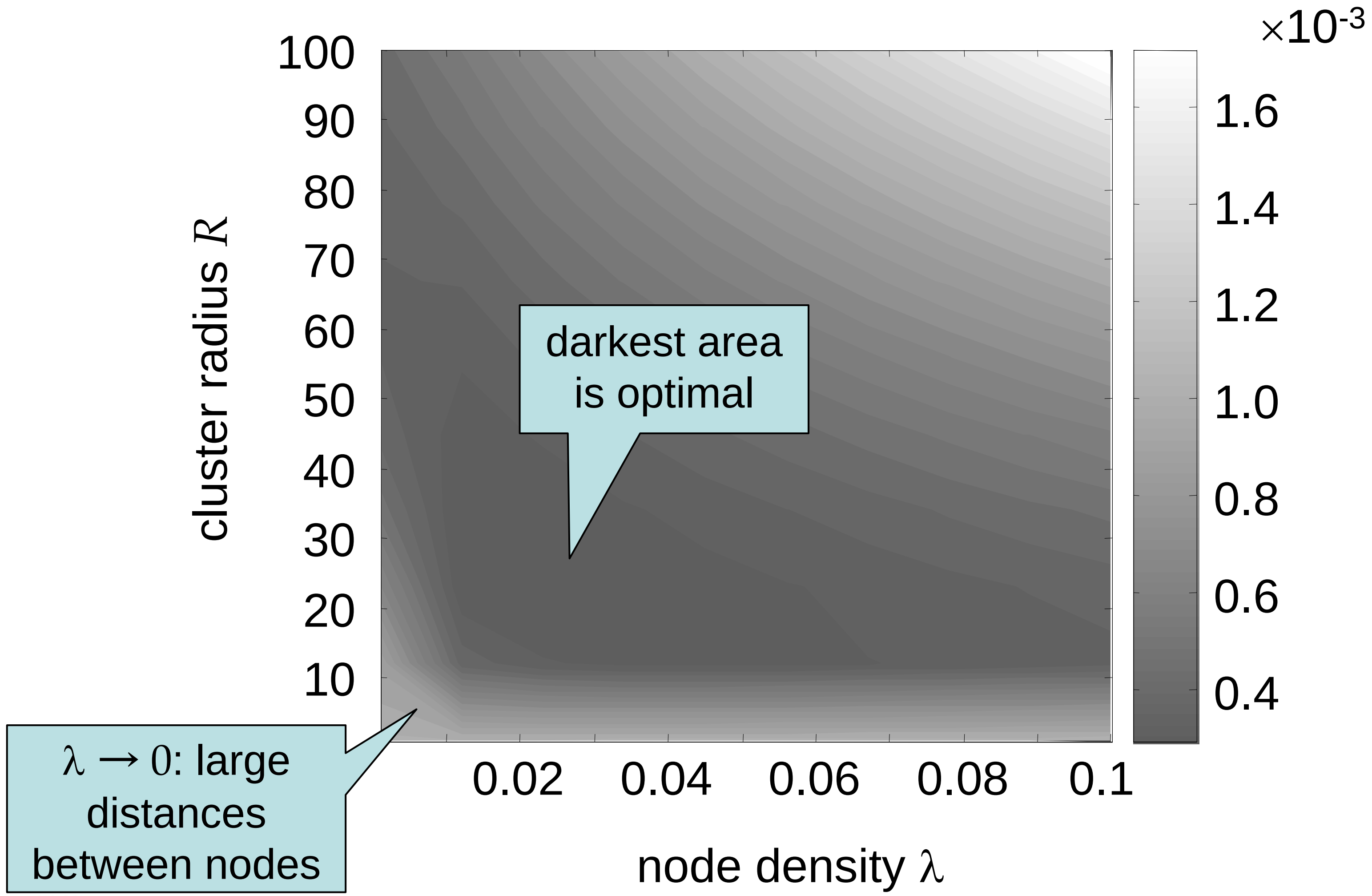
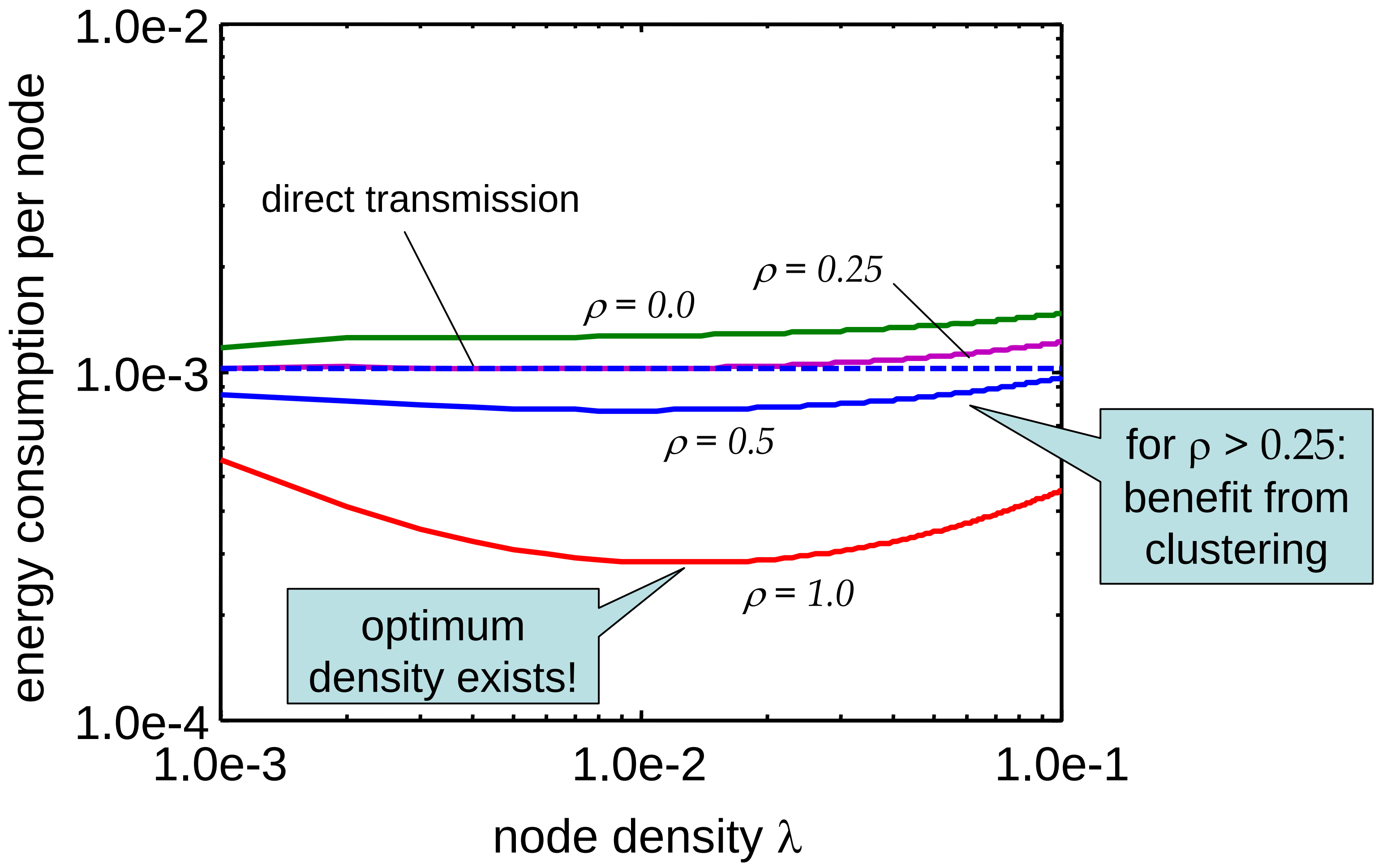
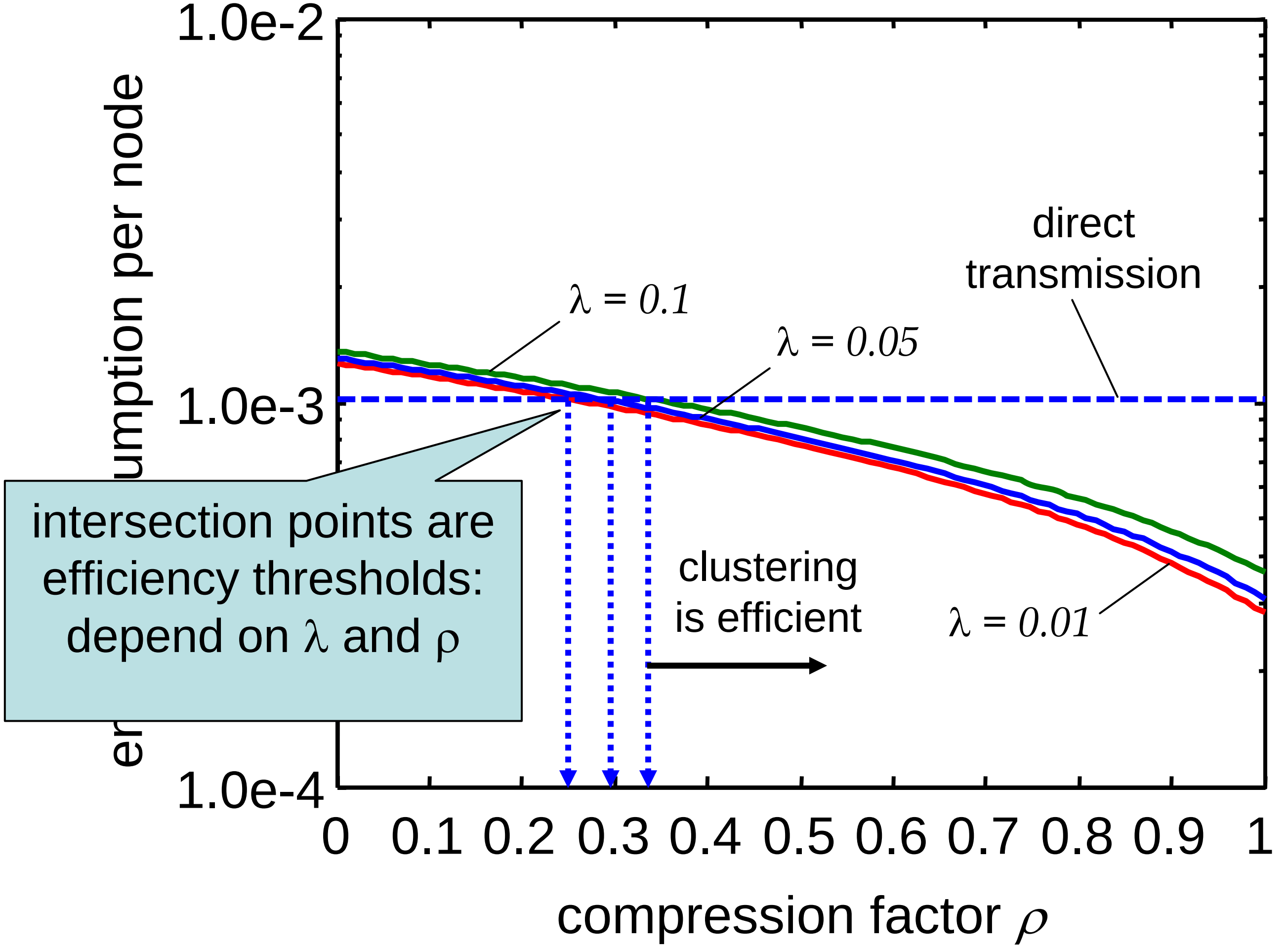
Cluster Radius vs. Node Density



Comparison to Direct Transmission



Efficiency of Clustering over ρ



Conclusion and Outlook

- Mathematical model for calculating the average energy consumption in biological clustering method
- Node distribution model from stochastic geometry
- Existence of optimal radius and tradeoff between node density and compression ratio
- No consideration of collisions on MAC layer! Direct transmission model is too optimistic
  ➔ Extension to CSMA/CA MAC like in IEEE 802.15.4