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Self-Adaptive Ad-Hoc/Sensor Network Routing with Attractor-Selection

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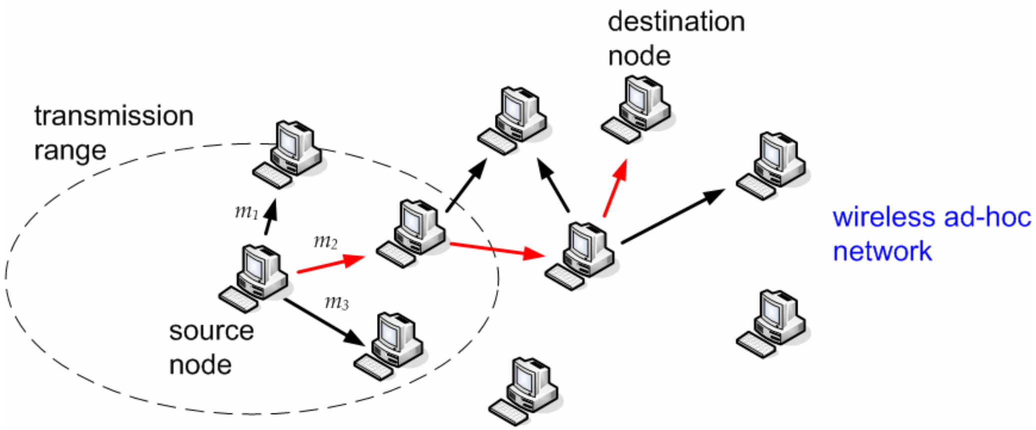
IEEE Globecom '06, San Francisco, CA.
November 2006

Outline of Presentation

- Introduction and motivation
- Adaptive response by attractor-selection
- Application to ad-hoc routing
- Numerical examples
- Conclusion and outlook

Introduction

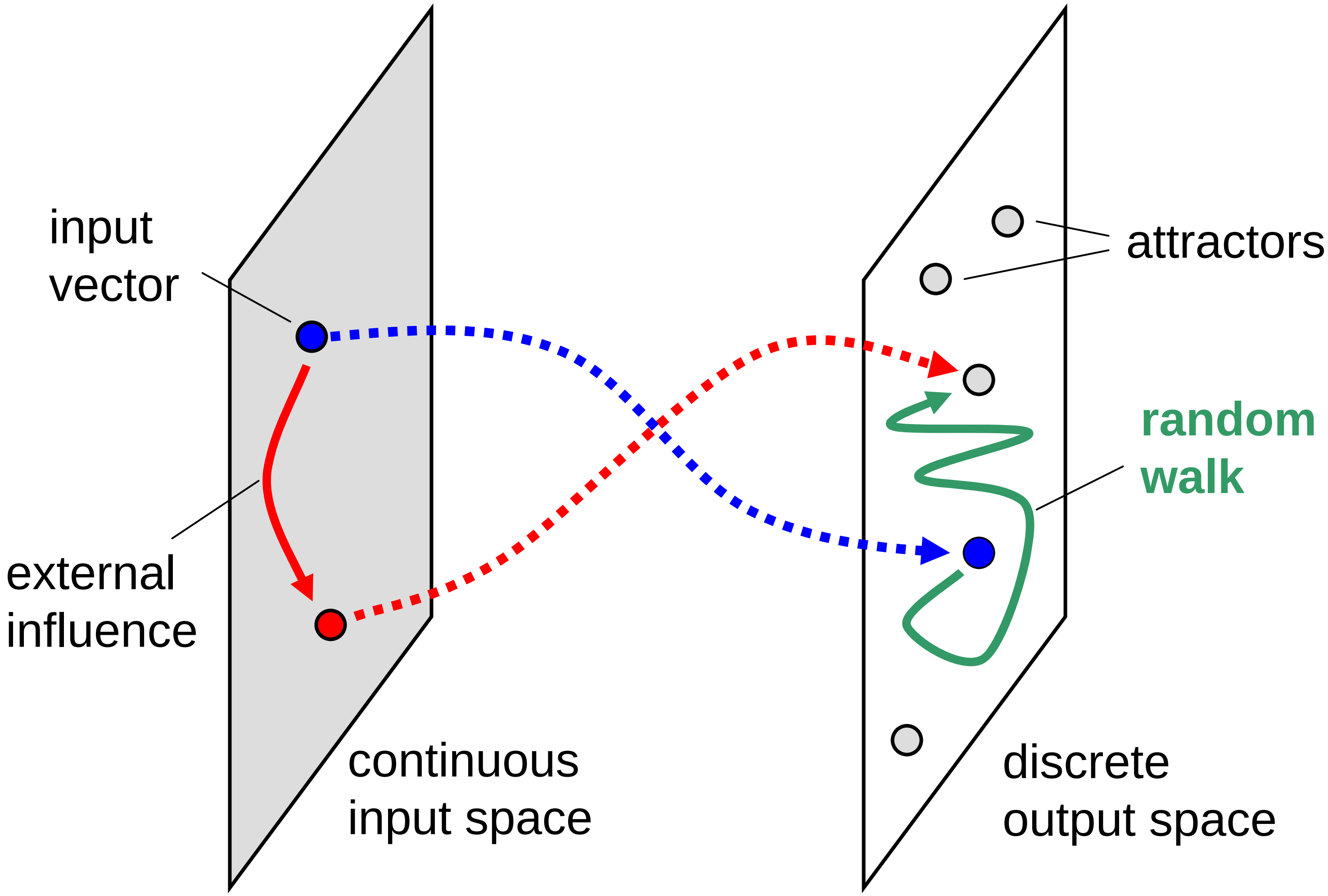


- Requirements in ad-hoc network routing: scalable, robust, adaptive, fully distributed and self-organizing
  - ➔ These features can often be found in biological systems (**swarm intelligence**)
- **Main idea:**
  randomized selection method of next hop using method inspired from biology

Adaptive Response by Attractor-Selection (ARAS)

- Method from cell biology:
  - reaction to lack of nutrient when no signaling pathway exists from environment to DNA
- Description by stochastic differential equation system
- **Attractor**:
  - region within which the orbit of dynamical system returns regardless of initial conditions and noise
- **Activity:**
  - mapping of environment to “goodness” of current system state

General Concept of ARAS



Mathematical Model of ARAS

- Consider a system with M possible choices m_i, $i = 1, \ldots, M$ with:

$$\frac{dm_i}{dt} = \frac{syn(\alpha)}{1 + \hat{m}^2 - m_i^2} - deg(\alpha)\, m_i - \eta_i$$

$$\hat{m} = \max_i \{m_i\}$$

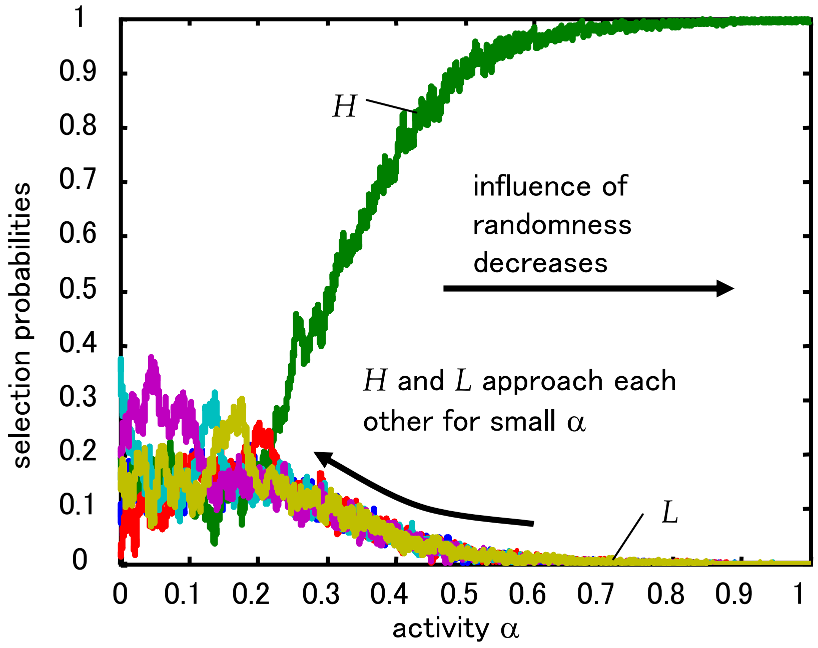
- $syn(\alpha)$ and $deg(\alpha)$ are the rate of synthesis and degradation and are functions of the activity α and η_i is white noise.

$$syn(\alpha) = \alpha\left[\beta\,\alpha^{\gamma} + \varphi^*\right] \quad \text{and} \quad deg(\alpha) = \alpha$$

Mathematical Model (2)

- Define

$$\varphi(\alpha) = \frac{syn(\alpha)}{deg(\alpha)}$$



- In equilibrium there are M solutions with entries

$$x_i^{(k)} = \begin{cases} \varphi(\alpha) & i = k \quad H \text{ value} \\ \frac{1}{2}\left[\sqrt{4+\varphi(\alpha)^2} - \varphi(\alpha)\right] & i \neq k \quad L \text{ value} \end{cases}$$

- H and L merge at $\varphi^* = \frac{1}{\sqrt{2}}$

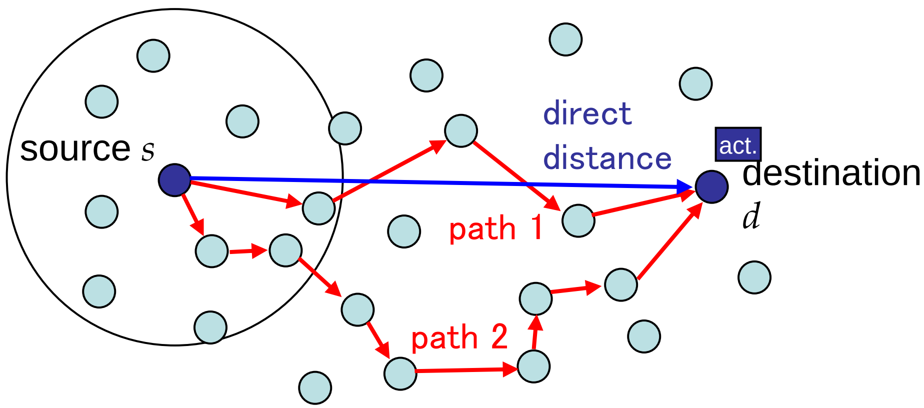
Mapping of Activity

- Activity reflects the “goodness” of the system.
- Initialized with 0 and dynamics follow as

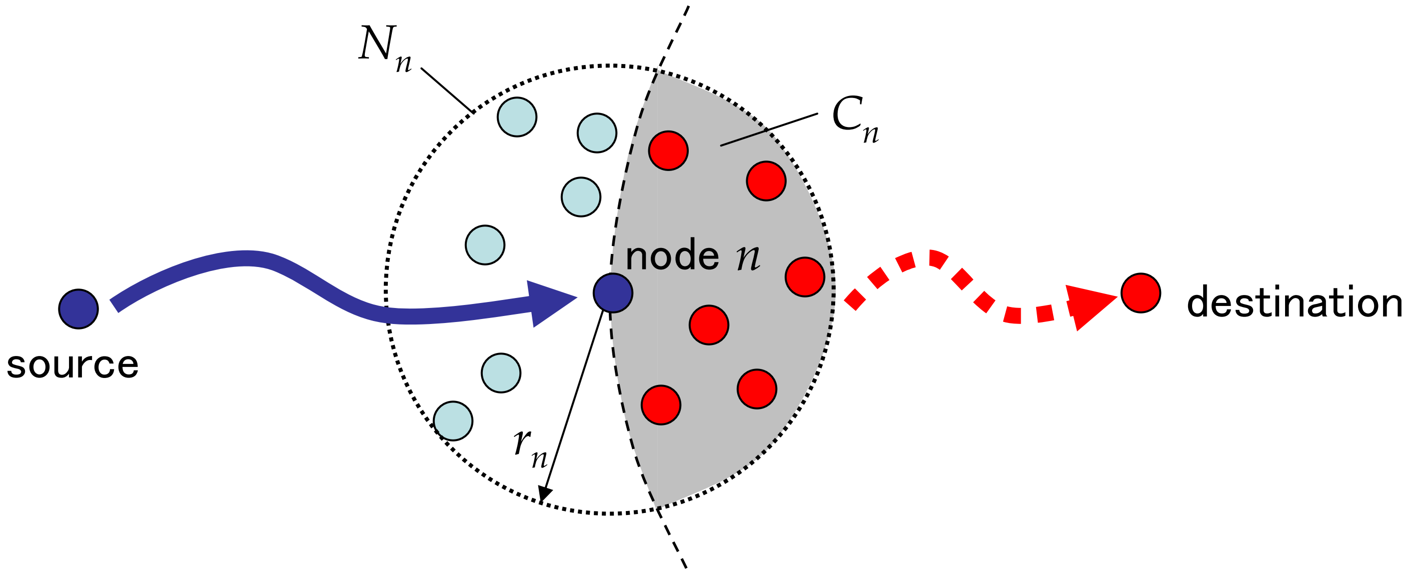
$$\frac{d\alpha}{dt} = \delta(\alpha^* - \alpha)$$

$$\alpha^* = 1 - \left(1 - \frac{distance(s,d)}{path\_length}\right)\left(1 - \frac{min\_hops}{hops}\right)$$

- **Objective:**
  short path lengths and low hop counts



Ad-Hoc Routing with ARAS



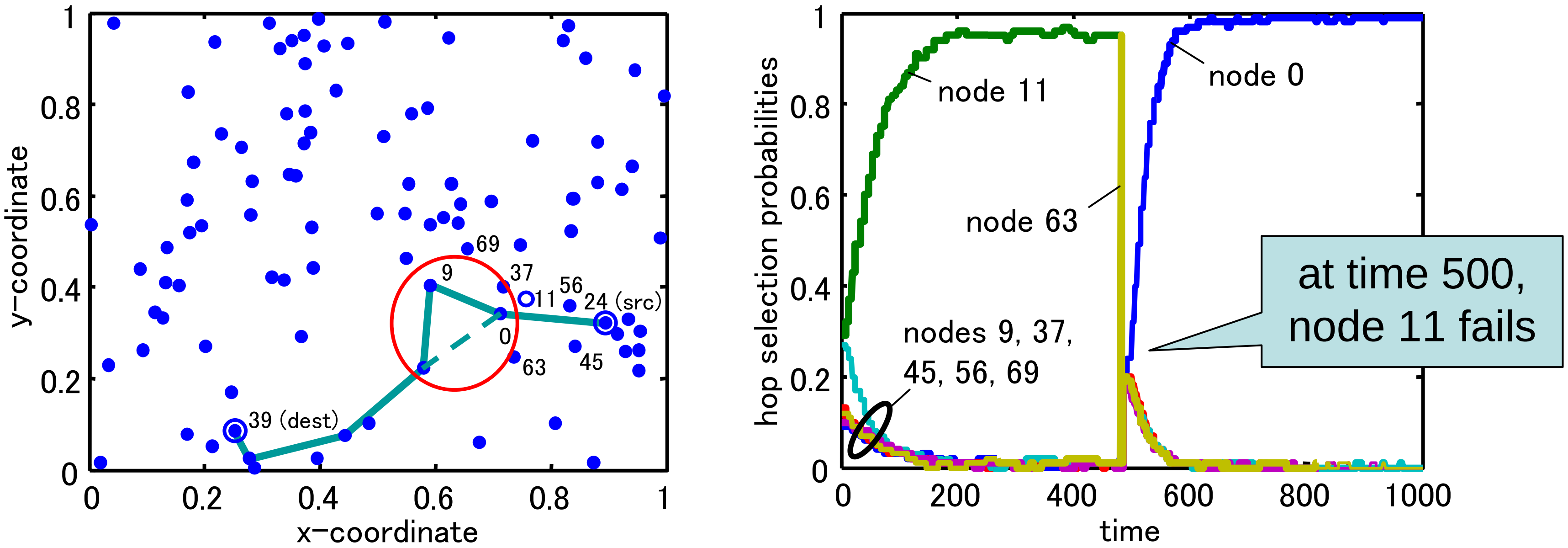
- MARAS – routing decision with ARAS
- Geographic information is used for routing
- At certain intervals, all nodes are probed for their relative distance to the destination and stored in sets: neighbor set N_n, candidate set C_n

Summary of Algorithm

Node n receives packet destined for d

- if $n = d$, calculate α^* and update all nodes along the path, process packet.
- determine neighbor and candidate set N_n and C_n
- if C_n is empty, set $A_n = N_n$. Otherwise set $A_n = C_n$
- Perform ARAS on set A_n and forward packet according to hop probabilities.

Example Behavior

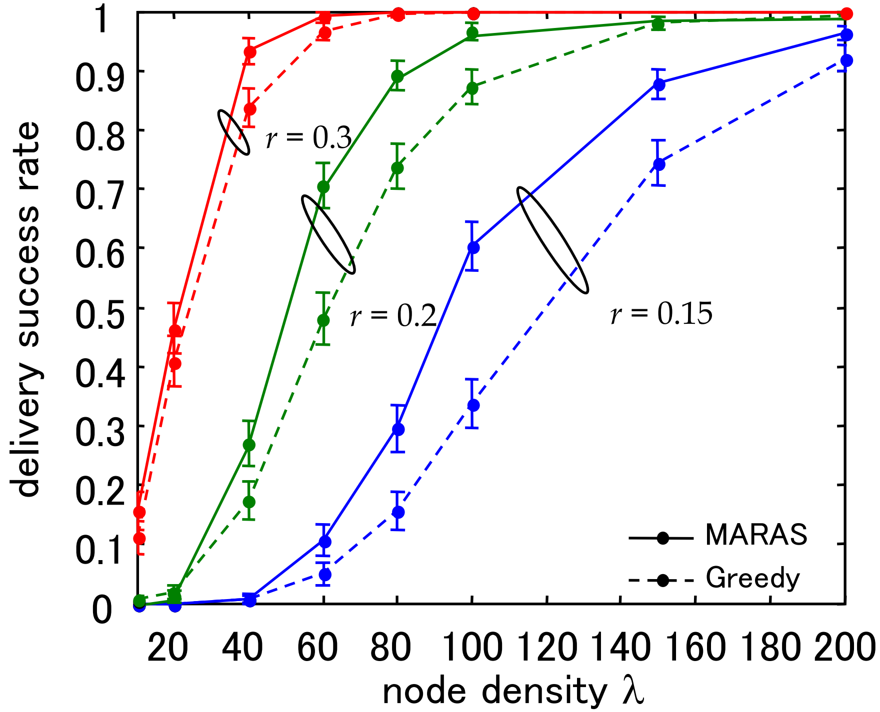


- Example scenario with source node (24) sending to destination node (29)
- Instant reaction to failure of node 11 at time 500
- Unnecessary detours removed on activity updates

Simple Numerical Results

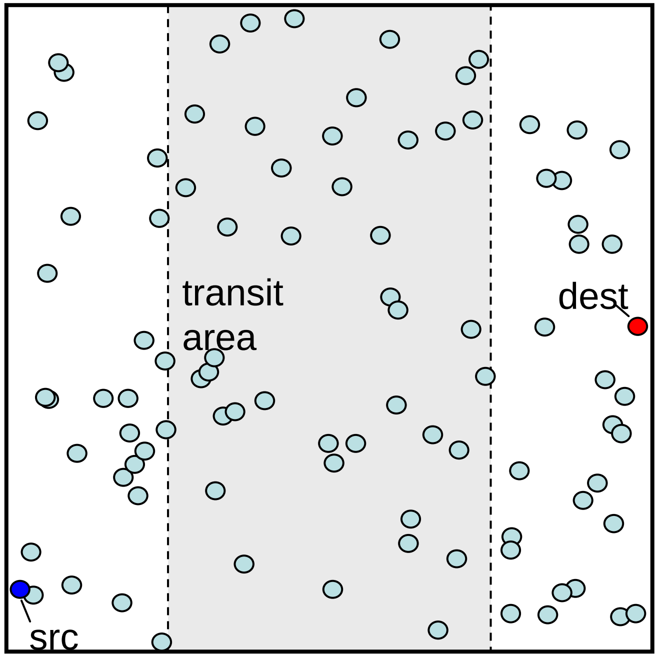
- Nodes randomly distributed (2-dimensional homogeneous Poisson Process with rate λ) in unit square
- source node and destination node are the ones with smallest/largest x-coordinates
- Results averaged from 500 simulations with 3000 time steps each
- 95% confidence intervals
- Comparison to Greedy selection of next hop
- Performance metric: success rate of packets

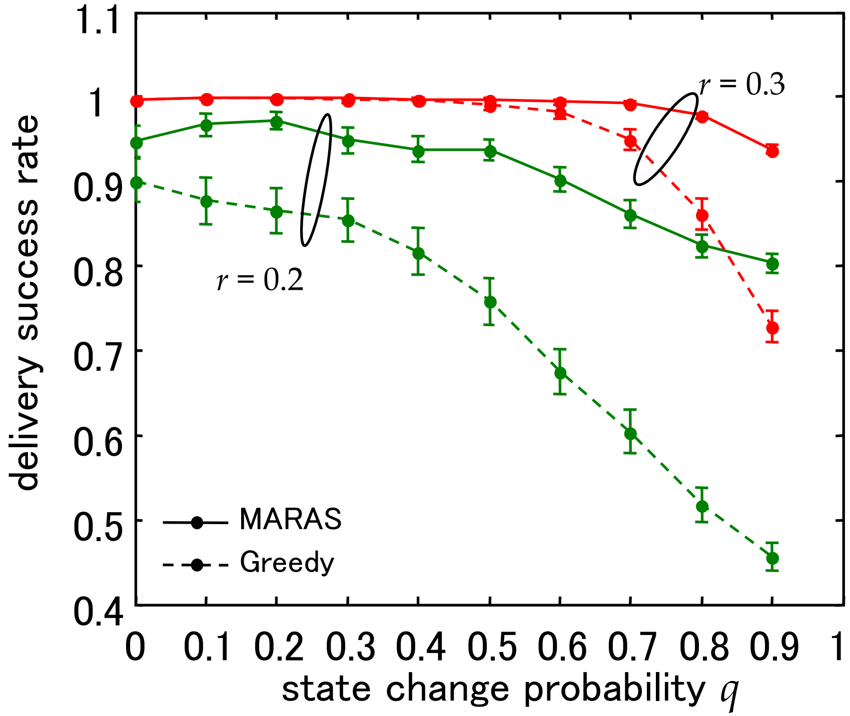
Delivery Rate vs. Node Density



- Low node density or range reduce success rate
- MARAS outperforms Greedy due to stochastic selection

Resilience to Topology Changes





- Nodes in "transit area" switch state with probability q
- Improvement of MARAS over Greedy

Density vs. Radius

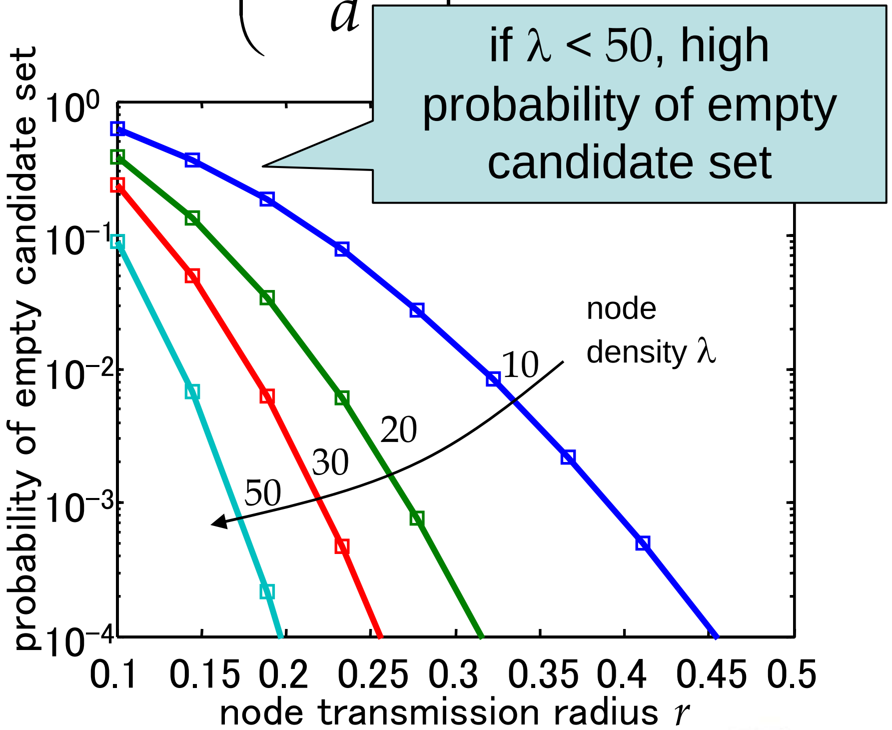
- Probability of empty candidate set computed over geometry of intersecting circles

$$V(r,d) = \arccos\left(\frac{\widetilde{X}}{r}\right) r^2 + \arccos\left(\frac{d-\widetilde{X}}{d}\right) d^2 - d\widetilde{Y}$$

with

$$\widetilde{X} = \frac{r^2}{2d}, \widetilde{Y} = \sqrt{r^2 - \widetilde{X}^2}$$

- Poisson process allows computation: $P(K=0) = e^{-\lambda \pi V(r,d)}$



Conclusion and Outlook

- Biologically-inspired method for selecting next hop in ad-hoc networks
- Increased resilience through stochastic routing
- Feedback based (reinforcement learning)
- Future work:
  – More in-depth comparison with other routing methods required
  – Definition of more accurate input/activity mapping