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# A Bio-Inspired Robust Routing Protocol for Mobile Ad Hoc Networks

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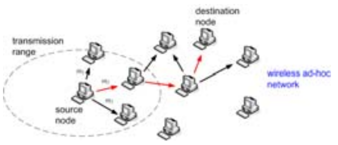
## Outline of Presentation

- Introduction and motivation
- Adaptive response by attractor-selection
- Application to routing in MANET
- Simple numerical examples
- Conclusion and outlook



## Introduction




- Required features in ad-hoc network routing: scalable, robust, adaptive, fully distributed, and self-organizing
  - ➔ Can often be found in biological systems (e.g. *swarm intelligence*)
- ***Main idea:*** randomized, noise-driven selection of next hop using bio-inspired method



## Adaptive Response by Attractor-Selection (ARAS)

- Method from cell biology:
  - reaction to lack of nutrient when no signaling pathway exists from environment to DNA
  - ***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
- Description by Langevin-type of stochastic differential equation system

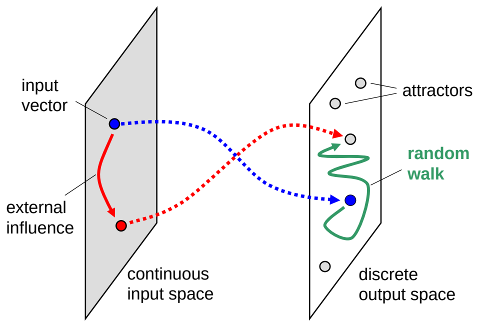
$$\frac{dm_i}{dt} = f(m_1,\ldots,m_M)\times\alpha + \eta_i$$

noise

activity



## General Concept of ARAS






## Mathematical Model of ARAS

- Consider a system with $M$ possible choices given by vector $\mathbf{m} = [m_1,\ldots,m_M]$

$$\frac{d\mathbf{m}}{dt} = \frac{s(\alpha)}{1+\max(\mathbf{m})^2 - \mathbf{m}^2} - d(\alpha)\,\mathbf{m} + \boldsymbol{\eta}$$

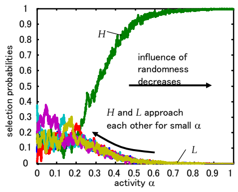
- The factors $s(\alpha)$ and $d(\alpha)$ are the rate of *synthesis* and *degradation* and are functions of the activity $\alpha$

$$s(\alpha) = \alpha\left[\beta\alpha^{\gamma} + \varphi^*\right]$$
$$d(\alpha) = \alpha$$

- $\boldsymbol{\eta} = [\eta_1,\ldots,\eta_M]$ is vector with white noise

## Mathematical Model (2)

- Define $\varphi(\alpha)=\dfrac{s(\alpha)}{d(\alpha)}$
- In equilibrium there are $M$ solutions with entries:




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

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



## Activity Dynamics

- Activity $\alpha$ reflects the “goodness” of the system

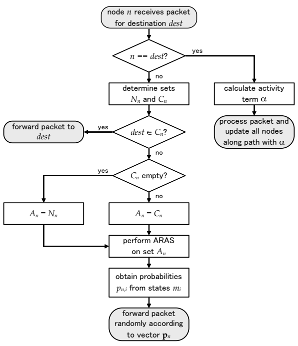
$$\frac{dm_i}{dt}=f(m_1,\ldots,m_M)\times\alpha+\eta_i$$

- Basic behavior:
  - $\alpha \approx 0$: dynamics dominated by noise term
  - $\alpha \approx 1$: convergence to attractor (noise influence recedes)
- We use ***packet delivery ratio*** of a flow as activity



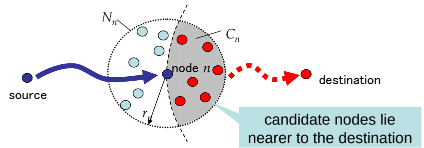
## MANET Routing with ARAS

- Consider reactive routing like AODV
- RREQ (***route requests***) are flooded for new/ broken paths
- Each node maintains ***next hop probability vector p*** which is initialized by RREP
- Route maintenance uses neighbor and candidate sets






## Route Maintenance Phase

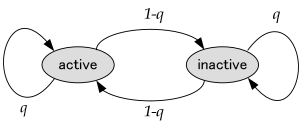



- At certain intervals, all nodes are probed for their relative distance to the destination and stored in sets: ***neighbor set*** $N_n$, ***candidate set*** $C_n$
- Next hop is chosen randomly according to probability vector $\boldsymbol{p}$
- ARAS state values $m_i$ decay over time at rate $\delta$



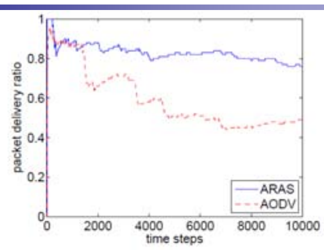
## Numerical Evaluation

- Nodes randomly distributed in unit square with spatial homogeneous Poisson process of density $\lambda$
- Transmission range $r = 0.2$
- Duration of each simulation $T_{max} = 10000$, each simulation repeated $1000$ times
- Node activity model with transition probability $q$



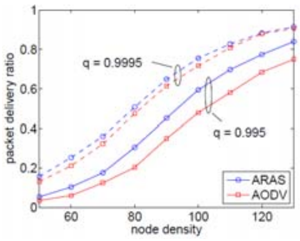



## Sample Trace Run




- Parameters: $\lambda = 120$, $q = 0.995$, $r = 0.2$
- Identical simulation conditions and layout
- AODV degrades over time, ARAS remains constant

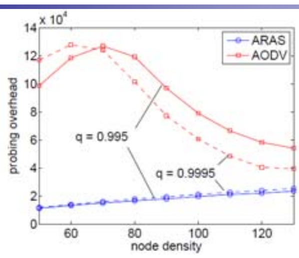
## Packet Delivery Ratio




- When $q$ is high, both methods are nearly equal
- Packet delivery is improved over AODV when there are frequent changes in activity phases



## Probe Packet Overhead




- Density has only small influence on proposal
- AODV overhead decreases with density, as path is found quicker (not all probe packets considered here)



## 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 comparisons with other routing methods
  - Investigation of other possibilities for activity mappings
  - Prototype implementation