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Biologically-Inspired Path Selection Scheme for Multipath Overlay Networks

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Outline of the Talk

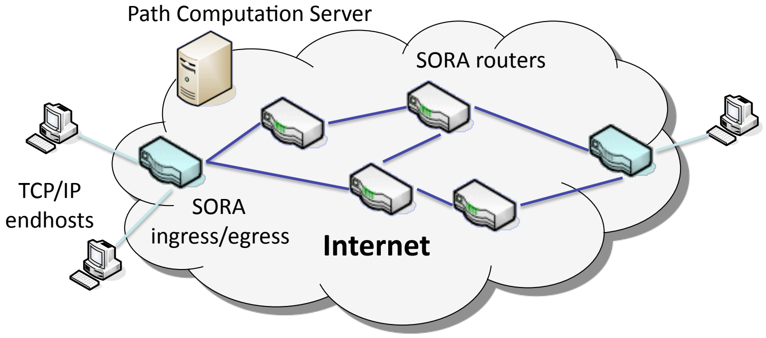
- Problem statement and motivation
- Considered network scenario
- Adaptive response by attractor selection
- Application to multi-path routing
- Numerical Evaluation
- Conclusion

Self-Organization in Biology

- Biological systems have the ability to self-organize and adapt to environmental changes
- Self-organization in nature is driven by two key factors:
  - adaptation through **feedback**:
    - **positive feedback** generates new possible solutions
    - **negative feedback** provides learning from bad experience
  - utilization of system-inherent **noise**
- Mostly communication is only performed locally between entities (e.g. swarm intelligence)

➔ **Beneficial for self-adaptive network control**

Network Scenario



- Overlay network architecture:
  - Higher flexibility through multi-path routing on overlay
  - Paths may have different latencies (“out-of-order” packets)
- Each SORA router acts as independent entity

Adaptive Response by Attractor-Selection

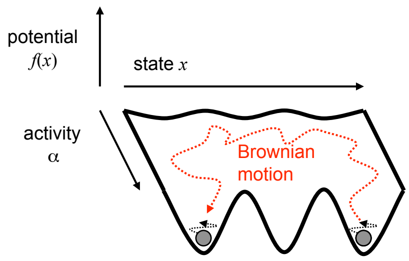
- Model of gene expression from cell biology:
  - reaction to lack of nutrient when no signaling pathway exists from environment to DNA
  - **attractor*:*** region within which the orbit of dynamical system returns regardless of initial conditions and noise
  - **activity:** mapping of environment to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

noise

$$\frac{dx_i}{dt} = f(x_1, \ldots, x_M) \times \alpha + \eta_i$$

activity

Basic Concept of Attractor Selection



sigmoid function

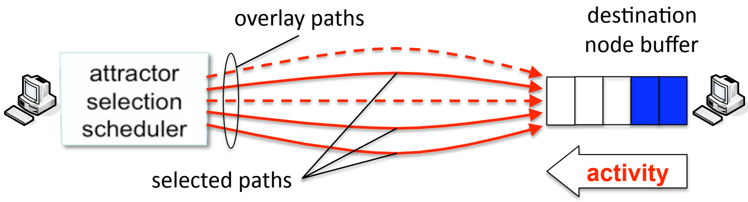
threshold

$$\frac{dx_i}{dt} = \left[s\left(\sum_{j=1}^{N} \alpha \, w_{ij} \, x_j - \theta \right) - x_i \right] \alpha + \eta_i$$

weights

- Noise constantly exists in the system
- Activity changes the depth of the potential landscape to escape from “bad” solutions
- Formulation using weighted activation like in recurrent neural networks

Application to Path Selection



- SORA path computation server determines set of possible paths
- Attractor selection is used to choose appropriate overlay paths among candidates
- Activity is determined by the destination node's relative buffer occupancy level

Application of Attractor Selection

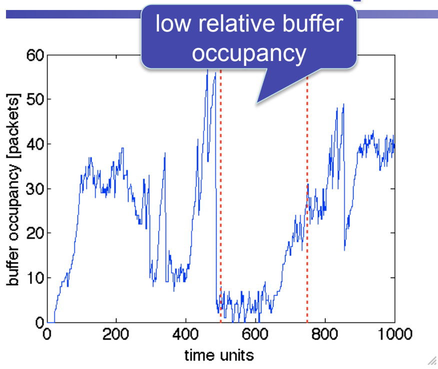
- Weights are chosen mutually inhibitory

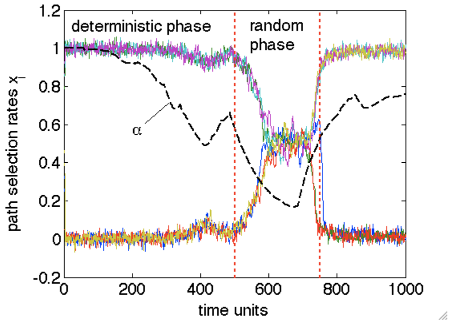
$$w_{ij} = \begin{cases} 1 & i = j \\ -\dfrac{1}{N-1} & i \neq j \end{cases} \qquad \sum_{j=1}^{N} w_{ij} = 0 \quad \Rightarrow \quad \theta = 0$$

- B: maximal experienced buffer occupancy over sliding window
- b: currently observed buffer occupancy
- Activity reacts with adaptation rate ρ to smoothen its reaction (like in simulated annealing):

$$\frac{d\alpha}{dt} = \rho\left(\frac{b}{B} - \alpha\right)$$

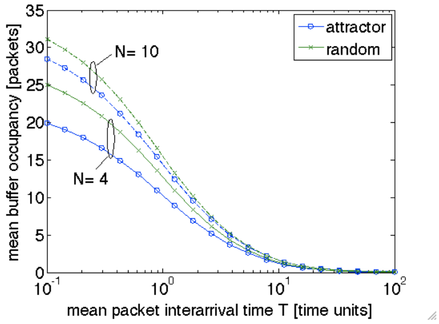
Example Scenario

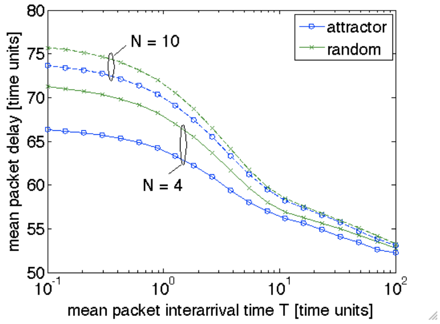




- Example simulation for $N = 6$ paths
- When relative buffer occupancy is high, system operates rather deterministically
- When it is low, we have a random phase (no preference)

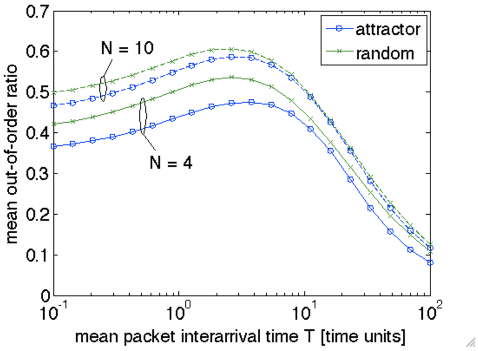
Simulation Experiments





- Comparison with random selection of paths:
  - proposal results in smaller buffer occupancy and delays
  - larger N increases diversity due to uniform randomly chosen path latencies

Out-of-Order Packet Ratio



- Ratio of all packets remaining in buffer over all received packets
- Peak value exists in all cases depending on packet interarrival time

Conclusion

- Attractor selection is meta-heuristic for self-adaptation of a system in an uncontrollable environment
- Application to the packet reordering problem in multipath overlay networks
- Fine-tuning of parameters can provide even further improvements (include neural network learning of weights)
- Areas of application:
  - feedback-based adaptation where the influence of control parameters on the metrics is unknown
  - system may react unpredictably
  - formulation of dynamics is implicitly defined by differential equation system ➔ no explicit adaptation rules