Proposal and Evaluation of a Predictive Mechanism for Ant-Based Routing

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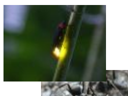
Background

- Rapid growth of networks in scale and complexity
  - Considerable overhead in managing up-to-date global information
  - Limitation of conventional information systems based on central control or distributed control with global information

New network systems with high scalability, adaptability, robustness and sustainability is required

- Bio-inspired self-organizing systems
  - Biological organisms have high evolvability, flexibility and adaptability
  - Various applications in network controls
    - Foraging behavior of ants → routing
    - Synchronization of fireflies → node synchronization



Objectives

- Strengths and limitations of self-organizing system
  - High scalability, adaptability, robustness and flexibility since･･･
    - Components behave autonomously based on local information
    - Global pattern emerges through interactions among components
  - Global optimality is not guaranteed
  - **Long time is needed for emergence**
    → Adaptation to environmental changes is slow

Enhance adaptability to environmental changes of self-organizing system by adopting a **predictive mechanism**

Predictive mechanism

- Outline
  - Each component predicts the future state of its neighbors from their past behavior
  - The component adapts its movement to conform the predicted state

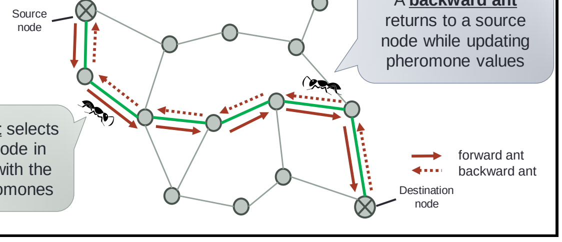
- Convergence of consensus in self-organizing behavior is accelerated[1]
  - E.g., adopting a predictive mechanism to bird-flocking model
- Application to network systems needs more discussion

We take AntNet[2] and show adaptability to environmental changes is enhanced by adopting a predictive mechanism

[1] H. Zhang, M. Chen, G. Stan, T. Zhou, and J. Maciejowski, "Collective behavior coordination with predictive mechanisms," *IEEE Circuits and Systems Magazine*, vol. 8, no. 3, pp. 67–85, August 2008.
[2] G. Di Caro and M. Dorigo, "AntNet: Distributed stigmergetic control for communications networks, " Arxiv preprintarXiv:1105.5449, vol.9, pp.317–365, Dec. 1998.

AntNet

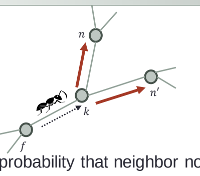
- A routing mechanism inspired by foraging behavior of ants
  - The source node launches mobile agents called ants at regular intervals and ants explore to find a path to the destination node in accordance with pheromones, which are laid by ants
  - Superior to conventional mechanisms regarding robustness and control overhead



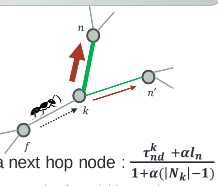
Forward ants

- Explore to find the path to the destination node in accordance with pheromones
- Change to backward ants when arriving at the destination nodes

If there are no pheromones, a forward ant selects a next hop node at random



If pheromones exist, a forward ant would select a neighbor node with more pheromones than others

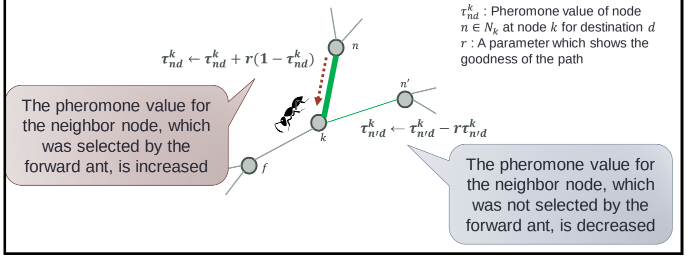


The probability that neighbor node n is selected as a next hop node : $\frac{\tau_{nd}^{k} + \alpha l_n}{1+\alpha(|N_k|-1)}$

N_k : A set of neighbor node of node k, l_n : The shortness of queue size for neighbor node n
τ_{nd}^{k} : Pheromone value of node $n \in N_k$ at node k for destination d

Backward ants

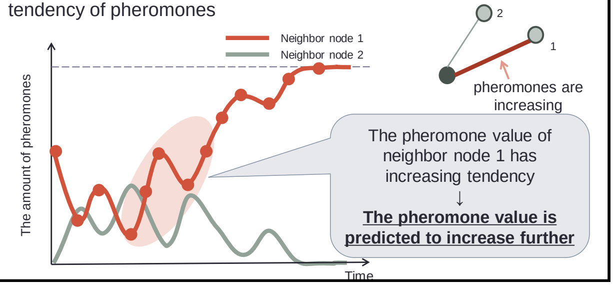
- Return to the source node while updating pheromone values
  - The shorter the path to the destination node is, the more the increasing amount of pheromones is
- Long time is required for path reestablishment when environment changes occur



Key idea

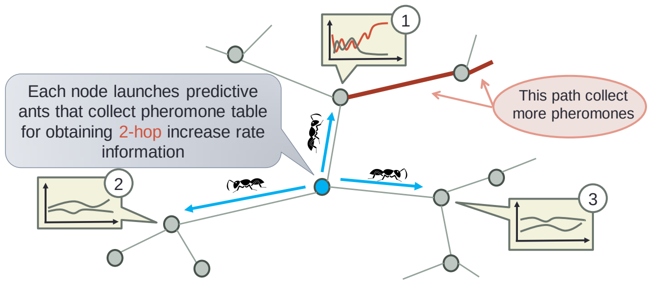
- Increase rates of pheromones indicate the goodness of a path
  - A shorter path collects more pheromones than do longer paths
  - The accumulated pheromones attract more ants

⟶ Predict the path which will obtain further pheromones with increase tendency of pheromones



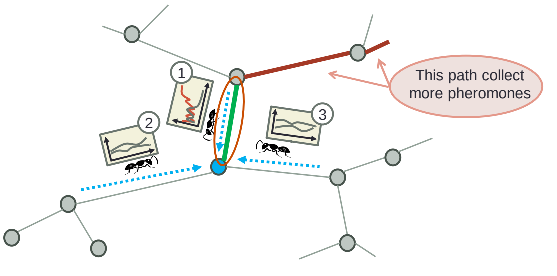
Outline of proposed mechanism (1/2)

- **Predictive ants** collect pheromone tables of neighbor nodes
  - To find a path which collects more pheromones



Outline of proposed mechanism (1/2)

- **Predictive ants** increase pheromones for the neighbor on the path whose increase rates of pheromones are large



Pheromone control with prediction

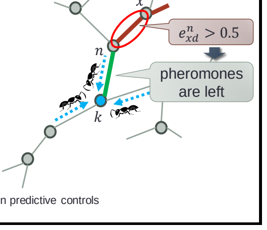
- Increase rates of pheromones of node k for neighbor node n regarding destination node d

$$e_{nd}^{k} \leftarrow \begin{cases} (1-\beta)e_{nd}^{k} + \beta \text{, if } n = f \\ (1-\beta)e_{nd}^{k} \text{, otherwise} \end{cases}$$

f : The neighbor node where the backward ant has left pheromones
β : The weight of individual pheromone increments

- Pheromone control with prediction
  - Predictive ants increase pheromones for neighbor node on the path whose pheromones are increasing

$$\tau_{nd}^{k} \leftarrow \begin{cases} \tau_{nd}^{k} + p\left(1 - \tau_{nd}^{k}\right) \text{, if } \max_{x \in N_n} e_{xd}^{n} > 0.5 \\ \tau_{nd}^{k} - p\tau_{nd}^{k} \text{, otherwize} \end{cases}$$

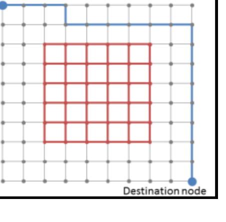


τ_{nd}^{k} : Pheromone value of node $n \in N_k$ at node k for destination d
p : A parameter that determines the increasing amount of pheromones in predictive controls
n_p : The neighbor node whose pheromones are increasing

Simulation settings

- Scenario
  1. We first have the network converge to a stable state
  2. After 1,000s have passed, we increase traffic loads around the center of the network (red colored area in the below network)
  3. We reestablish paths using original AntNet or our proposal, and evaluate the **path recovery time** and the **control overhead**
     - Path recovery is defined as 10 consecutive selections of the same path

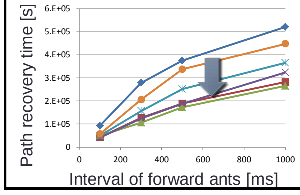
Parameter	Value
The interval of forward ants	100ms ∼ 1s
The interval of predictive ants	**100ms, 1s**
p	0.005 ∼ 0.1
β	0.2



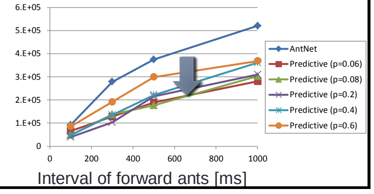
Evaluation of the path recovery time

- The path recovery time of our proposal is shorter
  - In AntNet, most ants go through a path whose current pheromone values are larger than others, even though there is a better path
  - In our proposal, predictive ants update pheromone values in a feed forward way with historical information of pheromone values
- Adaptability is enhanced with moderate control

Interval of predictive ants = 100ms



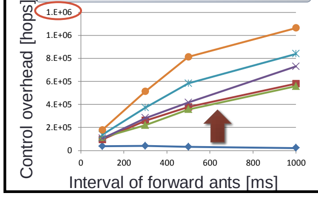
Interval of predictive ants = 1s



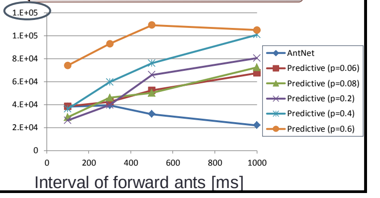
Evaluation of the control overhead

- Control overhead can be much reduced with a larger interval of predictive ants keeping the recovery time shorter
  - Control overhead of predictive ants is much larger with a smaller interval of predictive ants
  - If the interval of predictive ants is much larger than the interval of forward ants, the effect of prediction would be too small

Interval of predictive ants = 100ms



Interval of predictive ants = 1s



Conclusion and future work

- Conclusion
  - We adopt a predictive mechanism to AntNet
    - The adaptability to environmental changes is enhanced
    - Control overhead of prediction can be significantly reduced if the interval of predictive ants is large
- Future work
  - Evaluate our proposed mechanism in more real network situations
    - A random network, and multiple session scenario
  - Consider more general designs of a predictive mechanism for self-organizing systems based on Model Predictive Control
    - Improve slow adaptation to environmental changes which various self-organizing network controls besides AntNet have