Proposal and Evaluation of Ant-based Routing with Autonomous Zoning for Convergence Improvement

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  - Bio-inspired self-organization
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Research background

- Rapid growth of networks in scale and complexity
  - Control overhead for collecting and maintaining information of the entire system will drastically increase
  - Conventional central control and distributed control with global information suffers from the considerable overhead

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- A distributed and self-organizing network system
  - Bio-inspired self-organization
    - A natural phenomenon of distributed system
    - E.g. the foraging behavior of ants
      the firefly synchronization

Self-organization

- High adaptability and robustness with low overhead
  - Components (e.g. nodes) behave individually and autonomously based on simple rules and local information
  - Through direct or indirect interactions among components, a global behavior or pattern emerges
- Disadvantages
  - Long time is needed for emergence of a global pattern
  - Global optimality is not guaranteed

Controlled self-organization where a self-organizing system is moderately controlled

Controlled self-organization

- Moderately control self-organization
  - The system is moderately controlled through a feedback mechanism or adaptation of control parameters
    - To accelerate self-organization
    - To guide a system to achieve tasks effectively

Our goal : Show self-organization can be accelerated by moderate control

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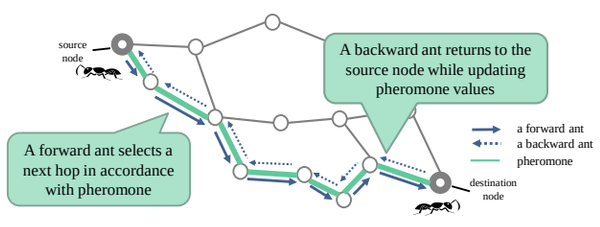
- Take AntNet as a test case
- Reduce the path convergence time by dividing the whole network to subareas

AntNet [15]

- A routing mechanism inspired by the foraging behavior of ants
  - Pheromones accumulated on a path indicate its goodness



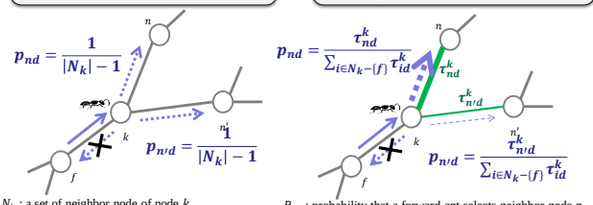
[15] G. Di Caro and M. Dorigo, "AntNet: Distributed stigmergeticcontrol for communications networks," Arxiv preprintarXiv:1105.5449, vol.9, pp.317–365, Dec. 1998.

Forward ants

- Select a next hop node stochastically in accordance with pheromone

If pheromones do not exist, a forward ant selects a next hop at random

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



N_k : a set of neighbor node of node k
τ_{nd}^k : pheromone value of node $n \in N_k$ at node k for destination d

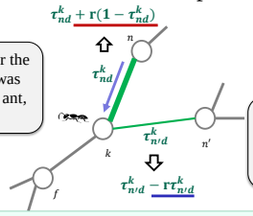
P_{nk} : probability that a forward ant selects neighbor node n as a next hop for destination d

pheromone

Backward ants

- Return to a source node while updating pheromone values

The pheromone value for the neighbor node, which was **selected** by the forward ant, is **increased**



τ_{nd}^k : pheromone value of node $n \in N_k$ at node k for destination d
r : a parameter which shows the goodness of the path

pheromone

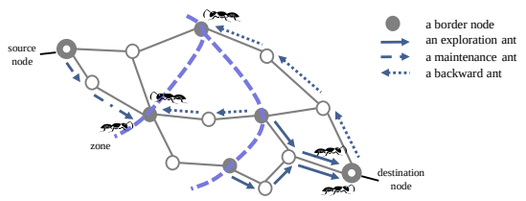
The pheromone value for the neighbor node, which was **not selected** by the forward ant, is **decreased**

In AntNet, the time required for path establishment to converge increases exponentially as the path length is longer

Accelerate path convergence by dividing the whole network into subareas called zones

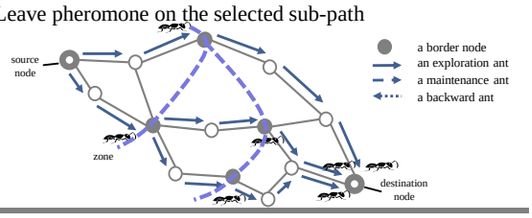
Approach

- Accelerate path establishment by autonomously dividing the whole network to zones
  - Limiting the search space of ants
  - Establish path par zone and construct the whole path by concatenating sub-paths



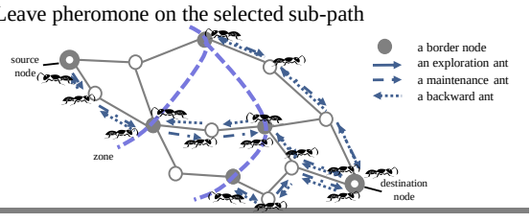
Our proposal (1/2)

- **Exploration ants**
  - Construct zones
  - Discover the path to a destination node
- Maintenance ants
  - Select a sub-path in accordance with pheromone
  - Leave pheromone on the selected sub-path



Our proposal (2/2)

- Exploration ants
  - Construct zones
  - Discover the path to a destination node
- **Maintenance ants**
  - Select a sub-path in accordance with pheromone
  - Leave pheromone on the selected sub-path

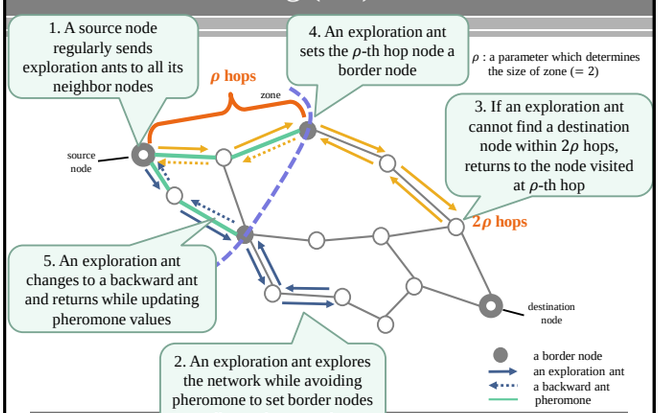


Autonomous zoning (1/2)

1. A source node regularly sends exploration ants to all its neighbor nodes

4. An exploration ant sets the ρ-th hop node a border node

ρ : a parameter which determines the size of zone (= 2)

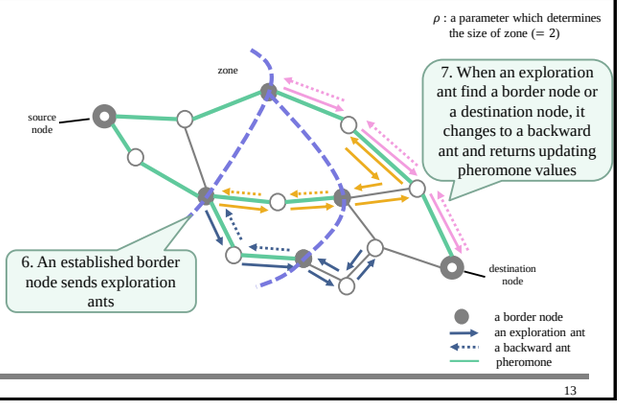


3. If an exploration ant cannot find a destination node within 2ρ hops, returns to the node visited at ρ-th hop

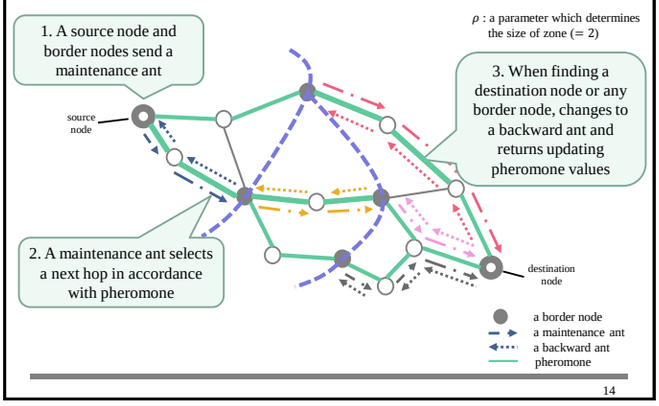
5. An exploration ant changes to a backward ant and returns while updating pheromone values

2. An exploration ant explores the network while avoiding pheromone to set border nodes all over the network

Autonomous zoning (2/2)

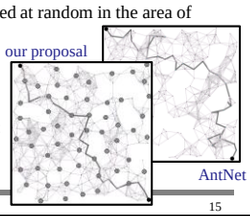


Path maintenance within zones



Simulation experiment

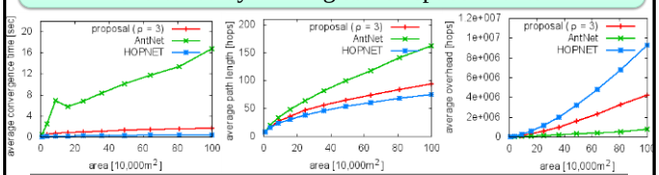
- We evaluate the convergence time, path length, and control overhead
- Simulation setting
  - Change the size of network from $scale = 1$ (100 m x 100 m) ~ 10 (1,000 m x 1,000 m) while keeping node density
    - At $scale = 2$, 150 nodes are distributed at random in the area of 200 m x 200 m
  - Communication range : 30 m
  - One-hop delay : 2 msec
  - Interval of ant emissions : 10 msec



Comparison with AntNet and HOPNET

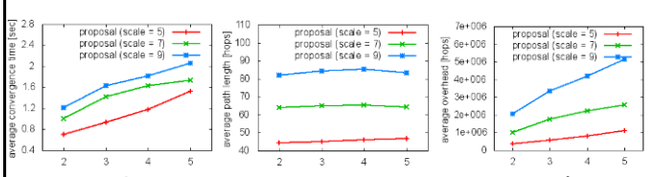
- Our proposal reduce the convergence time and establish shorter path compared with AntNet
- Our proposal reduce control overhead compared with HOPNET

The path establishment is accelerated and path length is shortened by limiting search space of ants



Influence of parameter ρ

- Convergence time is shorter and control overhead is lower with lower ρ
  - Because the size of zones is smaller with lower ρ



Conclusion and future work

- Conclusion
  - Accelerate the path establishment by limiting search space of ants
    - Path length is shorter than AntNet
    - Control overhead is smaller than HOPNET
- Future work
  - Controlled self-organization with prediction
  - Accelerate path convergence to adapt to environmental changes
    - Predict the future convergence from history of pheromone accumulation and adapt the convergence to the predicted state