Study on Interaction between Layered Self-Organization based Control

Hiroshi Yamamoto, Naoki Wakamiya and Masayuki Murata

Graduate School of Information Science and Technology,
Osaka University, Japan

Background

- Scale of network increases
  - Since collection and maintenance of global information in large network involve large amount of overhead, current control mechanisms will not work well in future
- Self-organizing control mechanism attracts attention
  - Node decides behavior based on local information and global control emerges through mutual interaction among neighbors
  - However, combination of multiple self-organizing mechanisms is not well-investigated

We focus on influence of interdependency among layered self-organizing routing on performance

Routing based on attractor selection model

- On-demand routing protocol
  - Path is established when it is required by source node
- Intermediate nodes selects forwarding node every time data message arrives
  - Attractor selection model is adopted for selection of forwarding node
  - Nodes maintain routing information for each destination nodes
    - Goodness of route: α
    - State vector: m
      - for all neighboring nodes

Attractor selection model

Mathematical model of adaptive behavior of biological system

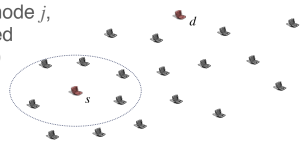
$$\frac{d\vec{m}}{dt} = f(\vec{m}) \times \alpha + \eta$$

state; noise; potential function; activity ($0 \leq \alpha \leq 1$) goodness of state

- With large α, state is dominated by $f(m)$ and drawn into stable state
- With small α, state changes randomly by noise

Route establishment

- Source s broadcasts route request (RREQ) message
- Destination d sends route reply (RREP) message
  - RREP travels along reverse path of corresponding RREQ message
- Intermediate nodes set up routing information
  - Activity α_d : 1.0
  - State value $m_{d,j}$ for node j, from which it received RREP message : 10
  - State value $m_{d,x}$ for other nodes : 0



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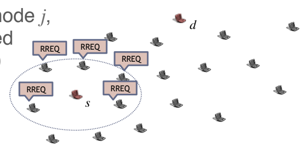

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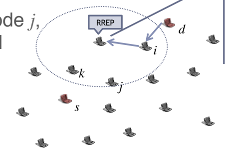


α_d	1
m_i	10
m_j	0
m_k	0

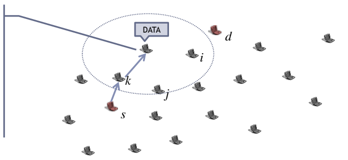
Data message forwarding

- Node selects next hop node
  - from neighboring nodes except node from which it received data message
  - according to probability $\frac{m_{d,j}}{\Sigma_{\bar{N}} \bar{m}_d}$

$\bar{N}$: all neighboring nodes except node from which it received data message

- If node has only one neighboring node from which it received data message, data message is discarded

state value	probability
$m_{d,i}$	$\frac{m_{d,i}}{m_{d,i}+m_{d,j}}$
$m_{d,j}$	$\frac{m_{d,j}}{m_{d,i}+m_{d,j}}$
$m_{d,k}$	0



Feedback and route maintenance

- Destination d sends feedback message, when it receives data message
  - Feedback message travels along reverse path of corresponding data message
- Intermediate nodes update routing information for d

minimum hop count within last T s; β, γ: constant

$$\alpha_d = \frac{\min_{t-T \le t' \le t} w(t')}{w(t)}, \quad \frac{dm_{d,i}}{dt} = \frac{\alpha_d(\beta\alpha_d^{\gamma} + 1/\sqrt{2})}{1 + m_{d,\max}^2 - m_{d,i}^2} - \alpha_i m_{d,i} + (1-\alpha_d)\eta_d$$

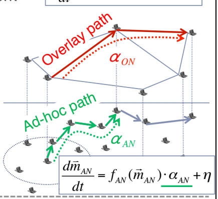
$w(t)$: current hop count of feedback message from destination; potential function; noise term

- Activity decays at intervals of τ and state vector is updated by using decayed activity

Layered self-organized routing

- Layered network model
  - Wireless ad-hoc network and overlay network
  - Our routing protocol is adopted on both layers
  - Node which belongs to both network maintains two lists of routing information
    - α_{AN} and m_{AN} for wireless ad-hoc network
    - α_{ON} and m_{ON} for overlay network
  - In overlay network, travelled hop count $w(t)$ is defined as hop count in ad-hoc network
    - α_{ON} is derived by physical hop count to destination node

$$\frac{d\bar{m}_{ON}}{dt} = f_{ON}(\bar{m}_{ON}) \cdot \alpha_{ON} + \eta$$



$$\frac{d\bar{m}_{AN}}{dt} = f_{AN}(\bar{m}_{AN}) \cdot \alpha_{AN} + \eta$$

Coupling layered self-organized routing

- We consider four alternatives of coupling which differ in the way of activity sharing
  - Independent
    - Each network tries to achieve their own goals

ON: $\frac{d\bar{m}_{ON}}{dt} = f_{ON}(\bar{m}_{ON}) \cdot \alpha_{ON} + \eta$ AN: $\frac{d\bar{m}_{AN}}{dt} = f_{AN}(\bar{m}_{AN}) \cdot \alpha_{AN} + \eta$

  - Ad-hoc aware overlay routing (ONuseAN)

ON: $\frac{d\bar{m}_{ON}}{dt} = f_{ON}(\bar{m}_{ON}) \cdot \alpha_{ON} \cdot \alpha_{AN} + \eta$ AN: $\frac{d\bar{m}_{AN}}{dt} = f_{AN}(\bar{m}_{AN}) \cdot \alpha_{AN} + \eta$

  - Overlay aware ad-hoc routing (ANuseON)

ON: $\frac{d\bar{m}_{ON}}{dt} = f_{ON}(\bar{m}_{ON}) \cdot \alpha_{ON} + \eta$ AN: $\frac{d\bar{m}_{AN}}{dt} = f_{AN}(\bar{m}_{AN}) \cdot \alpha_{AN} \cdot \alpha_{ON} + \eta$

  - Tight coupling (Both)
    - Both network try to maximize total performance by sharing goal

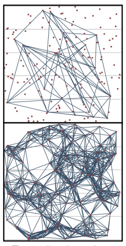
ON: $\frac{d\bar{m}_{ON}}{dt} = f_{ON}(\bar{m}_{ON}) \cdot \alpha_{ON} \cdot \alpha_{AN} + \eta$ AN: $\frac{d\bar{m}_{AN}}{dt} = f_{AN}(\bar{m}_{AN}) \cdot \alpha_{AN} \cdot \alpha_{ON} + \eta$

Simulation experiments

- We evaluate influence of different degree of coupling on performance
- Settings
  - 150 immobile ad-hoc nodes were arranged in 100 × 100 m randomly
    - 20 nodes were appointed as overlay nodes
  - Transmission range was 20 m
  - We generated 200 random topologies and evaluated four alternatives of coupling on each of the topologies
  - We randomly chose a pair of source node and destination node from overlay nodes. Then, source node sent data messages at regular intervals of 0.1 s for 400 s
  - There were no delay and no loss of messages

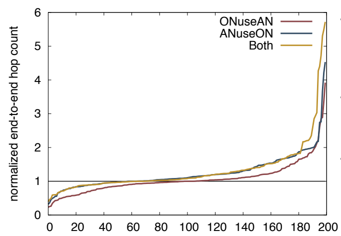
Parameter of attractor selection model

T	β	γ	τ	δ
5 [s]	10	5	1 [s]	0.1



Example of topology

Results: Normalized end-to-end hop count



- Results are the number of hops from source node to destination node in ad-hoc network averaged over whole simulation time
- Results are further normalized by averaged end-to-end hop count of “Independent” on same topology
- Results of 200 topologies are arranged along x-axis in ascending order

“ONuseAN” results in shortest path

- α_{ON} is derived from total number of hops from the node to destination node
  → Slight change in ad-hoc paths does not affect α_{ON} very much
  → Overlay network keeps current path
- In “ONuseAN”, since overlay network takes into account α_{AN}, decrease in α_{AN} triggers rerouting in overlay network to find better overlay path

Conclusion and future work

- Conclusion
  - To investigate mutual interaction among layered self-organization based control, we evaluated influence of different degree of coupling by changing the way how layered control share objective parameter
- Future work
  - Evaluation in more realistic scenarios
    - topology dynamically changes
    - messages are lost by collision
  - Evaluation for combinations of other self-organizing protocols
    - Ex.) clustering and scheduling etc.

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